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REGIONAL COCONUT WOOD TRAINING PROGRAMME

DU/RAS/81/110

Technical report: Mechanical properties of coconut palm wood*

Prepared for the Government of the countries participating in the regional project by the United Nations Industrial Development Organization, associated agency of the Food and Agricultural Organization of the United Nations, which acted as executing agency for the United Nations Development Programme

Based on the work of V. K. Sulc, wood technologist

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ABSTRACT

One of the objectives of Timber Utilization Division at Philippine Coconut Authority-Zamboanga Research Centre has been the assessment of the potential utilization value of relatively unknown wood species Cocos nucifera. One of the important factors is knowledge of mechanical properties of wood for construction purposes with the aim to develop stress grade classification.

The knowledge of its relationship or similarity to the properties of commonly used construction woods should aid in the better utilization of coconut palm sawn wood.

This paper describes the following:

1. Standard small specimen (20 mm) test with exception of compression perpendicular to grain where 50 mm specimens were used. The tabulated results for mechanical properties for coconut palm sawn wood in the green (unseasoned) and air-dry (seasoned) conditions are presented.

2. Full size specimen test represents construction sizes of sawn wood, partly dry (average 22% moisture content) with included normal defects as harvesting steps, wane and want, etc. Specimens were tested on the edge and based on condition that its length (span) is 21 times depth.

   Static bending test was conducted to obtain mechanical properties as modulus of elasticity, modulus of rupture, bending strength at proportional limit; with additional data as types of failure under maximum load and lateral stability with larger ratio of depth to width. At the same time, data were obtained for included defects and characteristics of coconut palm wood.

The full size test was supplementary to the small clear standard specimen test to obtain comparable data of relationship between small and full size specimens.

3. In addition to full size specimen test, relatively few coconut palm wood joints were tested in full size as coconut palm sawn wood is recovered in somewhat restricted cross section area due to large radial variation in its density. Therefore, use of simple joints is recommended to double or increase cross section area to obtain necessary design dimension.

The test results for individual specimen are tabulated on the basis of the values of basic density and are classified to three density groups for all tested strength properties.

Coconut wood has been classified for structural use according to the Australian system for strength and joint groups and stress grade.

Data are expressed in International System of metric units (SI units). Section E of Part II contains simple conversion tables if it is necessary or convenient to convert SI units to other commonly used units.

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PART I: STANDARD SMALL SPECIMEN TEST

1. INTRODUCTION

One of the objectives of Timber Utilization Division at PCA-Zamboanga Research Centre is to assess the potential utilization value of previously relatively unknown species, coconut palm wood. The important factor is knowledge of mechanical properties of wood, with aim to develop stress grade classification. It was found convenient to use assistance from the Australian national university Forestry Department to use their wood testing laboratory.

Further it was found convenient to use the Australian strength grouping system and minimum strength-class limits for grouping Philippine timber species. Strength grouping is prerequisite for the "stress grading classification" of the sawn coconut palm wood, if used as structural components for the light wood framing construction.

It is hoped that such information will assist coconut palm wood which is relatively unknown as a commercial material and its knowledge of a relationship or similarity to the properties of a commonly used commercial wood producing species and should assist to better utilization of coconut palm sawn wood.

The mature coconut palm stem is of such dimensions as could be converted by a number of methods to usable wood which could serve well to mankind - especially if its physical and mechanical properties are suitable for a number of uses. Some of the properties could be improved by such as cutting pattern, grading, preservation, surface treatment, etc. - mechanical properties to some level could be improved by increased dimension to compensate for deficiency in particular mechanical properties if the designer is aware of such problem.

Many commercially used species have known density variation within the stem or individual tress. Very few species have such steep density gradient within the stem as coconut palm wood. For this reason, originally coconut palm wood has been divided to four basic density* groups:

Hard	600 kg|m^3 and above
Medium	400 kg|m^3 to 599 kg|m^3
Soft	250 kg|m^3 to 399 kg|m^3
Very soft	below 250 kg|m^3

Basic density (specific gravity) of coconut palm wood within the stem varies in the radial and longitudinal direction between 200 kg|m^3 (.2 g|cm^3) to 800 kg|m^3 (.8 g|cm^3). As the density of coconut palm wood has close correlation between mechanical and other properties, it is necessary as a first step to utilization of the sawn wood to be separated to a number of density groups, where density alone determines the final end use of the material.

The original four density groups were for practical and simplicity reasons changed to three density groups:

600 kg|m^3 and above	Hard
400 kg|m^3 to 599 kg|m^3	Medium
below 400 kg|m^3	Soft

It is recommended that wood below basic density 400 kg|m^3 shall not be used as a construction material for permanent structures. This is one reason for the above given densities group division.

Note: The standard small specimen test for mechanical properties was conducted using the original four density groups classification.

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* Basic density is the ratio of oven dry weight and green volume.

The consideration to use only two density groups:

500 kg/m^3 and above - High density
below 500 kg/m^3 - Low density

was rejected on the basis that such simple grouping will limit the use of coconut palm wood for a number of final uses and would jeopardize lowering its proper utilization. The adopted three density groups look more conveneient for the utilization and final use of coconut palm wood.

2. STANDARD METHODS FOR MECHANICALLY TESTING SMALL CLEAR SPECIMEN OF WOOD

The tests for mechanical properties of coconut palm wood specimen were carried out in the testing laboratory of Australian University, Canberra, ACT, Australia to obtain detailed knowledge of the strength properties to assist in the determination of design stresses and better utilization of coconut palm wood.

The Australian method of testing small clear specimen is, in general, based on the British standard and American standard specification with some minor modification and addition. but the differences are not of fundamental importance.

Note: British and American standards include the test for "tension parallel to grain" which is normally omitted in the Australian testing method. Therefore, tension parallel to grain for the coconut palm specimen is not subject of the test.

The specimens were tested as 50 mm and 20 mm standard (International Standard) as described in "Standard Methods of Testing Small Clear Specimen of Wood".

The requirement that all various test specimens should be taken from one or more bolts sawn from one log or stem was followed as closely as possible.

The matched green and dry specimen is more difficult to obtain because of the high density gradient, e.g., to match basic density value for two or more specimens is not easily obtained with the coconut palm wood as density gradient is steep in the cross section of the selected "bolt".

The tests are: a. Static bending
b. Compression parallel to grain
c. Compression perpendicular to grain

A graph is plotted of the load against specimen deflection.

S.I. units were used for the test value and tabulated results.

For all static tests, rate of loading was used as prescribed by the "Standard Methods for Testing Small clear Specimen of Wood" (Ref.1 page 3).

Moisture content is determined by: Standard oven weight method immediately after the test.

Basic density is determined by: Volume is taken by water displacement method; and oven dry weight.

Nominal density for air dry wood is determined by:
Volume at 12% moisture content; and
Weight at 12% moisture content.

Note: In the tabulated results, only basic density is used: ratio of oven weight to green volume.

Air dry specimens (12% moisture content) were pre-machined in green condition to size such that seasoning defects as shrinkage, etc. could be removed in the final machining at the 12 percent moisture content to obtain the necessary specimen dimension.

NOTE: For Technical reason to save time, green specimens were pre-dried in low temperature experimental kiln and finally conditioned to 12 percent moisture content in the air controlled room at a temperature of 22°C and 64 percent relative humidity.

All tests were conducted in the laboratory at 21°C temperature and 60 to 65 percent relative humidity condition.

All testing results from test Part I and test Part II were combined and tabulated in Table No. 1.

3. PREPARATION, SELECTION OF THE SPECIMEN FOR STANDARD TESTING OF MECHANICAL PROPERTIES OF THE COCONUT WOOD (COCOS NUCIFERA)

The basic procedure has been intended for the broadest possible selection of material in evaluating mean value and its variability of the strength and related mechanical properties of wood in the form of small defect-free specimen, employing standard method of testing.

Brief description of procedure in the following order:

(i) Selection of palms
(ii) Felling and cutting stem to round wood length (logs)
(iii) Selection of the bolt section
(iv) Breakdown logs and recover bolt section
(v) Marking bolts and record green weight
(vi) Spray bolts by 3% solution of pentachlorophenate
(vii) Sealed bolts in air proof plastic and crated
(viii) Shipped to A.N.U., Canberra ACT - Forestry Department - Australia

(ix) Stored in cool room

(x) Preparation of standard testing specimen for "green" and air dry testing

(xi) Using standard testing procedure

Selection and Collection of Material

Standard requirement is minimum 5 trees selected as representative of the species from any particular location. The test was divided into two parts for a number of technical reasons, transport, quarantine regulations, availability of testing laboratory, etc.

Six average representative palms were selected - three palm stems for each part of test.

Palms were randomly selected from different parts of the 500 ha plantation at PCA-Zamboanga Research Center having approximately 300 hectares pure stand plantation of coconut palms "tall variety" approximately age 50-80 years. Palms population density appromately 100 per hectare (distance between rows - 10 meters) classified locally as Zamboanga or San Ramon Tall.

Age of selected palms:

Three palms approx. 60 years plus - Test Part I
Three palms approx. 50 to 60 years - Test Part II

To represent best average, the palms were selected from different site condition of different height, size, vigor, color of nuts*, stem form

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* Locally some farmers considered coconut palm bearing yellow nut, has much harder wood than coconut bearing green nut. In testing, sawing or machining no evidence has been found to support such phenomena. Between pure green and pure yellow are many "between" color shades.

and age. Height of selected palm vary from 16 meters to 26 meters, and average diameter at breast height (1.30 meters) from 30 cm - 36.0 cm.

* Colour of nuts - one pure green - Test Part I
two pure yellow - Test Part I
three in shades of colour between green and
yellow - Test Part II

The San Ramon tall variety are bearing one of the largest coconuts and is renowned for a tree of great height.

Shade in colour of wood in the relationship to colour of nuts

It appears that such a relationship exists. Palms bearing pure yellow fruit appear to have darker, higher density wood than found in palm bearing pure green fruit, the possibility that the colour shades in the higher densities follow the pattern of the colour of fruit, but this should be the subject of further investigation.

Selection of Bolts for Test Part I

Palm No. 1 G***Height of stem (from butt to first leaves) 22.5 meters
Stem BH** diameter ______ 31 cm
Stem Center diameter ______ 25 cm
Stem top diameter ______ 17 cm
Total volume of stem ______ 1.103 cu. m.

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* See footnote on previous page

** Breast diameter 1.30 meter above the gound level

*** G and Y stand for the Green and Yellow colour of the nuts of palms selected for the test.

Palm No. 2 Y***	Height of stem	25.6 meters
	Stem BH** diameter	36 cm
	Stem center diameter	27 cm
	Stem top diameter	19 cm
	Total volume of stem	1.46 cu. m.
Palm No. 3 Y***	Height of stem	21.4 meters
	Stem BH** diameter	30 cm
	Stem center diameter	26 cm
	Stem top diameter	19 cm
	Total volume of stem	1.13 cu. m.

The average age of selected palms was 60 years plus.

Sawn green materials in the form of bolts:

> 1,20 meters long, 60 mm x 60 mm cros section were treated by 3% solution of Pentachlorophenate to prevent attack of mold and wood staining fungi before packing in the plastic cover and crating.

Crated materials were shipped from PCA-Zamboanga Research Center to Australoan National University Forestry Department, Canberra, A.C.T., Australia which took considerable time from port of Manila to actual delivery to A.N.U. (approximately 4 months). The materials arrived relatively in good condition with slight attack of wood stairing fungi and mold and were stored in cool room for a further 3 months.

Preparation of Testing Specimen

The selected bolts were divided into two groups:

(a) green specimen (fully saturated)
(b) air dry specimen (12% moisture content)

** See footnote on previous page

*** See footnote on previous page

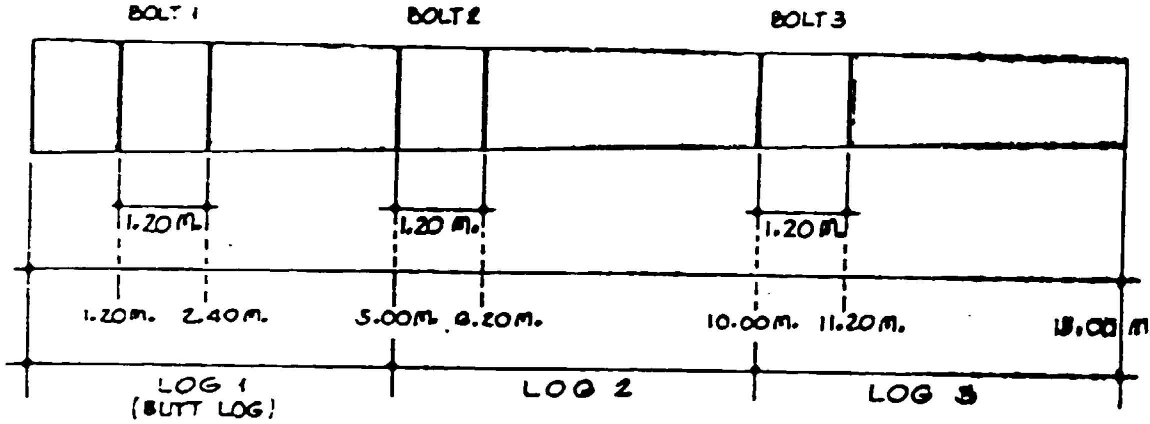
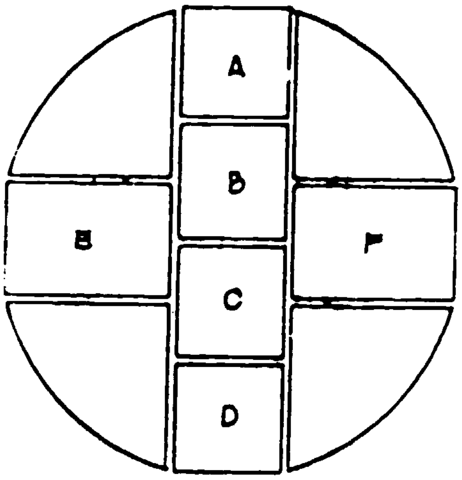


FIG. 1 A

DRAWING SHOWING METHOD OF CUTTING MARKED BOLTS.



A, B, C, D BOLTS - 8 cm. X 6 cm.

E, F BOLTS - 6 cm. X 9 cm.

FIG. 1B

Test Part I

Care was taken to have reasonable proportion of the testing specimens "green" and "air dry" in each density group.

From the adjusted length of each testing specimen, a sample was taken for the determination of moisture content and basic density.

The Specimen Dimensions and Type of Test

50 mm x 50 mm standard:

50 mm x 50 mm x 750 mm	Static bending (center point loading)
50 mm x 50 mm x 200 mm	Compression parallel to grain
50 mm x 50 mm x 50 mm	Compression perpendicular to grain
50 mm x 50 mm x 50 mm	Shear test

20 xx 20 mm standard:

20 mm x 20 mm x 300 mm	Static bending (center point loading)
20 mm x 20 mm x 300 mm	Impact test
20 mm x 20 mm x 70 mm	Tension perpendicular to grain
20 mm x 20 mm x 45 mm	Cleavage
20 mm x 20 mm x 60 mm	Compression parallel to grain
20 mm x 20 mm x 20 mm	Shear test

In the Part I of test for green and air dry specimens, it was decided to use for "Static Bending", "Compression Parallel to Grain", and "Shear Strength" both specimens 50 mm x 50 mm and 20 mm x 20 mm cross section; and supplementary range for different strength properties, using only specimen 20 mm x 20 mm cross section.

Bolts selected for air dry testing were cut to approximate sizes (with allowance for shrinkage during drying) and kept in conditioned room with approximately 20°C temperature and 65% relative humidity*.

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* Any wood kept in this atmospheric condition for a period of time will eventually reach Equilibrium Moisture Content approximately 12%.

Testing

(a) Shimadzu testing machine was used for specimen 50 mm x 50 mm cross section.

(b) Amsley testing machine was used for specimen 20 mm x 20 mm cross section.

Both testing machines were regularly checked and calibrated by the National Association of Testing Authorities, Australia (NATA).

One of the coconut palm wood characteristics is the very large deviation in density most pronounced in the radial direction at any given height of the stem. For this reason, specimens of small cross section as 20 mm x 20 mm have more uniform density (specific gravity) when taken at the cross section at any height of the stem. Further, small cross section specimens can be representative of a very high or very low average density which could not be obtained in construction material dimension sawn from coconut round wood. E.g., the large density gradient of a cross section of round wood limits sawmill recovery of large cross sections material.

To obtain better values for structural materials of a considerable density variation, the mechanical testing of small clear specimen has been followed by tests full size sawn coconut palm wood intended to be used for construction purposes (light frame housing construction). Results and evaluation of the full size tests are discussed in Part II of this report.

Test Part II

The tests for mechanical properties were reduced to:

(a) Static bending (center point loading)
(b) Compression parallel to grain
(c) Janka hardness test

Only specimens of 20 mm x 20 mm cross section were used in the green and air dry conditions.

Selection of bolts for Test Part II

Three palms were selected by similar process as described in the selection of specimen the Test Part I.

Palm No. 4 -	Stem height (from butt to first leaves)	20.1 meters
	Stem butt diameter*	38.8 cm.
	Stem top diameter	17.9 cm.
	Total volume of stem	1.071 cu.m.
Palm No. 5 -	Stem height	18.4 meters
	Stem butt diameter*	37.6 cm.
	Stem top diameter	19.1 cm.
	Total volume of stem	.977 cu.m.
Palm No. 6 -	Stem height	16.2 meters
	Stem butt diameter*	35.8 cm.
	Stem top diameter	18.0 cm
	Total volume of stem	.818 cu.m.

The average age of selected palm stems was 50 to 60 years plus.

NOTE: Test Part I.

Selection of the "bolts" and eventually the testing specimens were located in the lower portion of the stems, e.g., between the height 1.20 meters above the stump and 11.20 meters of a stem height. See Figure 1A.

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* Stem diameter measured over the bark.

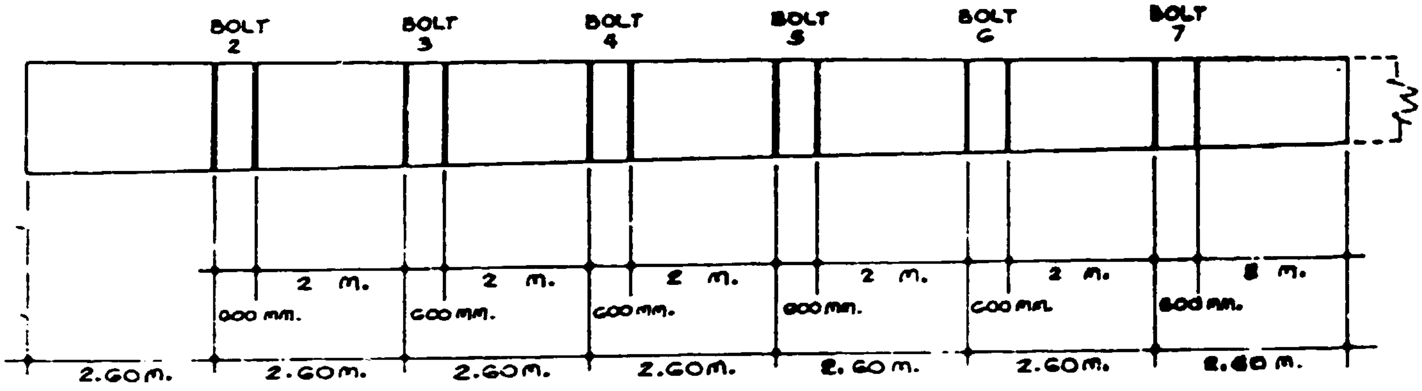
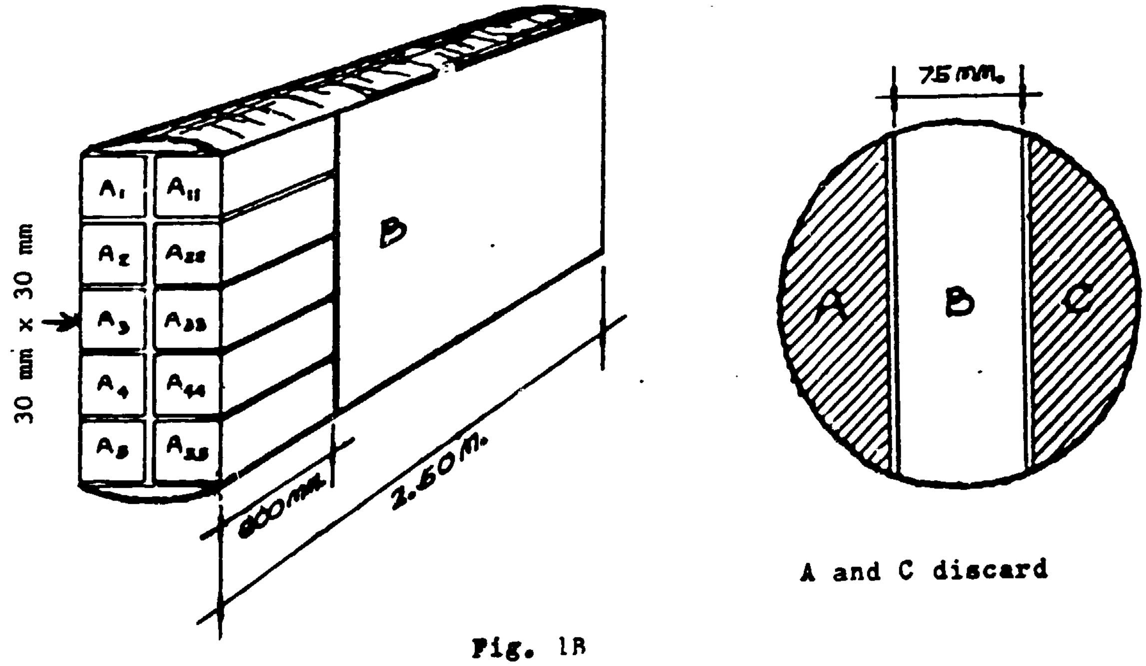


FIG. 1A



A and C discard

Fig. 1B

The testing specimens were pre-machined at the PCA- Zamboanga Research Center and carried as excess baggage to A.N.U., Canberra, Australia.

Final preparation of specimens for testing, air drying and determination of moisture content, basic density were processed in the University Laboratory.

NOTE: Test Part II

Selection of the "bolts" and eventually the testing specimens were located in the higher portion of the stems, e.g., between the height 2.6 m above the stump and 16.2 m of a stem height for the Palm No. 4. For the Palm Nos. 5 and 6, bolts were selected up to 13.6 height of the stem (bolt No. 6). See Fig 1A.

Table I-1: The average ultimate strength properties for Coconut Palm Wood (Cocos nucifera) obtained from standard test of small specimens (20 mm x 20 mm and 50 mm x 50 mm standard).

Condition	Ave. Moisture Content	Basic Density Group (kg/m3)	Cent. Pt. Static Bending			Compression Parallel to Grain		Impact Bending: Center Loading	Tension ⊥ to Grain
			Stiffness	Max. Bending Strength	Stress at limit of propor-tionality				
			Modulus of Elasticity	Modulus of Rupture		Modulus of Elasticity	Maximum Crushing Strength		
	%		MPa	MPa	MPa	MPa	MPa	Meter Newton	MPa
Green	57	600 and above	10857 1379.51 1/ .70 2/ 42* .062 3/	86 12.12 1/ .70 2/ 42* .062 3/	51.62 14.37 1/ .70 2/ 42* .062 3/	7988 1341.5 1/ .73 2/ 34* .052 3/	49 6.34 1/ .73 2/ 34* .052 3/	20.19 9.31 1/ .75 2/ 27* .065 3/	2.03 .30 1/ .76 2/ 21* .069 3/
Air Dry	12		11474 1659.25 1/ .73 2/ 41* .C58 3/	104 15.75 1/ .73 2/ 41* .C58 3/	61.73 15.57 1/ .72 2/ 41* .074 3/	9747 3479.72 1/ .67 2/ 30* .045 3/	57 5.09 1/ .67 2/ 30* .045 3/	20.09 8.51 1/ .69 2/ 21* .082 3/	1.96 .48 1/ .70 2/ 22* .065 3/
Green	107	400 to 599	6880 1693.47 1/ .51 2/ 36* .055 3/	53 11.81 1/ .51 2/ 36* .055 3/	30.43 8.79 1/ .51 2/ 36* .055 3/	6151 1694.83 1/ .50 2/ 24* .042 3/	31 6.81 1/ .50 2/ 24* .042 3/	18.28 8.80 1/ .52 2/ 8* .041 3/	1.47 .18 1/ .51 2/ 8* .042 3/
Air Dry	12		7116 1587.80 1/ .49 2/ .068 3/ 19*	63 13.90 1/ .49 2/ .068 3/ 19*	38.36 11.50 1/ .49 2/ .068 3/ 19*	5282 1187.41 1/ .44 2/ 14* .056 3/	38 7.42 1/ .44 2/ 14* .056 3/	10.12 1.28 1/ .43 2/ 8* .066 3/	1.56 .11 1/ .43 2/ 4* .058 3/
Green	240	250 to 399	3100 601.86 1/ .31 2/ 29* .046 3/	26 6.11 1/ .31 2/ 29* .046 3/	13.13 4.51 1/ .32 2/ 28* .050 3/	2287 502.25 1/ .32 2/ 13* .058 3/	15 3.05 1/ .32 2/ 13* .058 3/	8.39 2.96 1/ .31 2/ 4* .043 3/	.84 .11 1/ .31 2/ 4* .041 3/
Air Dry	12		3633 732.19 1/ .34 2/ 27* .031 3/	33 7.17 1/ .34 2/ 27* .031 3/	15.43 5.68 1/ .31 2/ 27* .047 3/	2914 1175.88 1/ .31 2/ 11* .031 3/	19 [illegible] 1/ .31 2/ 11* .031 3/	9.02 1.80 1/ .31 2/ 5* .013 3/	.67 .19 1/ .31 2/ 7* .036 3/
Green	336	below 250							

1/ - Standard deviation of values

2/ - Density in gm/cm^3

3/ - Standard deviation of density

Compression ⊥ to Grain		Shear		Cleavage Radial and Tangential combined Maximum Value	Janka Hardness		
C S L P**	CS at 2.5mm deflection***	Radial	Tangential		Radial	Tangential	End
M.	MPa	KPa	MPa	N/mm	Newton	Newton	Newton
8.34 2.93 1/ .666 2/ .068 3/ 2*	12.52 4.96 1/ .666 2/ .068 3/ 2*	10.04****	10.04****	11.98 2.32 1/ .77 2/ 18* .068 3/	4419 2212.81 1/ .80 2/ .040 3/ 2*	5288 -498.33 1/ .80 2/ .040 3/ 2*	3826 - .80 2/ .040 3/ 2*
9.03 3.15 1/ .673 2/ 4* .102 3/	13.96 3.83 1/ .673 2/ 4* .102 3/	13.39 2.82 1/ .73 2/ 7* .039 3/	13.39 2.82 1/ .73 2/ 7* .039 3/	11.41 1.82 1/ .69 2/ 18* .060 3/	4456 1584.62 1/ .69 2/ 4* .113 3/	4234 699.03 1/ .69 2/ 4* .113 3/	3289 742.23 1/ .69 2/ 4* .113 3/
2.85 1.36 1/ .519 2/ 11* .054 3/	5.08 2.11 1/ .519 2/ 11* .054 3/	5.97 1.18 1/ .46 2/ 4* .023 3/	6.33 1.43 1/ .51 2/ 3* .066 3/	8.58 1.40 1/ .51 2/ 8* .042 3/	2282 1256.20 1/ .46 2/ 7* .032 3/	2444 1224.95 1/ .46 2/ 7* .032 3/	2104 524.12 1/ .46 2/ 7* .032 3/
3.42 1.57 1/ .527 2/ 11* .068 3/	6.12 2.86 1/ .527 2/ 11* .068 3/	7.96 .091 1/ .45 2/ 3* .042 3/	7.96 .091 1/ .45 2/ 3* .042 3/	7.68 1.91 1/ .44 2/ 10* .060 3/	2354 886.98 1/ .44 2/ 4* .070 3/	2050 855.22 1/ .44 2/ 4* .070 3/	2961 1101.55 1/ .44 2/ 4* .070 3/
1.28 .615 1/ .316 2/ 9* .55 3/	2.33 .969 1/ .316 2/ 8* .55 3/		4.45 - .39 2/ 1* -	4.38 .512 1/ .31 2/ 4* .043 3/	611 2.69 1/ .34 2/ 9* .047 3/	688 259.7 1/ .34 2/ 9* .047 3/	1301 583.11 1/ .34 2/ 9* .047 3/
1.73 0.90 1/ .338 2/ .069 7*	2.70 1.17 1/ .338 2/ .069 3/			4.34 .46 1/ .29 2/ .030 3/ 4*	520 - .30 2/ - 1*	520 - .30 2/ - 1*	1128 - .30 2/ - 1*
					378 131.8 1/ .24 2/ 2* .011 3/	373 124.86 1/ .24 2/ 2* .011 3/	721 367.69 1/ .24 2/ 2* .011 3/

* Number of specimens tested

** Compressive stress at limit of proportionality

*** Compressive stress at 2.5 mm deflection

**** Approximate Value derived from air dry specimen

4. BRIEF DESCRIPTION OF DERIVATION OF STRESSES FOR THE CONSTRUCTION SAWN WOOD.

(i) Unit stresses are based on defect-free green wood (for long duration of load).

(ii) Basic working stresses are based on wood grade and moisture condition.

(iii) Design stresses are based on the condition to which wood is exposed to end use and where all allowances are made for such particular wood service.

Unit stresses are not design stresses but represent the first stage from which design stresses are derived.

Wood Variability

All commercial woods like all other materials have inherent characteristic variability in their properties - coconut palm wood displays a somewhat larger range of variability in the physical and as a consequence in the mechanical properties.

To make differentiation between inherent variability and variability caused by defects in the wood, the stress level are determined in such a way that there is only a small probability that a piece of wood assigned to a particular group or density group will have reduced strength below this assigned value.

The selected stress value is referred to as at the one percen exclusion value or lower probability value, e.g., that only one piece of wood in a bundle of one hundred pieces of a given grade is expected to have a lower stress value.

When the lower probability value (exclusion value) is chosen as one percent, then the bending strength (extreme fibre stress unit in bending) which is derived from the modulus of rupture is determined by:

Ave. value of ultimate bending strength minus 2.33 x SD*/2.22. See the values of average bending strength and standard deviation in Table 2.

When other level of exclusion is desired as:

1% - multiply standard deviation by 2.33
2.5% - " " " " 1.96
5% - " " " " 1.65
10% - " " " " 1.28

The level of exclusion depends on the application or on the importance in design and use of particular wood properties.

The normal frequency or probability curve for a given conventional wood species and its properties is a single histogram and a single curve. (See also Fig.2)

The approximate form could be obtained by drawing a smooth curve to fit the outline of the histogram. The curve is known as a frequency or probability curve for the population and is defined by two constants:

(a) mean value at the apex of the acurve; and
(b) standard deviation (the measure of distance along the horizontal axis from the mean to the point of inflection of the curve).

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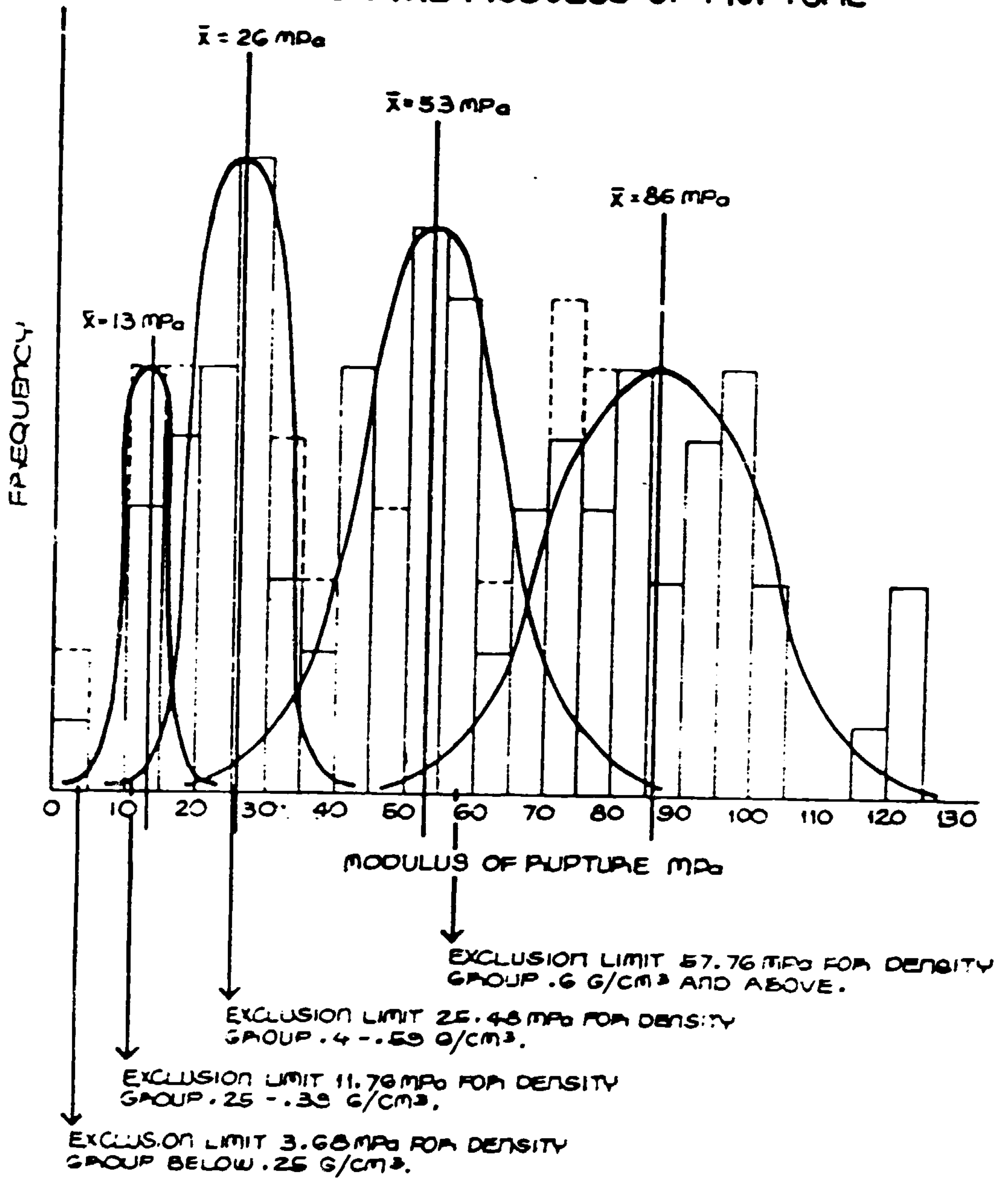
* Standard deviation

Fig. 2 DISTRIBUTION OF A POPULATION OF SPECIMEN TESTED FOR THE MODULUS OF RUPTURE



EXCLUSION LIMIT 57.76 MPa FOR DENSITY GROUP .6 G/cm^3 AND ABOVE.

EXCLUSION LIMIT 25.48 MPa FOR DENSITY GROUP .4 -.59 G/cm^3.

EXCLUSION LIMIT 11.76 MPa FOR DENSITY GROUP .25 -.39 G/cm^3.

EXCLUSION LIMIT 3.68 MPa FOR DENSITY GROUP BELOW .25 G/cm^3.

Table I-2: DERIVATION OF EXTREME FIBRE STRESS UNIT IN BENDING (FOR GREEN WOOD)

DENSITY GROUP	MODULUS OF RUPTURE in MPa			UNIT STRESS in MPa
G/cm3	AVE.	MAX.	MIN.	
.6 and ABOVE	86 SD 12 12	123.6	62.3	23.67
.4 -.59	53 SD 11 81	79.3	28.8	11.32
.25 -.39	26 SC 6 11	39.3	12.7	5.23
BELOW .25	13 SD [illegible]	16.2	4.1	1.63

The large density gradient and consequently variable mechanical and other properties leads to the introduction of density grouping as a first step in grading coconut palm wood. The range of basic density (specific gravity within the palm stem is approximately between limits 200 kg|m^3 (.2 c|cm^3) up to 900 kg|m^3 (.9 g|cm^3). To segregate wood for different end-use, three density groups were established as described before.

The limits of lowest and highest density could be recovered only for small laboratory samples. Sawn wood of structural size is based on average density representing each density group, e.g., average density of a sawn wood is considerably below or above the density limits.

For the above reason, the standard testing specimens 20 mm x 20 mm represent a range from minimum to maximum obtainable density.

The values obtained from the test procedure for the mechanical properties were tabulated in relation to the basic density (specific gravity) of the specimens and the values assigned to appropriate density group.

Fig. 2 shows a drawing of a histogram for the full range of modulus of rupture obtained from the testing of coconut palm wood specimens of different densities.

The four probability curves were drawn such that each represent a density group.

Table 2 shows maximum and minimum ultimate values for modulus of rupture obtained for each density group.

4.1. Determination of Unit Stress

Extreme fibre stress in bending expressed as:

$$F_b = \frac{\bar{X} - (2.33 \times \text{standard deviation})}{K}, \text{ where}$$

F_b = fibre stress in bending

$\bar{X}$ = mean value of modulus of rupture

2.33 = statistical constant used for determining 1 percent exclusion value

K = 2.22, a reducing value calculated from two factors:
- 9/16, the allowance for the effect of long time loading
- 4/5, a safety factor for accidental overloading, errors in design computation, defect in workmanship, etc.

The unit stress for tension parallel to grain: The value could be used for the extreme fibre stress. Tension parallel to grain is considerably affected by defects such as knots, from which the coconut palm wood is free. Where in the design tension parallel to grain is an important factor, the value could be proportionately reduced.

Stress unit for compression parallel to grain is:

$$\frac{\bar{X} - (2.33 \times \text{standard deviation})}{K}; \text{ where}$$

X = mean value of crushing length

2.33 = statistical constant used for determining 1 percent exclusion level

K = 1.66, a reducing value calculated from two factors:
3/4, for duration of load
4/5, a safety factor for overloading, etc.

Compression Perpendicular to Grain:

Compressive stress value at proportional limit is reduced to 75 percent.

Shear:

For shear, the reducing factor value is 5 to 6 or use the same formula as for extreme fibre stress unit *.

$$\frac{\bar{X} - (2.33 \times \text{standard deviation})}{K}, \text{ where}$$

$\bar{X}$ = mean value of shear
K = 2.25

Shear for the joint could be increased by up to 50 percent.

The mean modulus of elasticity is taken as a basic value and is used for calculation of deflection. Where in the design deflection of an individual member is critical, modulus of elasticity could be taken as minimum obtained by reducing the average value by 2.33 times standard deviation.

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* The formula commonly used in Australia is: $\bar{X}$. GF/412 where GF is the grade factor (typically 0.75 or 0.60 for coconut palm wood. The traditional Australian formula would give basic working stresses about 30% less than those given here.

4.2. Basic Working Stress

As the unit stress value appies to defect-free pieces of wood, basic stress is determined by:

(1) Grade value which is a modification of unit stress by a factor which is called strength ratio. (Strength ratio is the ratio of grade stress value including permissible defects to the corresponding unit stress for the wood free from all strength-reducing defects.

Therefor, strength ratio of wood "grade 80" means that permitted defects will reduce "unit stress value" by 20 percent, and "grade 60" means that permitted defects will reduce "unit stress value" by 40 percent.

(2) Moisture condition of the wood - usually two moisture contents are considered, namely, green wood and air dry to a range of equilibrium moisture contents which vary about 15 percent moisture content.

4.3. Design Stress

Design stress is basic working stress modified according to exposure to unusual conditions such as high winds and is usually based on design judgement.

4.4. The Effect of Three-Point Loading (centre-point loading) Used in Testing Procedure.

It is known from experience that the resulting values for small wood specimens tested by the centre-point loading method indicate somewhat lower values for modulus of rupture than are obtained from the four-point loading method.

The increased values could be as much as 3 to 15 percent greater which on average gives correction factor of 0.9.

4.5. The Effect of Three-Point Loading Method on the Value of Modulus of Elasticity.

For both methods, three-point loading or four-point loading, the centre deflection includes deflection due to shear which depend on the value of rigidity. (Approximate value of modulus of rigidity is ME|15 for conventional wood).

The shear effect on the value of modulus of elasticity for some wood species tested by three-point loading method decreases the value of modulus of elasticity by up to 20 percent.

4.6. The Effect of Sloping Grain on Coconut Palm Wood.

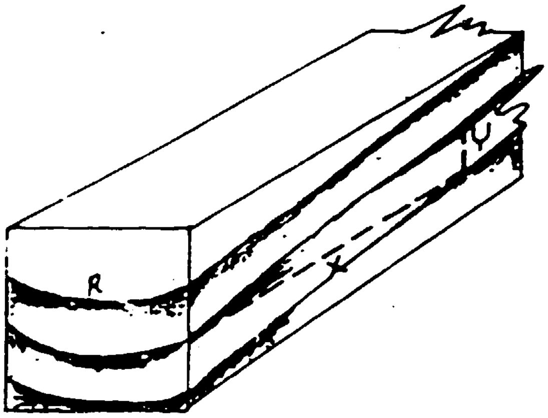
All the small coconut palm wood specimens tested for mechanical properties were celar of all defects except "sloping grain".

Sloping grain includes variation: Cross grain
Diagonal grain
Interlock grain
Spiral and wavy grain

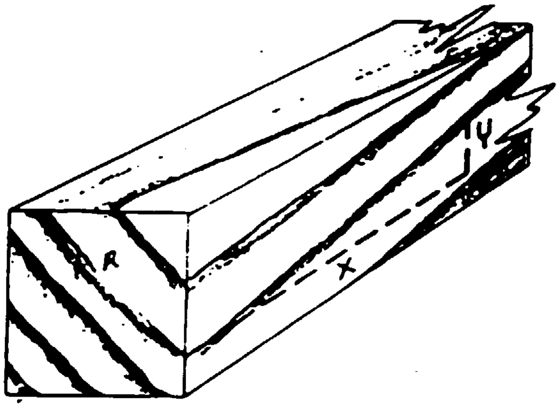
Sloping grain is an important characteristic of wood in general and has a considerable negative effect on wood strength properties as shown in the following table.

Slope of grain	25 mm in 500 mm	25 mm in 400 mm	25 mm in 300 mm	25 mm in 250 mm	25 mm in 200 mm
Reduction in strength in beam (percent)	0	20	30	40	50

Drawings A and B show the slope of growth rings (R) to longitudinal axis of the sawn timber from coniferious wood and its value could be calculated as the ratio x|y. This is not necessarily the same as grain slope which is more difficult to measure, especially in some tropical hard woods and a scribe is normally used.

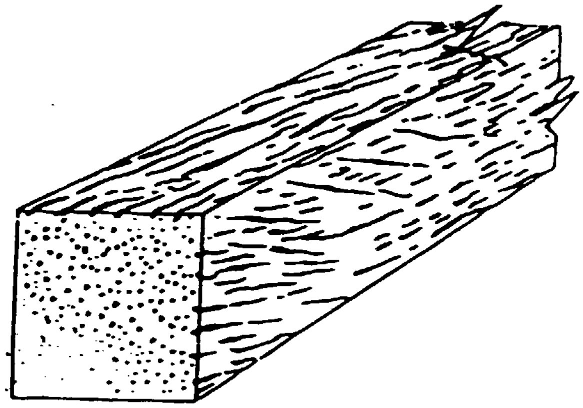


A



B

Drawing C shows arrangement of vascular bundles in palm wood where individual bundles deviate from the longitudinal axial direction.



C

In reference to sloping grain in coconut palm sawn wood the best description to apply is cross or interlocked vascular bundles. The vascular bundles do not follow the straight axial direction and deviate individually as seen in drawing C above.

The vascular bundles characteristics is an inherent property of coconut palm wood and it would be nearly impossible to obtain specimens free of this property. Therefore, all tested specimens and obtained property values include this characteristic.

The cross vascular bundles are more apparent than real and have probably less influence on the strength of coconut palm wood than sloping grain in conventional woods.

Monocotyledons and the genus coconut palm do not increase diameter by secondary thickening as do the dicotyledons or confierious species which yearly form layers of new wood which in the longitudinal direction form the grain lines.

One of the major differences between conventional wood-producing species and monocotyledons is that in the former, vascular bundles are arranged in the ring or enclosed in vascular cyliners; and the latter has vascular bundles scattered through the central cylinder or stem.

When round coconut palm wood is sawn at the tangeential and radial longitudinal surfaces, vascular bundles appear similiar to conventional wood grain with the difference that vascular bundles are not projected through depths of sawn piece of wood. Therefore, unless whole sequences of vascular bundles are inclined to the edge or surface the effect is not critical.

The types of failure in static bending for the small specimens are discussed together with types of failure for full size specimens.

Table I-3: Average Values for Physical and Mechanical Properties of some timbers to be used as a guide to compare values with coconut palm wood.

Timber	Origin	Classification *	Shrinkage 2/	Moisture Condition 1/	Density	Center Loading	
						Modulus of Rupture	Modulus of Elasticity
			%		kg/m³	MPa	MPa
TANGUILE S. polysperma	Philippines	H	Medium	G	500	58	10475
APITONG Dipterocarpus grandiflorus	Pacific Area	H	High to Very High	G D	565 683	61 115	12038 17750
FIGWOOD Ficus racemosa	Pacific Area	H	Very Low to Low	G	383	44	-
KERUING Dipterocarpus spp.	Pacific Area	H	Very High	G	682	73	20550
LAUAN RED Shorea negrosensis	Pacific Area	H	Medium	G	411	53	9325
LAUAN WHITE Pentacme contorta	Pacific Area	H	Medium	D	540	81	11738
MANGROVE Rhizophora apiculata	Pacific Area	H	Very High	G	852	103	20550
MERANTI RED (Combined Group) Shorea spp.	Pacific Area	H	High	G D	425 430	56 83	10325 11200
MERANTI WHITE Shorea spp.	Pacific Area	H	High	G D	480 540	59 73	10350 11775
BAGTIKAN Parashorea plicata	Asia	H	High to Very High	G	480	59	10350
ENG Dipterocarpus spp.	Asia	H	High to Very High	G	683	82	11775
KAMALA Mallotus philippinensis	Asia	H	High	G	608	57	7325
TEAK Tectona grandis	Asia	H	Very Low to Low	G	585	79	11088
BALSA Ochroma pyramidale	Central America	H	Low to Medium	D	165	22	3650
FIR DOUGLAS Pseudotsuga menziesii	Canada	S	Medium	G D	439 515	53 87	10375 12925
PINE RADIATA Pinus radiata (Syn.) P. insignis	New Zealand	S	Low	G D	382 480	44 70	7325 9150
OAK EUROPEAN Quercus spp.	United Kingdom	H	Medium to High	G D	525 646	59 94	8725 10275

* Classification: H = hardwood, S = softwood

1/ Moisture Condition: G = green condition, D = dry condition

2/ Strength Group: See tables 4 and 5, "The Grading of coconut palm sawn wood" UNIDO Document No. DP/ID/SER.A/649.

3/ Borer Suceptibility: LS = Susceptible to attack by Lyctus (powder post) borers.

Compression Strength	Shear Strength	Hardness (side)	Toughness	Cleavage Strength	Strength Group 2/	Borer Susceptibility 3/
MPa	MPa	Newton	Newtonmeter	N/mm		
28	7	3000	27	-	S5	LS
30 59	7 12	3700 6000	27 34	- -	S4 SD3	LS
22	4	1750	7	-	S7	LS
41	8	4250	13	42	S3	LS
29	6	2512	-	-	S5	LS
41	9	3150	-	-	SD5	-
59	15	10550	22	104	S1	LN
30 48	6 -	2512 2800	- -	47 -	light S6	LS
29 46	7 9	3200 3200	15 7	38 -	S4 SD5	LN -
29	7	3200	36	-	S5	LS
41	9	6700	22	-	S3	LS
22	8	3800	22	74	S6	LS
35	8	4775	19	-	S4	LS
12	3	1075	29	16	-	AS
26 52	7 9	2070 3090	11 12	28 28	S5 SD5	LN -
17 41	6 10	2000 2525	12 9	34 47	S7 SD6	LN AS
27 52	9 13	4710 5385	17 15	74 74	S5 SD5	LS AS

Con't. 3/ Borer Susceptibility: = LN = commercialy non-susceptible, i.e. either immune to attack or rarely attacked by Lyctus; AS = susceptible to attack by Anobiid borers.

2/ Shrinkage: See Table I-4 for Shrinkage Classification

Table I-4: Shrinkage Classification

Description of shrinkage	Shrinkage from green to oven-dry (%)	
	Tangential	Radial
Very low	0 - 3.5	0 - 2
Low	3.5 - 5	2 - 3
Medium	5 - 6.5	3 - 4
High	6.5 - 8	4 - 5
Very high	8 plus	5 plus

PART II - FULL SIZE SPECIMEN TEST

1. FULL SIZE SPECIMEN "IN-GRADE TEST" FOR COCONUT PALM WOOD STRUCTURAL MEMBERS

The full size cross section of coconut palm sawn wood was tested by PCA-FAO|UNIDO (Coconut Wood Utilization Project RAS|81|110, Zamboanga Research Centre) in co-operation with the Forest Products Research and Development Institute whose testing laboratory was used.

The full size specimen test was conducted to obtain comparable data in relationship to the small size test.

the processed data from both tests were used to determine strength group and stress grade classification for coconut palm wood.

Testing

Static Bending - Four-point loading to maximum load applied parallel to largest dimension of a specimen cross section (edge loading).

Specimens were tested in such a way that the highest density wood close to cortex was not necessarily in tension. The speed of loading was calculated on the basis of the depth of the specimen.

Properties Data Obtained:

(i) Modulus of elasticity
(ii) Modulus of rupture
(iii) Bending strength at proportional limit

Supplementary Data

(i) Types of failure under maximum load
(ii) Lateral stability of specimens with larger ratio of depth to width.

In addition, a limited number of wood joints were tested for "static bending" (4-point loading) with length of specimen 21 times depth.

Hardness Test (Janka Test) data were obtained for side and end hardness.

Testing Specimen Selection

Fourteen palms were randomly selected representing the plantation average - height varied between 16 and 25 metres; all were aged approximately aged 60 years and over. Stems were cut into pieces 3 to 5 metres long up to 20 metres height (e.g., from each stem, 4 pieces of round wood 3 to 5 metres long were obtained).

Fourteen (14) coconut palm stems were randomly selected from the PCA-ZRC plantations for full-size test specimens: (See table on following page).

Stem No.	Height Stump to First Leaf	Average Diameter	Volume
	(m)	(cm)	(m^3)
1	22.1	27.25	1.29
2	22.9	24.75	1.10
3	24.8	28.0	1.53
4	22.6	23.5	0.98
5	24.1	28.0	1.48
6	23.7	26.75	1.33
7	22.2	27.0	1.27
8	24.5	29.5	1.67
9	21.6	28.25	1.35
10	24.1	27.25	1.41
11	22.4	26.25	1.21
12	23.5	29.5	1.61
13	19.7	28.0	1.21
14	21.4	27.0	1.23

Round wood logs were sawn to recover maximum number of sawn material for the end use as construction wood. All sawn material in green condition was visually graded to represent two basic density groups: (a) 600 $kg|m^3$ and above, and (b) 400 to 599 $kg|m^3$. At the same time, green moisture content was calculated by oven dry method. Selected material was stacked, stickered and air dried for nearly 4 months.

Before the material was shipped to Forest Research Laboratory Los Baños, specimens were regraded and cross cut to lengths representing 21 times the depth of each specimen. At the same time, mositure content by oven dry method and preliminary average basic density* were calculated for each individual specimen.

Unfortunately, larger cross section specimens were unable to reach moisture content equilibrium and were tested at moisture contents as stated in the tabulated results.

After testing a sample was cut from each specimen and weighed for final moisture content and density determined at <u>PCA-Zamboanga Research Centre Laboratory</u>.

As the tabulated results show, a number of specimens fall below average basic density 400 kg/m^3 (Table 3). Most specimens of lower density represent larger cross sections which underlines the difficulty of limitation recovering larger cross sections of a higher density necessary for load bearing members in construction.

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* Basic density determined as ratio oven weight and green volume. (Considerable variation in average density exists in a piece of sawn coconut palm wood as determined by a number of samples taken along the length).

Full Size Speciment Test

Average Moisture Content of Samples when tested

175 x 38 163 x 38 150 x 63 150 x 50 150 x 38	Average M.C. = 24%
125 x 100 125 x 75 125 x 63 125 x 50 125 x 45 125 x 38	Average M.C. = 22%
100 x 100 100 x 75 100 x 63 100 x 50 100 x 45 100 x 38	Average M.C. = 25%
75 x 75 75 x 50 75 x 38	Average M.C. = 18%
50 x 45 50 x 38 45 x 45 38 x 38 50 x 50	Average M.C. = 16%

Table II-1 In-Grade Full Size Specimen Test: All specimen loaded on the edge (length 21 times depth).
Static Bending (four-point loading - ultimate properties). Cross section dimensions > 50 mm
Density > 600 kg/m³

Density Group	Dimension H x W	Ave. Basic Density	Standard Deviation	Ave. M.C*	No. of Specimens	Average Modulus of Rupture		Average Stress at Proportional Limit		Average Modulus of Elasticity		
Kg/m³	(mm)	g/cm³		%		MPa	SD**	MPa	SD**	1000 MPa	SD**	
600 and above	75 x 38	.722	.061	18	19	51.35	13.49	36.80	6.66	9.41	1.94	
	75 x 50	.692	.058	18	18	59.07	9.12	43.52	7.23	11.56	1.25	
	100 x 38	.726	.088	26	11	54.61	13.52	37.74	10.21	10.84	2.51	
	100 x 50	.723	.089	26	14	54.92	9.74	42.65	9.94	11.49	0.91	
	100 x 63	.733	.104	26	5	58.50	11.62	41.05	11.08	10.88	1.20	
	125 x 36	.665	.047	22	5	46.29	8.42	32.9	4.97	10.70	0.88	
	125 x 50	.670	.045	22	5	55.03	8.29	35.03	4.71	10.90	1.09	
	125 x 63	.800	.110	22	3	56.20	7.31	42.65	8.94	10.06	0.79	
	150 x 50	.709	.160	24	3	61.16	21.22	44.96	16.07	12.28	1.32	
	150 x 63	.625	.036	24	4	52.82	8.12	36.25	6.80	10.46	6.60	
	75 x 75	.610	-	18	1	45.05	-	28.42	-	6.40	-	
	100 x 75	.704	.035	26	3	59.05	17.56	41.79	14.81	9.45	1.95	
	125 x 75	.750	.008	22	2	33.17	12.58	29.39	8.51	8.13	0.68	
	163 x 38	.644	-	24	1	34.24	-	25.37	-	10.09	-	
Mean Value ***		.710	.070	22		54.55	10.86	39.82	7.89	10.76	1.46	

* Moisture Content
** Standard Deviation
*** The values data from the specimen less than 4 are not included in the mean value.

Srength Group Classification: S3
Stress Grade Classification : F11

Table II-2 In-Grade Full Size Specimen Test: All specimen loaded on the edge (length 21 times depth). Static Bending (four-point loading - ultimate properties).

Density Group	Dimension H x W	Ave. Basic Density	Standard Deviation	Ave. M.C.*	No. of Specimens	Average Modulus of Rupture		Average Stress at Proportional Limit		Average Modulus of Elasticity	
Kg/m^3	(mm)	g/cm^3		%		MPa	SD**	MPa	SD**	1000 MPa	SD**
400 - 599	75 x 38	.515	.060	18	22	31.70	4.70	23.64	5.53	6.02	1.16
	75 x 50	.524	.063	18	7	42.01	6.79	32.49	4.33	7.70	0.77
	100 x 38	.490	.059	26	33	32.51	9.40	22.69	6.82	6.65	1.84
	100 x 50	.569	.011	26	5	49.77	10.40	35.65	7.50	9.57	1.06
	100 x 63	.459	.085	26	3	31.17	7.75	23.32	6.55	7.34	1.52
	125 x 38	.564	.052	22	9	32.71	9.70	22.08	5.11	7.18	1.62
	125 x 50	.549	.057	22	4	47.64	5.30	33.73	5.22	10.26	1.12
	125 x 63	.487	.052	22	4	43.53	10.36	30.76	11.19	8.45	1.95
	150 x 38	.569	-	24	1	38.52	-	32.05	-	10.28	-
	150 x 50	.496	-	24	1	46.54	-	32.25	-	8.93	-
	150 x 63	.518	.067	24	5	38.70	2.81	28.71	4.13	8.33	0.75
	75 x 75	.533	.033	18	3	38.37	6.43	26.60	4.11	7.41	1.28
	100 x 75	.477	.050	26	7	29.29	5.06	20.26	2.91	5.66	1.15
	100 x 100	.499	.020	26	3	34.46	7.49	22.23	3.30	5.84	1.48
	125 x 100	.445	-	22	1	36.46	-	28.92	-	7.03	-
	150 x 75	.473	-	24	1	42.08	-	28.69	-	7.80	-
	163 x 38	.523	-	24	1	32.83	-	21.06	-	7.81	-
	Mean Values***	.498	.056	23		35.11	7.42	25.17	5.91	7.02	1.41

* Moisture Content

** Standard Deviation

*** The values data from the specimen less than 4 are not included in the mean value.

Strength Group Classification: S6

Stress Grade Classification : F5

Table II-3 In-Grade Full Size Specimen Test: All Specimen loaded on the edge (length 21 times depth). Static Bending (four-point loading - ultimate properties).

Density Group	Dimension H x W	Ave. Basic Density	Standard Deviation	Ave. M.C.*	No. of Specimens	Average Modulus of Rupture		Average Stress at Proportional Limit		Average Modulus of Elasticity		
kg/m³	(mm)	g/cm³		%		MPa	SD**	MPa	SD**	1000 MPa	SD**	
below 400	75 x 38	.357	.011	18	5	26.36	6.30	18.31	4.78	4.75	1.13	
	100 x 38	.359	.034	26	18	20.71	5.26	14.73	4.36	4.47	0.91	
	100 x 50	.280	.054	26	2	12.29	3.08	-	-	3.10	0.43	
	100 x 75	.378	.016	26	2	26.22	3.19	17.08	2.33	4.75	1.16	
	100 x 100	.243	.043	26	3	18.21	5.05	11.03	2.98	4.00	1.61	
	125 x 38	.321	.014	22	4	17.11	6.13	12.66	4.88	4.43	1.56	
	125 x 50	.217	-	22	1	26.15	-	16.87	-	4.96	-	
	125 x 63	.359	-	22	1	24.50	-	17.01	-	5.73	-	
	125 x 100	.320	-	22	1	15.66	-	10.90	-	3.11	-	
	150 x 38	.372	.007	24	2	22.58	9.24	17.96	11.00	4.88	1.90	
	150 x 63	.356	-	24	1	29.48	-	26.72	-	6.74	-	
Mean Value***		.373	.027	24		21.22	5.58	15.08	4.51	4.52	1.05	

The coconut palm wood of basic density below 400 kg/m³ is not recommended for load bearing construction uses.

Such wood could be used for a number of different uses: inside lining, ceilings, etc., where it is fully protected from weather conditions. It is recommended to be protected by "Boron" chemicals as a protection against house borers.

Another use is for temporary and auxiliary buildings such as agricultural sheds, etc.

* Moisture content

** Standard deviation

*** Values from less than 4 specimens are not included in the mean values.

Table II-4 **In-Grade Full Size Specimen Test: All specimen loaded on the edge (length 21 times depth). Static Bending (four-point loading - ultimate properties).**

Density Group	Dimension H x W	Ave. Basic Density	Standard Deviation	Ave M.C.*	No. of Specimens	Average Modulus of Rupture		Average Stress at Proportional Limit		Average Modulus of Elasticity		
Kg/m^3	(mm)	g/cm^3		%		MPa	SD**	MPa	SD**	MPa	SD**	
600 and above	38 x 38	.771	.070	16	13	69.57	13.00	53.74	9.52	10.57	1.37	
	45 x 45	.715	.066	16	8	70.70	10.38	51.90	5.39	11.80	1.51	
	50 x 38	.711	.090	16	14	48.45	9.77	36.19	9.16	9.24	1.71	
	50 x 50	.722	.086	16	12	66.06	10.98	46.17	8.06	10.77	1.17	
	Mean Values*	.731	.079	16		62.58	11.08	46.27	8.34	10.43	1.44	
400 - 599	38 x 38	.493	.051	16	2	38.35	16.39	25.44	10.76	6.38	2.03	
	45 x 45	.547	.038	16	4	52.97	15.22	33.82	8.37	7.65	1.97	
	50 x 38	.502	.058	16	12	40.99	9.15	29.01	4.64	7.89	1.94	
	Mean Values*	.513	.053	16		43.98	10.67	30.21	5.57	7.83	1.95	

* Moisture content

** Standard deviation

*** Values from less than 4 specimens are not included in the mean values.

Density group 600 kg/m^3 and above - Strength Group Classification: SD5

Density group 400 - 599 kg/m^3 - Stress Grade Classification : SD8

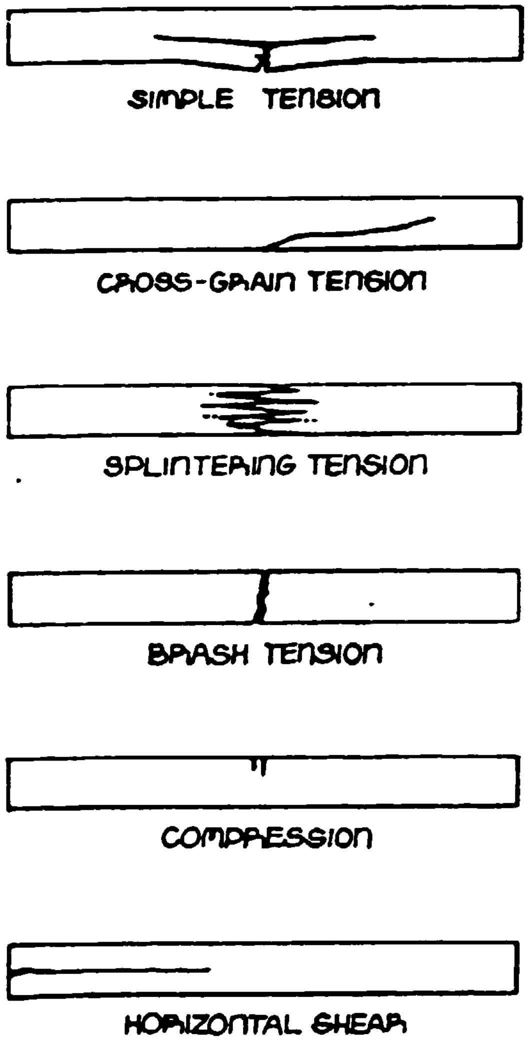
NOTE: The above specimens of a cross section dimension below 50 mm were tested in length 21 times the largest depth to obtain strength information of such material for battens (purlins) to be used for support of roofing shingles.

2. COMMENTS ON LABORATORY TESTS

2.1. Standard Small Clear Specimen Test - Types of Failure - (Static Bending - center point loading)

FIG. 3

TYPES OF FAILURES IN STATIC BENDING



Total specimens tested: 203

Type of Failure	No. of Specimens	Percentage
Cross grain tension	107	53.0 %
Splintering tension	82	40.5 %
Brash tension	2	1.0 %
Horizontal shear*	1	0.5 %
Cross grain and splintering tension	10	5.0 %

---

* Horizontal shear failure was observed for a specimen tested in green condition with basic density .93 g/cm^3 (highest density specimen tested).

2.2. Full Size Specimen Test - Types of Failure - (Static Bending - four point loading)

Total specimens tested: 296

Type of failure	No. of specimen	Percentage
Simple tension	41	14.0 %
Cross grain tension	213	72.0 %
Splintering tension	9	3.0 %
Brash tension	10	3.0 %
Compression	9	3.0 %
Simple and cross grain tension	2	1.0 %
Cross grain and splintering tension	10	3.0 %
Splintering tension and compression	1	0.5 %
Simple tension and compression	1	0.5 %

2.3. Comments on the failure of coconut palm wood under maximum load

In both tests (small and full size specimens) cross grain failure is dominant.

As cross grain (vascular bundles) is an inherent characteristic of coconut palm wood, all specimens were tested for a number of mechanical properties with this characteristic and it is included in the obtained properties data.

It is recommended that if a piece of wood is chosen as a beam or joist for a particular demanding design where maximum strength properties are necessary, to check by visual inspection for the level of inclination of the vascular bundles to the edge of the wide surface.

Low density coconut palm wood has a tendency towards "splinter tension failure".

No different types of failure were observed between green and air dry wood. Under a final maximum load, air dry wood specimens break somewhat more rapidly than those in green condition.

2.4. Summary of structural classification

The following are the 'best estimates' so far possible based on the data obtained during this project:

	Hard Grade (density above 600 kg/m^3)	Medium Grade (Density 400-600 kg/m^3)
Strength Group		
Unseasoned	S3	S6
Seasoned	SD5	SD8
Joint Groups		
Unseasoned	J3	J4
Seasoned	JD4	JD5
Stress Grade		
Unseasoned	F11	F5
Seasoned	F11	F5

NOTE: A conservative estimate has been made for the joint group classifications.

3. DENSITY EFFECT ON THE PROPERTIES OF COCONUT PALM WOOD STRUCTURAL MEMBERS

A close correlation exists between density and the mechanical properties.

Density variation:

The range of density of coconut palm wood is so large that it is necessary to grade sawn wood (preferably green, directly from the saw)[1] to density groups.

The density groups were used at the PCA-Zamboanga Research Centre. Each density group represents, from the technical point of view, different kinds of wood with characteristic properties and different end-uses.

The tabulated results from both tests (small and full size specimens) are arranged and classified by density groups. As was discussed already, small standard specimens (20 mm x 20 mm cross section) have more uniform average density. The full size specimen density variation is considerably larger.

Coconut palm wood should always be flat sawn in order to recover material with minimum density variation.

The drawing on the following page explains and shows the range of the density variation between two surfaces of a piece of wood, 50 mm thick when sawn from this particular location in the data for full size specimens strongly influences by the large density variation. The standard rule used

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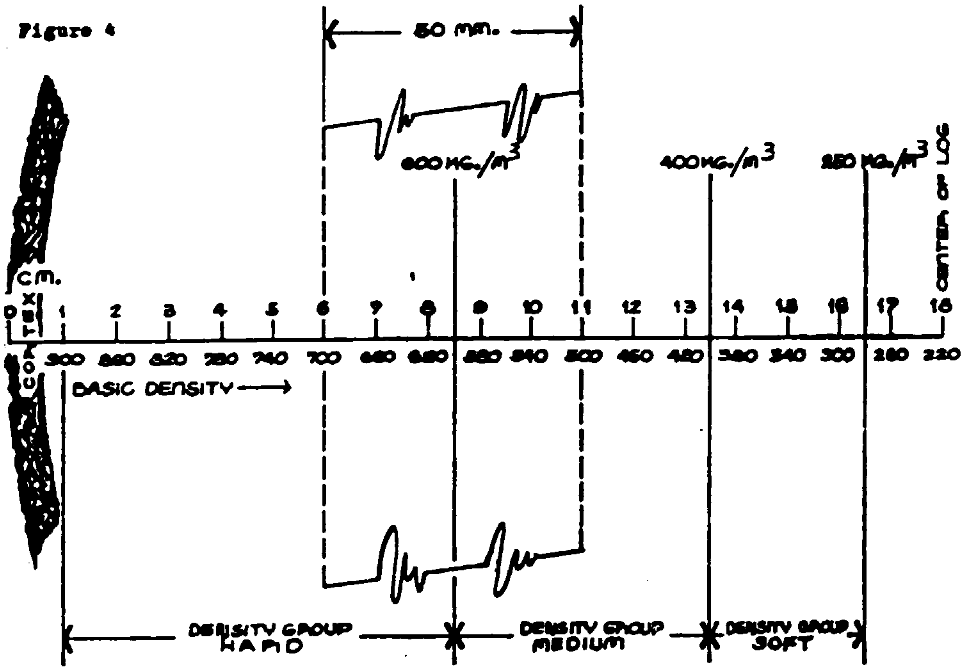
[1] Some authorities advise grading by density after kilning to allow drying defects to be taken into account and to base the classification on a more constant moisture content.

Figure 4



for the small specimen test (static bending) was that the stronger side (close to cortex) was placed in such way as to be in tension. This rule was not applied for the full size specimen tests. The full size specimen test was to include the effects of randomly located defects.

Any grading system will only be effective if there are simple means to control classification of sawn wood to assigned density groups.

This subject is discussed in detail in reports on coconut palm wood grading.

3.1. Modulus of Rupture

Ta II shows ultimate mean value of the modulus of rupture for:

(i) Standard small specimen - Static bending (3-point loading)
(ii) Full size specimen (depth over 50 mm) Static bending
(iii) Full size specimen (depth below 50 mm) (4-point loading)

Table II-5: Comparison of Small and Full Size Specimens on Test Results

Density group	Standard small specimens		Full size specimens			
			depth larger than 50 mm		depth less than 50 mm	
	Ave. basic density	Mean value of MR*	Ave. basic density	Mean value of MR*	Ave. basic density	Mean value of MR*
kg/m3	g/cm3	MPa	g/cm3	MPa	g/cm3	MPa
600 and above	.70	86	.71	55	.73	63
400 to 599	.51	53	.50	35	.51	44
below 400	.31	26	.37	21	-	-

* Modulus of Rupture

Depth Effect:

The effect of depth on the strength of conventional wood has been studied by many wood technologists. It has been shown that modulus of rupture at maximum load decreases as the depth of beam or joist increases. This usually apply where the depth is greater than 300 mm. Normally beams below 300 mm are used without any modification.

Coconut palm sawn wood is technically and physically restricted to a maximum depth up to 175 mm, 63 mm thick and therefore should not be affected.

From the tabulated results of standard small and full size specimens of different dimensions, it can be seen that modulus of rupture is affected by the joist or beam depth in a similar way to conventional woods.

In the derivation of stress grade from the small specimen test, the effect of depth is included in the reduction factor,

$$F_b = \frac{\overline{MR} - (2.33 \times SD)}{2.22}, \text{ where}$$

F_b = unit working stress in bending

SD = standard deviation

The same factor is used to derive stress grade for the full size specimen.

It is possible that some depth modification for grade stress of coconut palm wood joists will be appropriate.

No investigation has been made on the effect of depth on other mechanical properties.

The strength-depth relationship is a subject of future study combined with correct interpretation of the test data from green and air dry specimens.

As can be seen in Table 5, density of wood (specific gravity) is the most important factor reducing the value of modulus of rupture.

3.2. Modulus of Elasticity

Table II shows mean value of the modulus of elasticity for:

(i) Standard small specimen - Static bending (3-point loading)
(ii) Full size specimen (depth over 50 mm ⎫ Static bending
(iii) Full size specimen (depth below 50 mm)⎭ (4-point loading)

Table II-6: Comparison of Small and Full Size Specimens on Test Results

Density group	Standard small specimens		Full size specimens			
			depth larger than 50 mm		depth less than 50 mm	
	Ave. basic density	Mean value of ME*	Ave. basic density	Mean value of ME*	Ave. basic density	Mean value of ME*
kg/m^3	g/cm^3	MPa	g/cm^3	MPa	g/cm^3	MPa
600 and above	.70	10857	.71	10760	.73	10430
400 to 599	.51	6880	.50	7020	.51	7838
below 400	.31	3100	.37	4520	-	-

* Modulus of Elasticity

As can be seen from the Table II, modulus of elasticity is nearly constant and is not affected by the depth of a specimen.

Modulus of elasticity increases only for the air dry wood.

Density (specific gravity) is the most important factor affecting the value of modulus of elasticity.

Different testing procedures were used for small and full-size specimens in static bending with the former being tested by centre-point loading method and the latter by four-point loading method. It was expected that lower values of modulus of elasticity would be obtained from the small specimen test since it was subject to shear deflection.

There is no indication from the obtained values that specimen size or different type of loading in static bending affected modulus of elasticity for coconut palm wood.

In general, many conventional timbers tested by four point loading method increase the value of modulus of elasticity in comparison to three point loading method.

FURTHER COMMENTS ON COCONUT PALM WOOD

- Brief comment on the standard small specimen test and compression parallel to grain.
- The values of "Janka Hardness" obtained from the full size specimen test at Los Baños, Laguna, Philippines. See Table II-7.
- Relationship between modulus of rupture and modulus of elasticity, modulus of elasticity and unit stress, basic density and modulus of elasticity, basic density and modulus of rupture. See Figs. 5-11.

Compression Parallel to Grain

The mean values of compression parallel to grain obtained from standard small specimen tests are relatively high.

The mean values were obtained by using two types of standard test specimen:

(i) Standard 50 mm x 50 mm x 200 mm with loading speed of 0.6 mm/min.

(ii) Standard 20 mm x 20 mm x 60 mm which should have loading speed as low as 0.18 to 0.01 mm/min. It is possible that the loading speeds for 20 mm specimens were higher than the given values.

As the obtained data from both types of specimen were combined, it is possible that some errors were introduced.

The second reason for relatively high values is that the 20 mm specimen has higher density values (20 mm cross section specimen has more uniform density and individually could reach up to .9 g/cm^3).

Types of Failure Observed During Test

(i) Crushing - the plane of rupture is approximately horizontal.
(ii) Shearing - the plane of rupture is 45° or more to the horizontal.

The types of failure were approximately equal in number. The higher density wood tended to have shearing failure and the lower density wood tended to have crushing failure.

TABLE II-7
Janka Hardness Test

Condition and M.C.	Basic Density Group	Average Nominal Density	Tangential	Radial	End
	Kg/m^3		Newtons		
Air dry to 16% Moisture Content	600 and above	830	8860 1/ 1380 2/ .69 3/ .043 4/ 12 5/	8750 1/ 1290 2/ .69 3/ .043 4/ 14 5/	9140 1/ 1570 2/ .69 3/ .048 4/ 12 5/
	400 - 599	675	5610 1/ 760 2/ .56 3/ .048 4/ 7 5/	5390 1/ 1070 2/ .56 3/ .048 4/ 3 5/	5340 1/ 860 2/ .56 3/ .046 4/ 5 5/
	below 400	400	2190 1/ 2060 2/ .33 3/ .091 4/ 2 5/	2190 1/ 2060 2/ .33 3/ .091 4/ 2 5/	1590 1/ 680 2/ .33 3/ .091 4/ 2 5/

1/ Mean value

2/ Standard deviation of mean value

3/ Average basic density in g/cm^3

4/ Standard deviation of basic density

5/ Number of specimens tested

FIGURE 5

Standard Small Clear Green Specimen Test

Static Bending (three-point loading)

Linear Relationship Between Modulus of Elasticity and Modulus of Rupture

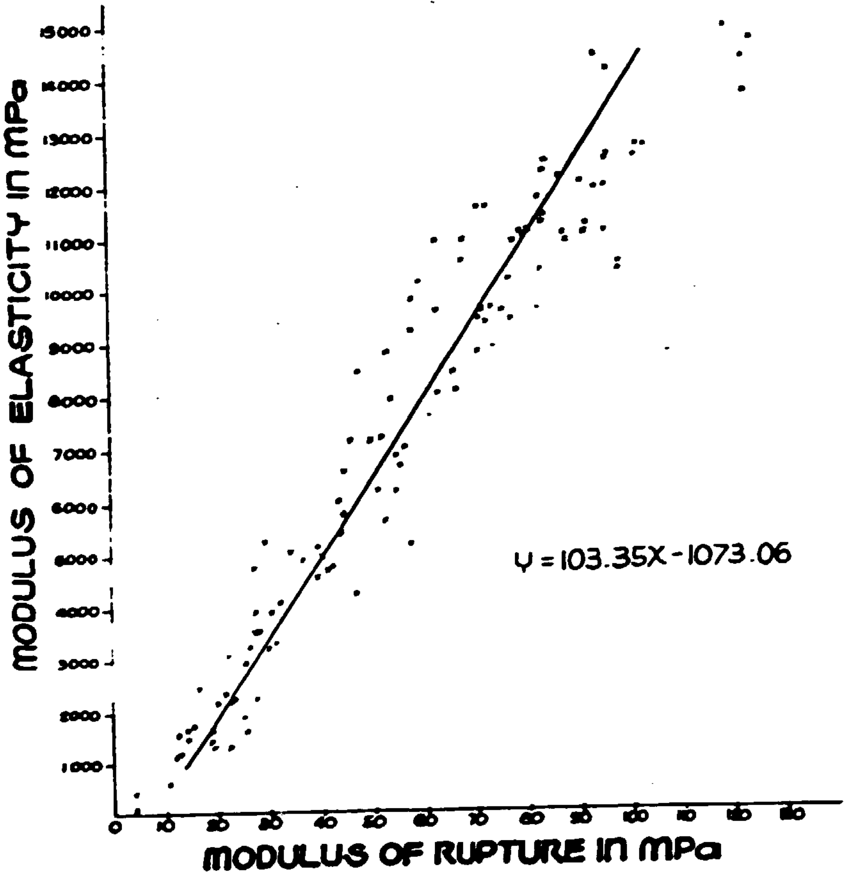


FIGURE 6

Standard Small Clear Green Specimen Test

Static Bending (three-point loading)

Linear Relationship Between Modulus of Elasticity and Unit Stress

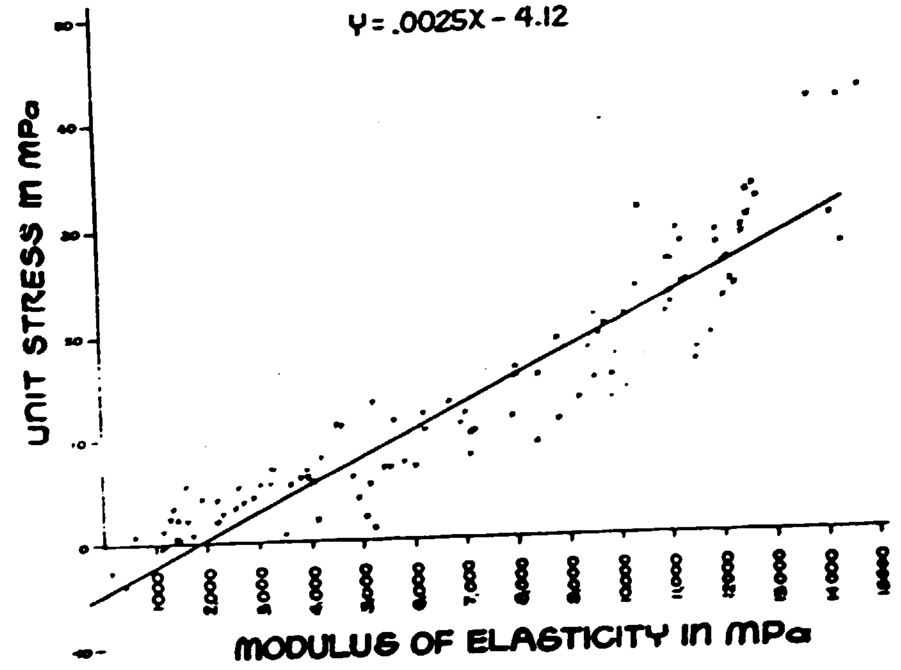


FIGURE 7

Standard Small Clear Dry Specimen Test

Static Bending (three-point loading)

Linear Relationship Between Modulus of Elasticity and Modulus of Rupture

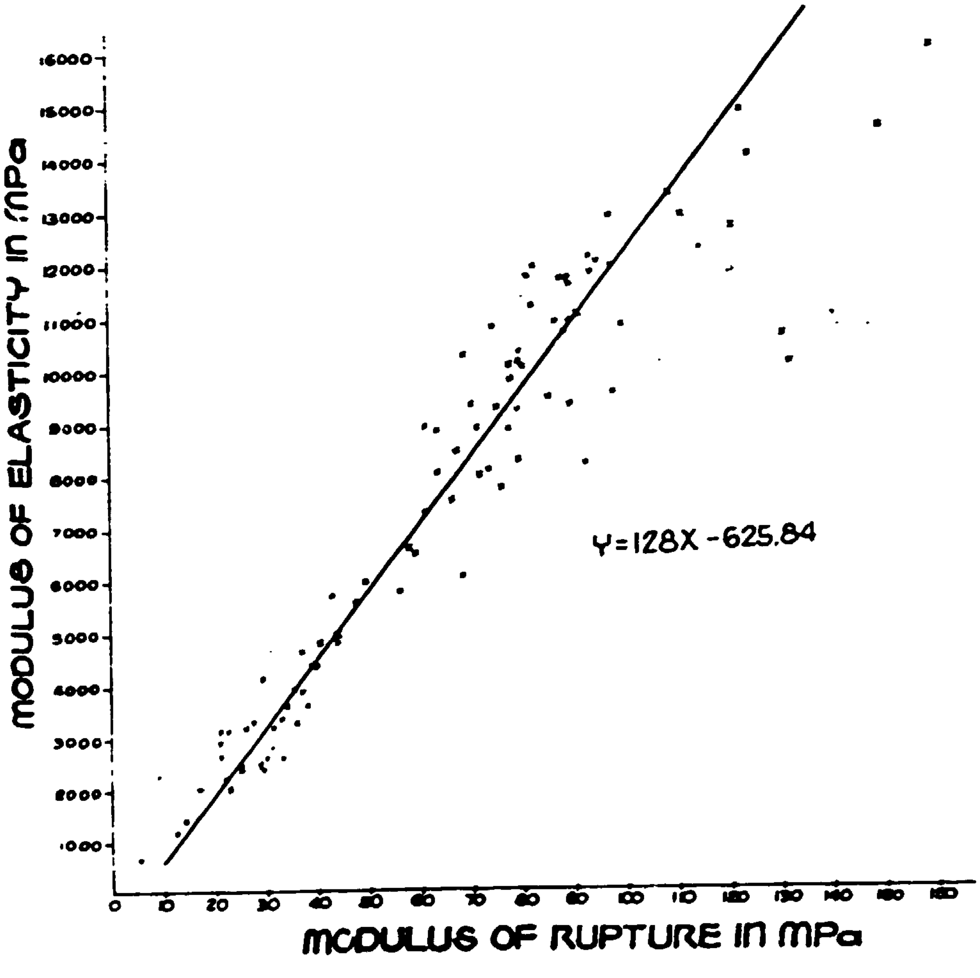
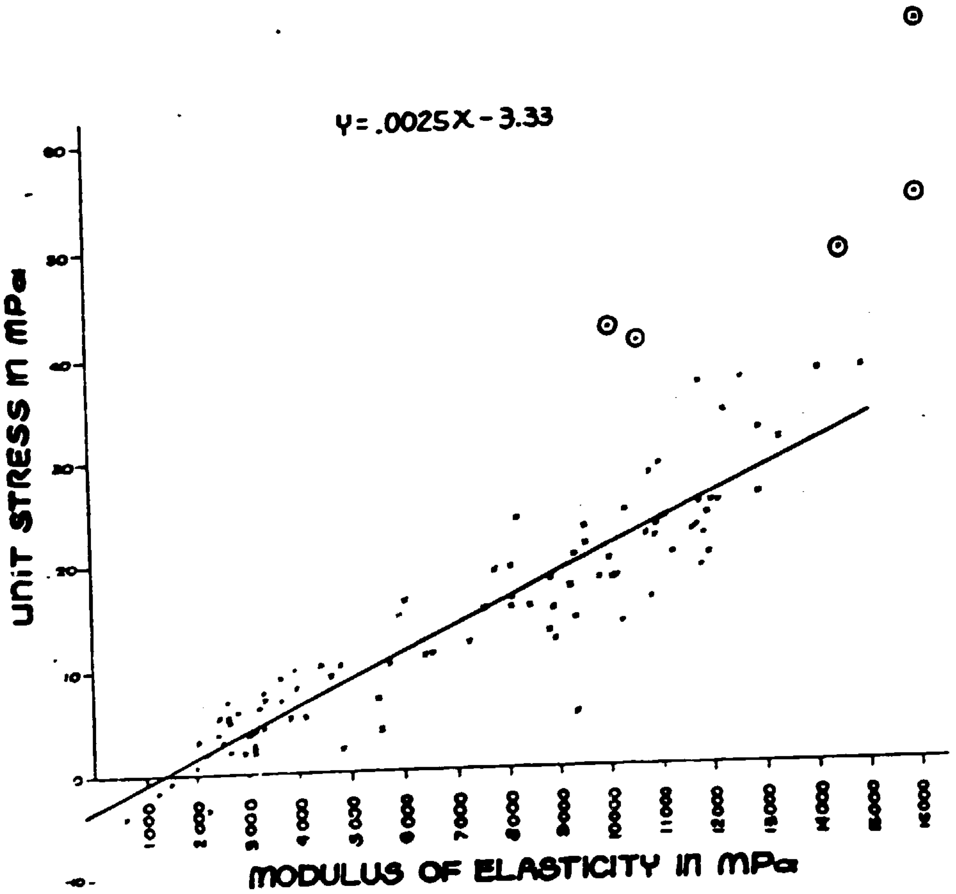


FIGURE 8

Standard Small Clear Dry Specimen Test

Static Bending (three-point loading)

Relationship Between Modulus of Elasticity and Unit Stress



NOTE: The five values indicated by symbol ⊙ are not included in the determination of the equation of the line. See pages 23 - 24, "Standard Small Specimen Test".

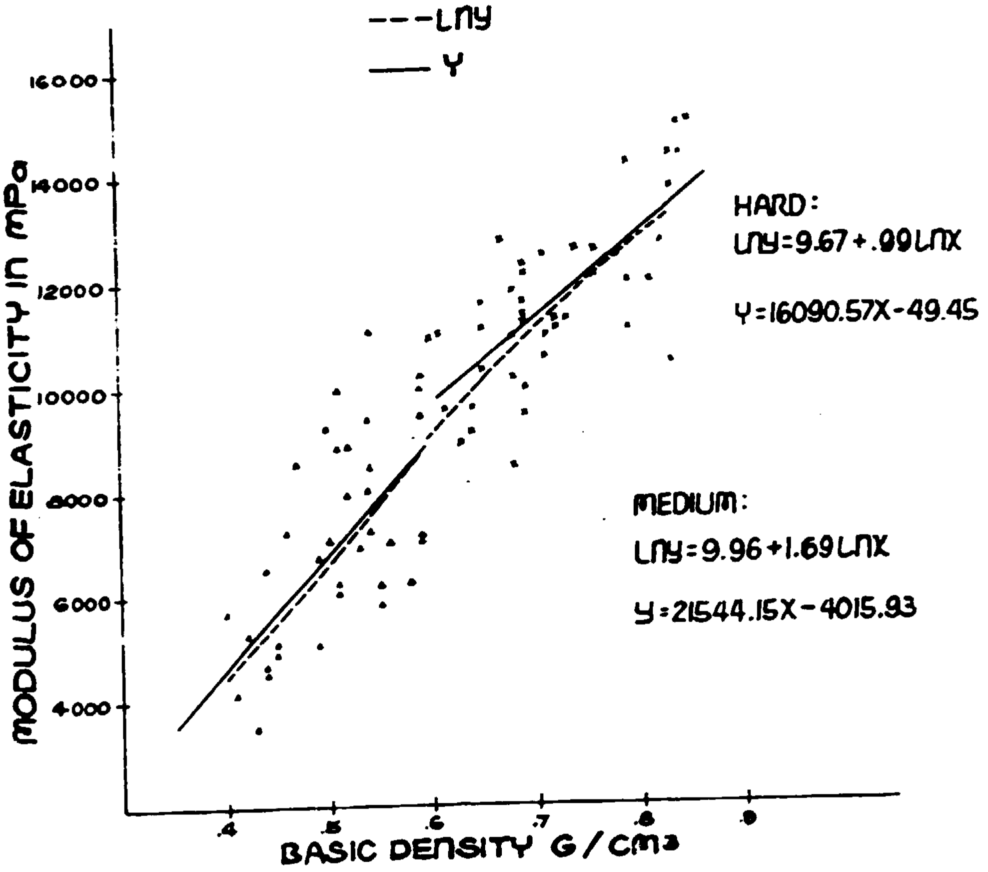
FIGURE 9

Standard Small Clear Green Specimen Test

Static Bending (three-point loading)

Relationship Between Basic Density and Modulus of Elasticity

(Hard: .60 g/cm^3 and above; Medium: .40-- .59 g/cm^3)

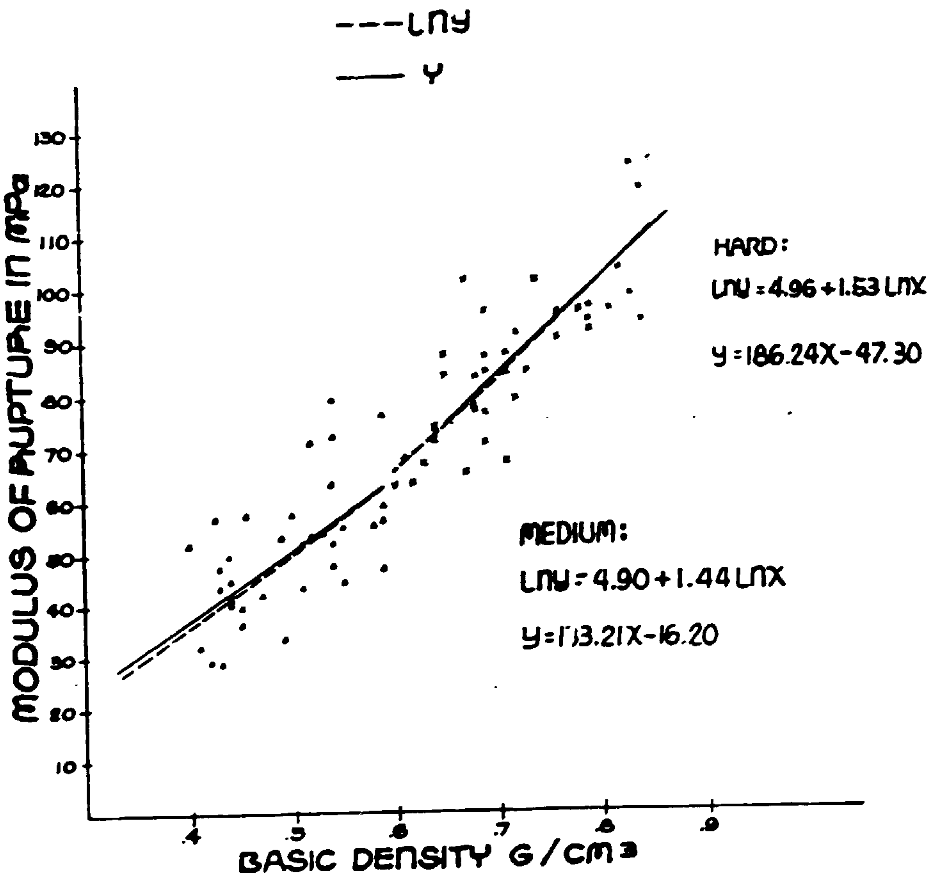


NOTE: Comparison of correlation coefficient values between the straight line and the exponential curve fitted to the data points,

	$y = mx + b$	$lny = lnb + mlnx$
Hard	.717	.694
Medium	.646	.692

FIGURE 10

Standard Small Clear Green Specimen Test
Static Bending (three-point loading)
Relationship Between Basic Density and Modulus of Rupture
(Hard: .60 g/cm³ and above; Medium: .40 - .59 g/cm³)



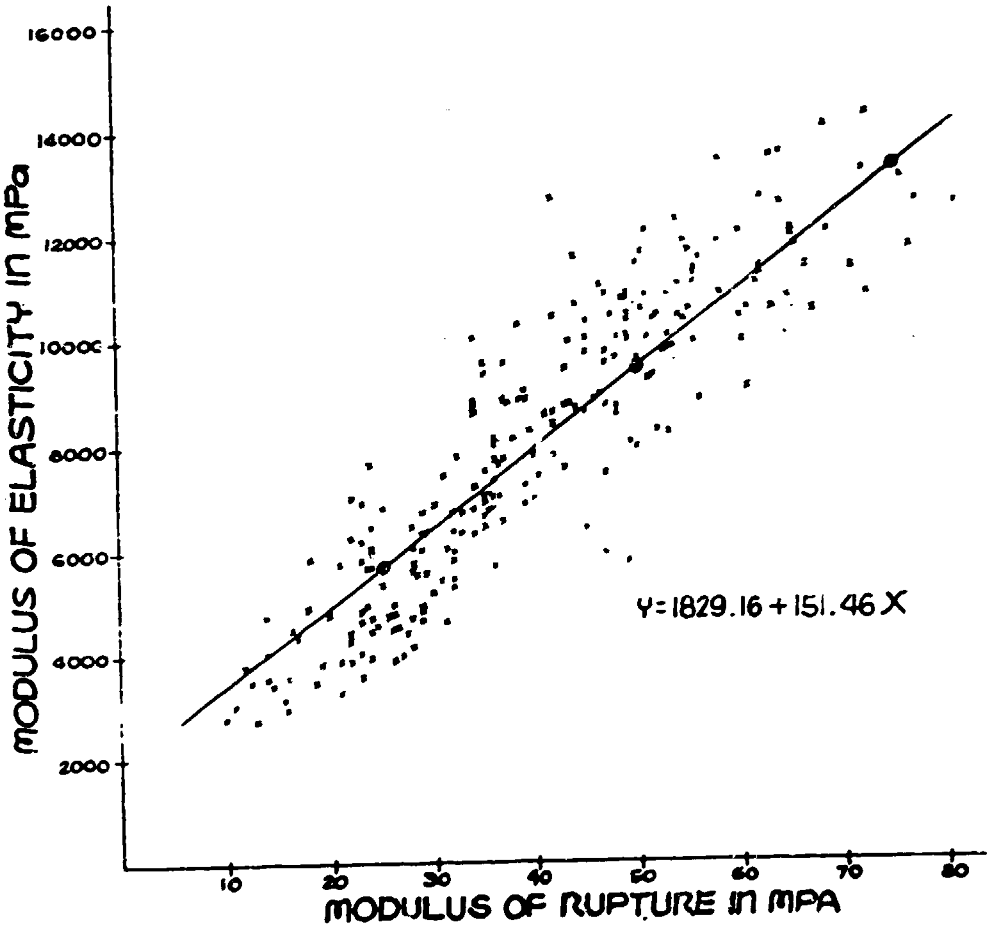
NOTE: Comparison of correlation coefficient values between the straight line and the exponential curve fitted to the data points.

	$y = mx + b$	$\ln y = \ln b + m \ln x$
Hard	.828	.829
Medium	.606	.618

FIGURE 11

Full size Specimen Bending Test (four-point loading)

Linear Relationship Between Modulus of Elasticity and Modulus of Rupture



5. SI - SYSTEM INTERNATIONAL UNITS

Unit of Force: Newton (N)

One Newton (N) is the force required to accelerate a mass of one kilogram (kg) at the rate of one meter (m) per second squared in the direction of applied force.

$$1\ \mathrm{N} = \frac{1\ \mathrm{kg}}{g} \times \frac{1\ \mathrm{m}}{\mathrm{second}^2}\text{, where}$$

g = acceleration force 9.81 kg m/sec^2

NOTE: 1 kg f = 9.81 Newtons (N)

therefore 1 N $\approx$ .101 kg f

or 1 N $\approx$ .225 lb f

Unit of Pressure: Pascal (Pa)

Pascal is a pressure or stress which arises when a force of one Newton is applied uniformly over an area of one meter square.

1 Pa + 1 N/m^2

therefore 1 MPa = 1 N/mm^2

SI Prefixes:

Giga symbol G = multiplying factor 10^9 (1 billion)
Mega symbol M = Factor 10^6 (1 million)
Kilo symbol K = Factor 10^3 (1 thousand)

SI prefixes are combined with unit name as:

MPa = Mega pascal = 10^6 Pa
kPa = Kilo pascal = 10^3 Pa

Units of Density (specific gravity): Kilogram/cubic meter (kg/m^3)

Gram/cubic centimeter (g/cm^3)

British Imperial Units:

Unit of Pressure: Pound force per square inch (lbf/in^2)

Note: $1\ N/mm^2 = 1\ MPa = 145\ lbf/in^2$

Unit of Density: Pound per cubic feet (lb/ft^3)

Note: $1\ kg/m^3 = .0624\ lb/ft^3$

Conversion of SI Units to British Imperial Units and vice versa

Examples:

1. MPa to lb/in^2 and vice versa (Conversion factor = 145)

given: $8300\ N/mm^2 = 8300\ MPa = 8.3\ GPa$

therefore: $8300\ N/mm^2 \times 145 = 1203500\ lb/in^2$

$= 1.2035 \times 10^6\ lb/in^2$

given: $100000\ lb/in^2$ ($10^5\ lb/in^2$)

therefore: $\frac{10^5\ lb/in^2}{145} = 689.655\ N/mm^2 = 689.655\ MPa$

2. kg/m^3 to lb/ft^3 and vice versa (Conversion factor = .0624)

given: $500\ kg/m^3$

therefore: $500\ kg/m^3 \times .0624 = 31.1\ lb/ft^3$

given: $40\ lb/ft^3$

therefore: $\frac{40\ lb/ft^3}{.0624} = 641\ kg/m^3$

3. kgf/cm^2 to lbf/in^2 and vice versa (Conversion factor = 14.2)

given: $100\ kgf/cm^2$

therefore: $100\ kgf/cm^2 \times 14.2 = 1420\ lbf/in^2$

given: $1850\ lbf/in^2$

therefore: $\frac{1850\ lb/in^2}{14.2} = 130.28\ kgf/cm^2$

<u>To convert SI Units as:</u>

1. kgf/cm^2 to MPa and vice versa (Conversion factor = 10.2)

Examples: given: $100\ kgf/cm^2$

therefore: $\frac{100\ kgf/cm^2}{10.2} = 9.8\ N/mm^2 = 9.8\ MPa$

given: $12.7\ N/mm^2 = 12.7\ MPa$

therefore: $12.7\ MPa \cdot \times 10.2 = 129.54\ kgf/cm^2$

2. kg/m^3 to g/cm^3 and vice versa

Examples: $450\ kg/m^3 = .45\ g/cm^3$

$.62\ g/cm^3 = 620\ kg/m^3$

Relationship Between SI Units and British Units

LENGTH	millimeter (mm)	1 mm = .0394 inch 25.4 mm = 1 inch 305 mm = 1 foot
	centimeter (cm)	1 cm = 10 mm = .394 inch 2.54 cm = 1 inch 30.5 cm = 1 foot
	meter (m)	1 m = 39.4" = 3' 3 3/8" 1 m = 100 cm 1 m = 1000 mm (10^3 mm)
AREA	meter square (m^2)	1 m^2 = 1,000,000 mm^2 (10^6 mm^2) = 10,000 cm^2 (10^4 cm^2) = 10.8 ft^2 = 1550 in^2
	centimeter square (cm^2)	1 cm^2 = 100 mm^2 6.45 cm^2 = 1 $inch^2$ 1 cm^2 = .155 $inch^2$ 645 mm^2 = 1 $inch^2$
VOLUME	cubic meter (m^3)	1 m^3 = 1,000,000 cm^3 (10^6 cm^3) 1 m^3 = 1,000,000,000 mm^3 (10^9 mm^3) 1 m^3 = 35.3 ft^3 or 423.6 bd. ft. of lumber
	cubic centimeter (cm^3)	1 cm^3 = 1000 mm^3 (10^3 mm^3)
WEIGHT	kilogram (kg)	1 kg = 1000 g (10^3 g) = 2.205 lb 454 g = 1 lb

PART III: FULL SIZE JOINT SPECMEN TEST

1. COCONUT PALM WOOD JOINTS

In general:

Coconut palm sawn wood recovery is restricted in cross section dimension by stem diameter and its large variation in wood density.

This problem is more pronounced in geographically marginal zones (far south or north from the equator or poor dry soil) where palms are relatively short and twisted or bent. Consequently, short lengths and small diameter round wood result in recovery of relatively small dimension sawn material. Therefore, simple types of construction joints in coconut palm wood must be investigated in detail and information to produce satisfactory simple joints of necessary strength and stiffness should be made available with other essential information for successful utilization of coconut palm wood as a construction material.

A limited number of a coconut palm wood joints were tested in full structural sizes at the Forest Products Research and Development Institute, Los Baños, Laguna. Further testing and different joints should be designed and tested.

General types of wood joint connectors:

Nails - Bolts - Screws - Metal side plate - Metal straps - Variety of angle-shaped metal connectors - Steel plate connectors - Toothed plate connectors - glue (lamination)

Many types of metal side plates, metal straps, etc. could be made by cutting G.I. plain sheet approximately 18 Gauge (1.24 mm) with simple tools and pre- drilled for nailing.

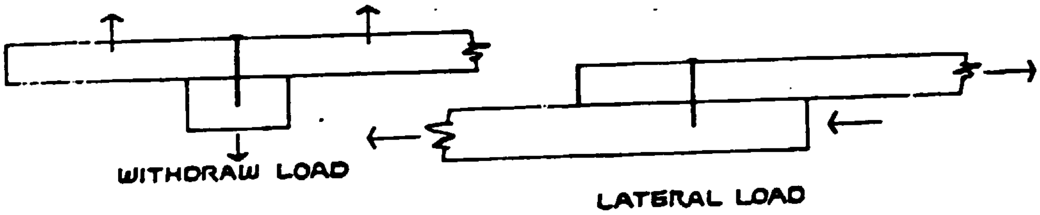
Box nails[*], zinc coated, approximately 38 mm long, 9 - 10 Gauge (3.76 mm or 3.40 mm) should be used.

1.1. Nailed joints:

Nailed joints are most simple and economical,suitable for light structures like timber frame housing construction. Nailed trusses are suitable for spans up to 6-7 meters and spacing up to 2 meters.

Basic withdrawal and lateral load for nailed joints:

The nails perform best when loaded laterally as compared to axially.



Withdrawal load resistance:

The resistance to withdrawal is related to the density (specific gravity) of wood. In general, higher density wood has higher withdrawal resistance. If nails are driven into the wood when green, withdrawal resistance increases as wood dries to lower moisture content.

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[*] Flat head

Coconut palm wood:

No withdrawal test was carried out at Zamboanga Research Center. From practical experience withdrawal values are high, especially for higher density wood.

Higher density coconut palm wood has considerable tendency to split and pre-boring holes up to the 80 percent diameter of nails is recommended, especially when nails are driven close to the end or edge. Possibility of splitting increases for the dry wood.

Lower density wood has less tendency to split and permits a closer spacing of nails.

The withdrawal resistance decreases:

i) For lower density wood.
ii) When nails are driven in the end of a piece of wood.
iii) With use of finishing nails with small heads.

The withdrawal resistance increases:

i) With correct nail diameter and length.
ii) With use of clinched nails (if possible).
iii) With use of rust-proof, coated nails.
iv) With use of nails square shank or spirally grooved.
v) For low density wood, if cement coated nails are used. (If used for higher density wood, the coating is cleaned off when nails are driven).

Pre-bored holes up to 80 percent of the diameter of nails do not effect withdrawal resistance.

Lateral (shear) resistance:

Factors which increase lateral load resistance:

i) Use correct diameter of nails.

ii) Use correct length of nail in relation to penetration.

iii) Density of wood is only slightly less important for lateral resistance than for withdrawal.

iv) Correct nail spacing.

v) Nails loaded laterally should be driven at right angle to the load (e.g. not skew or slant).

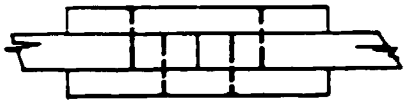
vi) The thickness of a main and side member of a joint in the two members joint should be equal.

vii) If nails in three member joints fully penetrate all three members, the joint will sustain increased lateral loads.

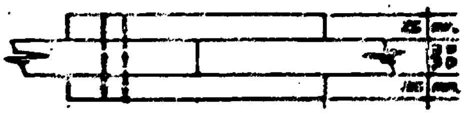
viii) Clinch nails increase the double shear load to twice the single shear value.

ix) The lateral resistance is reduced if joint is assembled from the wood in green condition and will stay such in the service. If wood is dry, lateral resistance increases.

The lateral (shear) or withdrawal resistance decreases considerably if the joint members are split.



NAILS IN SINGLE SHEAR



NAILS IN DOUBLE SHEAR

Basic lateral load on one nail in single shear driven perpendicularly to the grain, e.g. side grain (Vascular bundles for coconut palm wood).

For green coconut palm wood:

Size of Nail			Lateral load per nail member	
Gauge SWG	Diameter (mm)	Length (mm)	J3 Strength Density Group 600 kg/m^3 and above	J4 Strength Density group 400-599 kg/m^3
9	3.76	75	400 N (45 kg)	330 N (33 kg)
10	3.40	64	350 N (36 kg)	265 N (27 kg)
11	3.05	50 or 63	305 N (31 kg)	242 N (25 kg)
12	2.77	50	265 N (27 kg)	198 N (20 kg)

Note:
1. If the nails used in double shear fully penetrate 3 members and protrude about 3 nail diameter and are clinched, value of double shear could reach double value of single shear.
2. For double shear, the value could be increased by 30 to 40 percent.
3. The latest draft revision of AS 1720 Document DR 83171 has the following recommendation:

Nail diameter (mm)	Lateral load per nail in unseasoned timer (N)	
	Joint group J3	Joint group J4
2.80	225	160
3.15	275	195
3.75	375	265

Moisture condition:

If joints are assembled in green condition and dry before used to moisture equilibrium (15 - 16%), value of single shear can be increased up to 25%, although some timber joints deteriorate in drying. More tests on coconut palm wood joints are indicated.

1.2. Multiple nail joints:

The total permissible load for a joint containing more than one nail is the sum of the permissible load for each individual nail.

Note: If metal side plates are used, the load per nail can be increased by 25%.

Minimum spacing of nails in the joint:

Distance from side or edge	Hole not pre bored	Hole pre bored 80% of nail diameter
End	20 D	10 D
Edge	5 D	5 D

Distance between nails	Hole not pre bored	Hole pre bored 80% of nail diameter
Along the vascular bundles (grain)	20 D	10 D
Across the vascular bundles (across the grain)	10 D	3 D

D = diameter of nail

For coconut palm wood, especially higher density, pre-boring is recommended as higher density wood has a tendency to split.

Spacing of nails:

Spacing of nails is to some extent determined by the splitting tendency of the wood in the joint.

Splitting could be minimized by:

i) Using the recommended nail spacing based on nail diameter.
ii) Blunting the nail point before driving.
iii) Pre-boring the nail holes to approximately 80 percent of the diameter of the nails to be driven*.
iv) Staggering the nails.
v) Using nails of such diameter, which could be driven without bending.

* (The permissible load is not affected by pre-bored holes up to 80 percent of the nail diameter).

Penetration of nail:

If two pieces of wood are joined with nails, at least half of the length of nail must penetrate the member which receives penetrating nail point for higher density coconut palm wood. In lower density, penetration of nail point should be two thirds of its length.

Skew (slant) nailing:

i) Nails loaded laterally should not be skew driven.
ii) Skew nailing, if used, should be in such direction that the joint under load has tendency to tighten up.
iii) Skew nailing is properly used to connect studs to bottom wall plate, rafter to top wall blade, etc.

It is recommended to use rust proof nails as much as possible, galvanized or cobalt coated nails especially, if used in green or Tanalith impregnated coconut palm wood, or when a wood is in service subject to permanent or temporary (in short intervals) increase of moisture content.

2. EXTENSION OF THE GROUPING TECHNIQUE TO JOINTS

It has been found that grouping is also a very useful technique in developing the basic loads applicable to metal fasteners (Mack, 1978). When revised, the Australian Timber Engineering Code will be using the following classification system based on basic and air-dry density as shown in Table III-1.

Table III-1

PROPOSED MINIMUM DENSITY FOR JOINT STRENGTH GROUPS

Green timber		Seasoned timber	
Group	Basic density (kg/m^3)	Group	Air-dry density* (kg/m^3)
J1	750	JD1	940
J2	600	JD2	750
J3	475	JD3	600
J4	380	JD4	475

* **Density at 12% moisture content after reconditioning.**

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* Assignment to J2 will be justified by basic density and mechanical properties using the value of shear property. Conservative assignment to J3 is a subject of further review.

Application to coconut palm wood

Preliminary classification to joint strength group of coconut palm wood: Basic density 600 kg/m^3 and above is assigned to J3 group*.
Basic density 400 - 599 kg/m^3 is assigned to J4 group.

NOTE: Multiple nail joints

The total load for a joint containing more than four nails should be multiplied by the factor as follows:

Condition of wood	Total number of nails per interface (face between joined members)			
	up to 4	5	10	20 or more
	Value of factor			
Unseasoned	1	.9	.8	.75
Seasoned to 15% MC or less	1	.95	.9	.85

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* Assignment to J2 will be justified by basic density and mechanical properties using the value of shear property. Conservative assignment to J3 is a subject of further review.

Withdrawal loads for joint strength group - J3 and J4:[1]

Strength group	Nail diam. mm (Gauge)			
	2.77 (G12)	3.05 (G11)	3.4 (G10)	3.76 (G9)
	Withdrawal load N/mm penetration per nail			
J3	7.3	8.0	8.5	9.6
J4	3.8	4.1	4.6	5.1

The above nail withdrawal values are used for conventional timber assigned to Strength Goups J3 and J4 respectively. Nail withdrawal tests have not been carried out at PCA-Zamboanga Research Center for coconut palm wood. The given values can be used safely for coconut palm wood as it is known from practical experience that the withdrawal load is high when splitting of wood is avoided.

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[1] It should be noted that the latest draft revision of AS 1720 Document DR 83171 recommends:

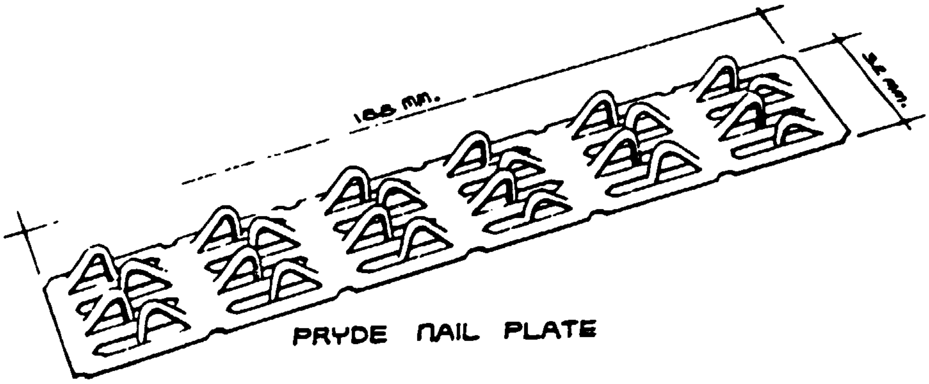
Nail diameter (mm)	Withdrawal load per nail in unseasoned timber (N/mm penetration of nail)	
	Joint group J3	Joint group J4
2.80	8.5	7.5
3.15	9.6	8.4
3.75	11.0	10.0

3. TEST OF FULL SIZE JOINT SPECIMENS

3.1. Pryde nail-plate wood connector

Specification:

- 11 mm nail length 1.2 mm (18 G), galvanized steel
- Total penetrating nails: 4 x 24 = 96
- Manufacture recommendation:
  - Safe nail load 110 N per nail (all nails can be counted)
  - Safe plate shear per mm shear line: 25 N/mm
- Use 2 pieces 32 mm x 188 mm at each side



Ultimate Test Value

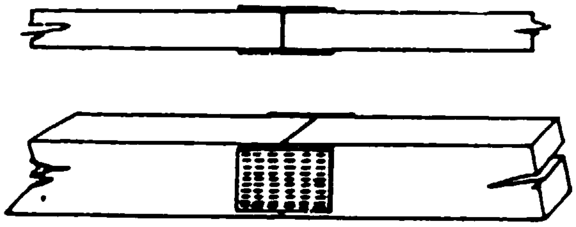
Type of Joint	Dimension H x W (mm)	Basic Density g/cm³	Modulus of Rupture MPa	Stress at Proportional Limit MPa	Modulus of Elasticity 1000 MPa	Remarks
Pryde Connectors	75 x 38	.895 .557	15.00 22.54	10.67 15.44	5.47 4.64	Average Moisture Content of Specimens is 16%

Type of failure: withdrawal of nail

3.2. <u>Gang-Nail (Philippines)</u> (locally purchased)

Specification:

- Gang nail connectors dimension: 95 mm x 140 mm
- Total number of penetrating nails: 91
- Length of penetrating nails is not equal, each alternate row has length of nails 11 mm following a row of 15 mm.
- Galvanized steel
- Thickness: 1.2 mm (18 G)
- Average yield stress: 280 MPa
- Average tensile strength: 380 MPa
- Safe load per tooth parallel to grain: 160 N
- Tooth density: 1 tooth per 146 mm^2



MULTI-NAIL CONNECTOR

Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Gang Nail Connectors	100 x 38	.759	24.04	17.31	7.12	Average Moisture Content of Specimens is 19%.
		.594	24.68	16.83	6.11	
		.329	12.48	7.80	3.50	
		.518	23.86	15.07	4.35	

Type of failure:

For higher density wood, vertical shear in plate.

For density .329 g/cm^3, cross grain tension failure in wood.

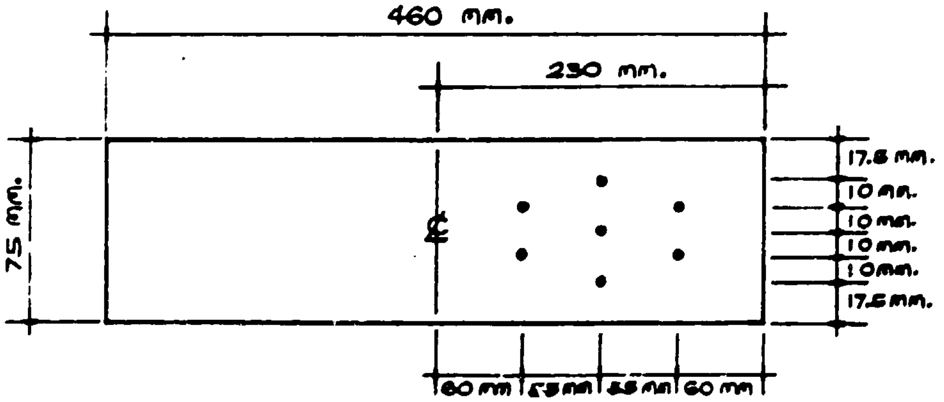
3.3. Multiple nail joints

Multiple nail joint - A

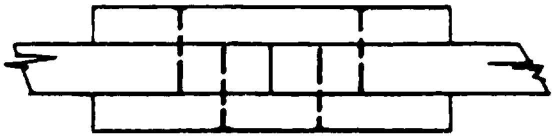
Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Wood splice plates (75 mm x 25 mm x 460 mm)	75 x 50	.680 .580	33.06 25.27	13.78 15.66	6.35 6.28	Average Moisture content of specimens is 18%.

Nail Spacing:



Joint Arrangement and Penetration of Nails:



NAILS IN SINGLE SHEAR

Nails: CW - 64 mm, 3.4 mm dia. (G 10)
14 for each side (Total 28 nails)

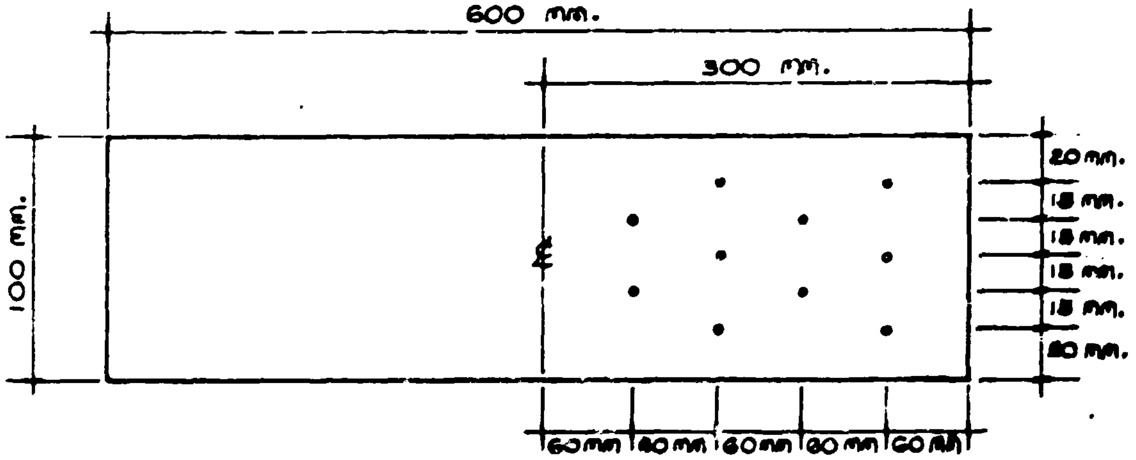
Type of failure: Cross-grain tension at main member and wood splice.

Multiple nail joint - B

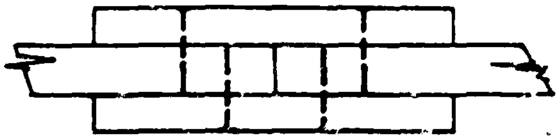
Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Propor-tional Limit	Modulus of Elas-ticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Wood splice plates (100 mm x 25 mm x 600 mm)	100 x 38	.636 .707	26.59 37.98	19.48 19.88	6.53 7.57	Average Moisture content of specimens is 19%.

Nail Spacing:



Joint Arrangement and Penetration of Nails:



NAILS IN SINGLE SHEAR

Nail: CW - 64 mm, 3.4 mm dia. (G 10)

20 nails on each side (Total 40 nails)

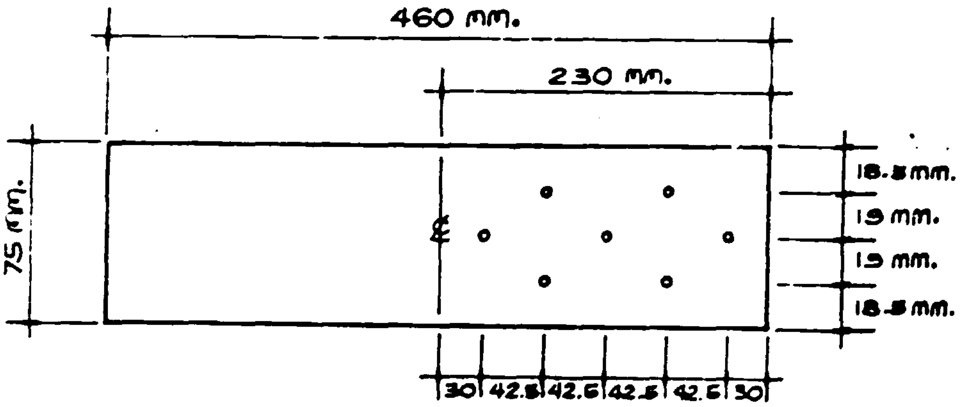
Type of failure: Cross-grain tension at main members and wood splice (plates split along the nail line).

Multiple nail joint - C

Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Plywood splice plates (75 mm x 10 mm x 460 mm)	75 x 38	.530	12.60	9.05	3.29	Moisture Content of Specimen is 16%.

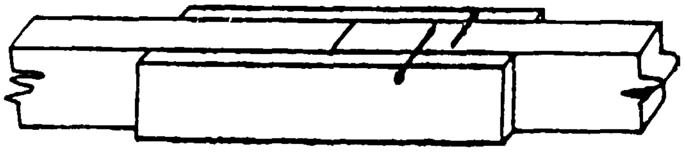
Nail Spacing:



Total number of nails: 28

Galvanized iron, box type nail, 38 mm long and 3.4 mm diameter.

Type of failure: Brash tension in both plywood splice opposite the butt joint of main members.



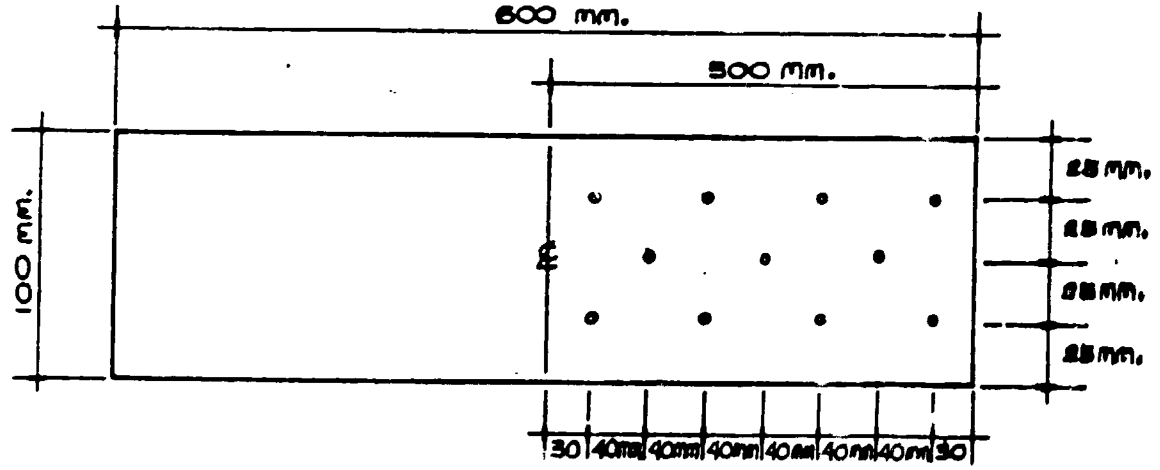
Schematic drawing of a joint assembly
(main members end joined)

Multiple nail joint - D

Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm³	MPa	MPa	1000 MPa	
Plywood splice plates (100 mm x 10 mm x 600 mm)	100 x 38	.749	15.47	12.89	5.18	Moisture Content of Specimen is 18%.

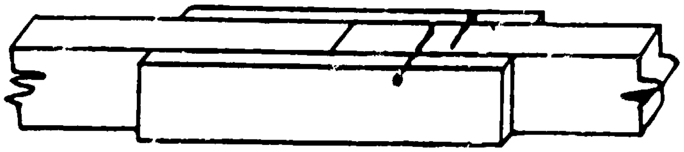
Nail Spacing:



Total number of nails: 44

Galvanized iron, box type nail, 38 mm long and 3.4 mm diameter.

Type of failure: Brash tension in both plywood splice - close to the butt joint of main members (following nail line).

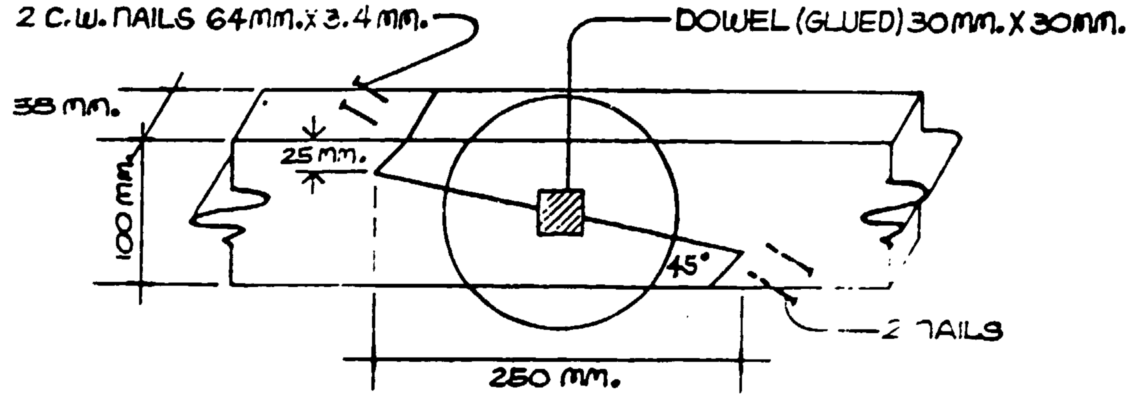


Schematic drawing of a joint assembly

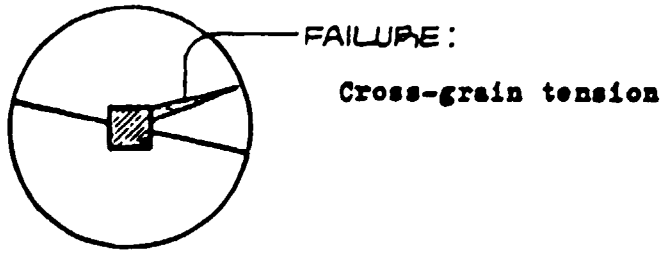
3.4. Scarf joint with dowel

Ultimate Test Value

Type of Joint	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm3	MPa	MPa	1000 MPa	
Scarf with dowel (2 nails each side)	100 x 38	.794	6.46	2.87	3.83	Moisture content of specimen is 16.5 %.
Scarf with dowel (1 nail each side)	100 x 38	.719	3.28	1.40	1.11	Moisture content of specimen is 16.5 %.



SCARF JOINT WITH DOWEL



NOTE: This type of scarf joint is commonly used in the Philippines, thus the value is more decorative as the strength of joint is low.

4. GLUED JOINTS WITH REFERENCE TO COCONUT PALM WOOD

In the last 20 - 30 years, there has been an advancement in the development of synthetic types of moisture and fungi resistant glues capable to resist the most extreme conditions. A number of types of glue can be set at moderate temperatures.

Consequently, this led to widespread development in the field of glued-laminated wood used for construction purposes with less restraint on the architectural possibilities.

The term glued-laminated construction applies to structural wood members glued up from smaller dimensions of wood pieces, otherwise unusable or unsuitable for the required member dimension. This applies directly to coconut palm wood which is restricted by the steep density gradient in the radial direction.

Coconut palm wood utilization division at PCA-Zamboanga Research Centre did some experimental work with laminated coconut palm wood and the products were used in construction of up to 10 meters span. This experimental work could be considered successful as laminated wood exposed to weather conditions had not shown any deterioration in the glue line or wood after 5 years in service and exposure.

Full tests for mechanical properties (shear of glue line) of glued-laminated coconut palm wood were conducted.

A number of simple tests were, however, carried out in the division laboratory such as "Chisel test", "Boiling Test" (72 hours) which could be considered satisfactory.

Four coconut palm wood specimens were tested at Forest Products Research and Development Institute laboratory in Los Baños, Laguna. (Data for one specimen were lost during the test).

Test: Static Bending (4-point loading)
Specimen dimension: 80 mm x 75 mm, length 21 times depth

NOTE: Specimens were assembled from four laminae 12 months before the test.

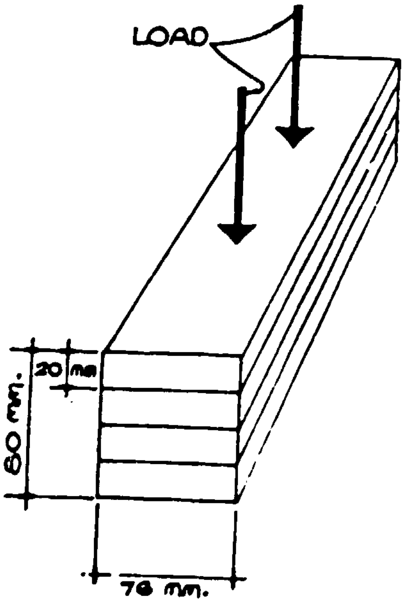
Dimension of laminae: 90 mm x 20 mm
High density wood (basic density .755 g|cm^3)
Glue used: Cascopen RS 240 M technically known as resorcinol phenol-formaldehyde which could be set in room temperature 21° C and above.
Catalyst FM - 124 M: 100 parts of glue
20 parts of catalyst
Glue spreading by brush: .340 kg per m^2 (.75 lb|10 ft^2)
Clamp spacing: 350 mm (14 inches)
Pressure applied: .69 MPa (100 lb|in^2)
pressure is applied for 20 hours.
A normal curing period: 6 - 10 days depending on the room temperature.

4.1. Horizontally laminated wood

Ultimate Test Value

Type of Laminae	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Horizontally laminated *	75 x 80	.796 .722	85.82 79.73	55.43 56.55	14.50 13.17	Average Moisture content of specimens is 16%.

* Load was applied perpendicular to the laminae.



Types of failure:

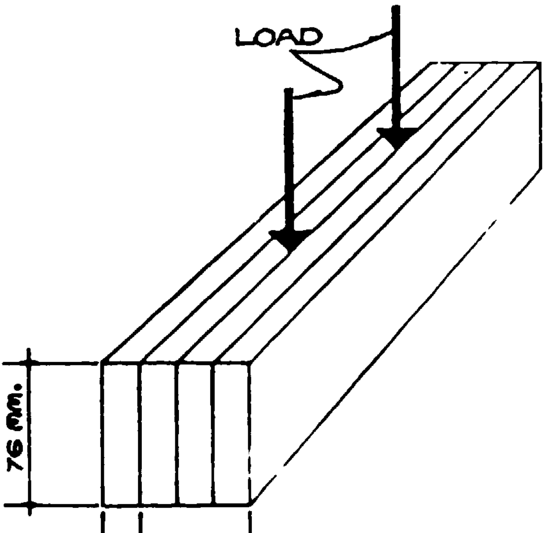
1. Cross grain tension plus glue line failure
2. Cross grain tension and out of glue line failure

4.2. Vertically laminated wood

Ultimate Test Value

Type of Laminae	Dimension H x W	Basic Density	Modulus of Rupture	Stress at Proportional Limit	Modulus of Elasticity	Remarks
	(mm)	g/cm^3	MPa	MPa	1000 MPa	
Vertically laminated*	75 x 80	.747	64.47	47.74	12.61	Moisture content of specimen is 16%.

* Load was applied parallel to the laminae.



VERTICALLY LAMINATED

Type of failure: Cross grain tension below the loading point.

It is of interest to compare the test data for glulam with expected values. From Table II-1 the mean strength for the 'hard' grade of structural size timber is 54.5 MPa. From Table I-1 the effect of drying the timber is seen to be a factor of 1.2 on bending strength. The effect of local reinforcement of defects would be roughly a factor of 1.1. Hence the average expected strength of the glulam (either horizontally or vertically laminated) would be about 54.5 x 1.2 x 1.1 = 71.9. MPa. This compares with the values of 85.8 and 79.7 MPa for horizontally laminated timber given in the Table on p.83, and the value of 64.5 MPa for vertically laminated timber given in the table on p.84.

The expected modulus of elasticity is the value of 11,414 MPa given in Table I-1 for small specimen of dry timber. This compares with the values of 14,500 and 13,200 MPa for horizontally laminated timber on p.83 and 12,600 MPa for vertically laminated timber on p.84.

The measured strengths and stiffnesses of the glulam are not predicted particularly well but, considering the variability in the structural properties of coconut wood, are feasible.

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