AN EXPERIMENT ON MECHANICAL PROPERTIES
OF WESTERN YEW IN STATIC BENDING

by
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Approved:

[Signature]
Professor of Forestry
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INTRODUCTION

PURPOSE OF THIS STUDY

The main objective of this study was to attempt to determine by experimentation whether there are mechanical differences in heartwood and sapwood of Western Yew (Taxus brevifolia) when pieces are subjected to static bending. Data was also kept for the purpose of finding the degree of differences of wood from various trees.

IMPORTANCE OF THE PROBLEM

The most extensive use of Western Yew, at least in proportion to value, is in the manufacture of archery bows. Occasionally it is experimentally used for casting rods, canoe paddles, pack frames, boat framework, and handles. In these, bending properties are the main requisite. Non-bending uses are fence posts, dead men, novelties, interior finish, small cabinet work, lathe turning, and carving. Western Yew resembles the conifers in foliage and general appearance but it belongs to the Taxaceae family of the Gymnosperms. Very small tracheids constitute the principle wood element, and contain thickened spirals. No parenchyma (resin cells) or ray tracheids are found. The wood is uniform and dense, the heartwood being bright orange to brownish red, and the thin sapwood a pale creamy yellow or nearly white. It grows sparsely scattered from sea level to about 8000 feet elevation and ranges from Alaska to Mexico. A very slow growing, shrub-like tree, it often has branches nearly to the base. The trunk is often fluted and seldom
exceeds eighteen inches in diameter making it difficult to obtain clear straight pieces. Because Yew is a specialty wood usually handled by individuals, definite information regarding the volume and value used is not available. It is relatively expensive when compared to other commercial species of wood. Western Yew commands the highest bowstave prices in the world. These rough air-seasoned staves about 2" x 2" x 6' long (or two billets of half length) sell for $1.00 to $15.00. There are at least a half dozen cutters who take out of the forests approximately one thousand or more staves per year. Hundreds of individuals cut varying lesser amounts. Staves are priced, bought, and used according to their degree of "quality." The most desirable characteristics of bows are good "cast" or distance shooting ability and the ability to be repeatedly drawn to the user's arrow length without breaking. The determination of the quality is a rather vague process. Whittling, tapping, "hefting", and comparing the macroscopic appearance with other pieces of past experience are the principal methods used.

PREVIOUS FINDINGS

It is generally conceded by users that sapwood, when used on the tension or convex side of a bending member, prevents the member from breaking unless it is subjected to a greater deflection than the rupture point of an all-heartwood piece.

"In over 500,000 tests which have been made by the Forest Products Laboratory, Madison, Wisconsin, on the various
species of wood grown in the United States, no effect upon
the mechanical properties of the wood due to its change
from sapwood into heartwood has been found in most species.
However, in some species, in which the heartwood is high in
infiltrations or "extractives", such as redwood, western
red cedar, and black locust, the heartwood has been found to
be considerably stronger than sapwood.¹

Other than a few incomplete tests by individuals to
determine "cast" of Yew sapwood, the only published material
available on Yew mechanical properties is U.S.D.A. Technical
Bulletin No. 479.² In this is tabulated the results of mech-
anical tests on five green Western Yew trees and two dry ones.
Apparently all-heartwood pieces were used or else no account
was taken of the sapwood on the pieces.

PROCEDURE OF EXPERIMENT

It was necessary to obtain the timber, select and manu-
facture the samples, condition the samples, make bending tests,
record test data, determine moisture content, specific gravity,
rings per inch, percentage of sapwood, and to make computations
and deductions. Timber, in the form of bowstaves and billets,
was donated by bowyers interested in the study.

SAMPLE SELECTION

As far as was known the staves were cut from green trees
and included no wood from the "compression" side. The pieces
had been air dried for more than two years. As many as pos-
sible clear, straight grained samples were cut from each stave.
About one half the samples from each tree was all-heartwood
taken adjacent to the sap line and about one half the samples included approximately one third sapwood. One stave or less was available from each of nine trees and from two to nine acceptable samples were obtained from each stave. In all, thirty-two samples were chosen for the bending tests.

MANUFACTURE

A bench power saw, jointer, and hand scraper were employed in cutting the samples, which were 1" wide on the tangential face, 3/4" high on the radial face, and 12" long. The samples were first machined, then slightly scraped if needed. A maximum allowance of 1/64" was made in width of pieces from the same tree, but practically none as measured by a caliper rule was allowed in height. This was because the strength of a beam varies directly as the width, but directly as the square of the height. There would be no deflection advantage due to varying widths as there would in varying heights. An individual letter index was used for each sample and each sample was marked with its tree number. To have as much uniformity as possible it was desirable to have the pieces, especially within the same tree, nearly the same in moisture content so that corrections would not have to be made for differences. In view of this, previous to testing the samples were stored for two weeks in an unheated workshop with air-space around each piece.

TESTING

The Tinius Olson mechanical testing machine of the School of Forestry Wood Products laboratory was used in the static bending tests. The steel supports for the beam were
set ten inches between centers and bolted tightly in place. Flat plates and rollers were inserted between the supports and the test samples to facilitate longitudinal motion due to bending. The machine was operated to apply a constant-speed center load of 0.05 inches per minute. A hard maple block with a compound curve face was used to apply the load halfway between the steel supports. A beam deflectometer with the indicator attached to the maple block by a linen thread gave relatively accurate readings since the dial was about ten inches long and was graduated into 400 parts per inch of bend of the Yew sample. The scales were set at twenty pound intervals beginning with sixty pounds. Whenever the scales beam was balanced by the load, the deflection reading was taken and recorded in a column with the corresponding load at that moment. One operator and one recorder enabled almost simultaneous readings to be made. Each sample was bent with the sapwood side on the bottom which was the tension or convex face. At the first definite indication of rupture the deflection reading was taken, the machine reversed, and the sample removed.

**ADDITIONAL DATA**

After the samples were broken, a cross section about 1\(\frac{1}{2}\)" long was taken two inches from the end of each sample, weighed on new beam type gram scales (capacity 200 grams) and the samples were placed in a constant temperature drying oven at about 110° F. After twenty-four hours the samples were re-weighed. The moisture content at the time of breaking
was determined by the formula 100 (original weight - oven-dry weight) \+ oven-dry weight \= moisture content in \% of oven-dry weight.

From these oven-dry pieces, one all-heart sample and one sap-heart sample was taken from each tree number (with a few extra for checking purposes) and dipped in hot parafin to make it water-proof. The pieces were again re-weighed to determine how much parafin each one took on. The specific gravity of parafin was found by weighing a block of it, immersing it in a tumbler of water while re-weighing it, then dividing its weight in air by its weight in water (after the weight of tumbler and water have been subtracted). Knowing the weight of each piece of wood, the weight of parafin on each piece, and the S. G. of parafin, the specific gravity of each wood sample was found in the same way as that of parafin after allowing for the displacement of water by the parafin on the block. The simplified formula is then weight in air \+ weight in water \= specific gravity. The annual growth rings per inch were counted on each sample and the percentage of sapwood approximately determined by measurement.

COMPUTATION OF STRENGTH VALUES

The bending test data for each sample was plotted graphically. From the graphs were obtained the load at proportional limit and deflection at proportional limit. With the size of piece, span, and maximum load which were already known the following values were computed.

Stress at proportional limit--this is the stress in pounds per square inch that exists in the top and bottom
fibers of a beam at the proportional limit load (the highest point where load and deflection are still increasing proportionally).

Modulus of Rupture--this is the stress in pounds per square inch that exists in the top and bottom fibers at the maximum load.

Modulus of Elasticity--this is the measure of stiffness. The deflection of a beam under load varies inversely as the modulus of elasticity; that is, the higher the modulus the less the deflection. The formula gives the value at proportional limit; therefore, it does not show the true value near maximum load.

The following formulas, which are the same ones used by the Forest Products Laboratory\textsuperscript{2}, give the above values for center-loaded beams.

\[
\text{Spl} = \frac{3 \times P' \times L}{2 \times b \times d^2} \quad R = \frac{3 \times P \times L}{2 \times b \times d^2} \quad E = \frac{P' \times L^3}{4 \times b \times d^2 \times y}
\]

Spl = stress at proportional limit.

R = modulus of rupture.

E = modulus of elasticity.

P' = load at proportional limit, pounds.

P = maximum load, pounds.

L = span length, inches.

b = breadth or width, inches.

d = depth or height of beam, inches.

y = deflection, inches.
RESULTS

The computed results for each of the thirty-two tested samples are given in TABLE I. The moisture content was averaged for each tree, since it was found that there was less than 0.5% difference in M. C. in any one tree. The table shows less than 2.5% difference in M. C. of the wettest and dryest trees. This was not thought to affect other values to any appreciable extent. The specific gravity was determined for only one sample in each all-heartwood and sap-heartwood group and applied to all other samples in that group. The specific gravity determinations involved long, laborious computations and weighings. The checking samples gave results relatively close to others in the same group. Because larger, more inaccurate scales had to be used and many processes were necessary in determining the specific gravity, the results are probably considerably less accurate than those in M. C. determinations. The S. G. was higher for all-heart samples in every case. The ring counts were somewhat similar in samples of the same tree, though obviously the rings are not of the same number in both types of samples because growth rate occasionally changes.

In seven of the nine trees all of the sap-heart samples bent more before rupturing than any of the all-heart samples from the same tree. In number 9 tree, having nine samples, some of the all-heart samples bent to a greater deflection than some of the sap-heart samples, but the sap-heart pieces averaged 0.58 inches deflection against 0.53 inches
for the all-heart pieces. In Number 4 tree, having only one sample of each type, the all-heart sample bent 0.93 inches while the sap-heart sample bent only 0.74 inches. This wood was fairly dense, but had abnormally low $S_p$ and $E$ values. The explanation for this is not clear, though it is possible that it was compression wood which it somewhat resembled in appearance.

The sap-heart and all-heart group averages are given in TABLE II. The averages of the totals show the $S_p$ and $R$ to be slightly higher for the sap-heart samples than the all-heart ones. This is somewhat of a mystery, since in most species these values are roughly proportional to the specific gravity. The $E$ or stiffness of the all-heart samples is somewhat greater than that of sap-heart averages.

The most significant difference is in deflection. The averages of the totals show that the sap-heart samples gave an average deflection of about 14% greater than the all-heart samples. In a bow, a deflection of 14% would give more than 14% more draw to the arrow because the nock ends of the bow come nearer each other and therefore allow more rearward movement of the string. Theoretically, then, from the above data it can be seen that a Yew bow with a sapwood back could be drawn about 28 inches in contrast to an all-heartwood bow from the same tree whose maximum draw was 24 inches. Since the samples were bent only once, the effects or differences of fatigue were not learned. Between trees there was a wide variation in all values except moisture content.
To find possible causes of variations in wood from different trees, correlations of values in TABLE I and TABLE II were searched for. Graphs were made in which specific gravity was plotted against maximum deflection, Sp1, R, and E. The curves were so erratic that little could be derived from them except in the case of the S. G.--deflection curve, which showed a fairly steady trend upward in deflection with an increase in S. G. The E showed practically no upward trend while the Sp1 and R weighted curves did rise somewhat with increase in S. G., but the plotted averages showed a very wide variation.

The Rank Order method was used in determining coefficients of correlation of values in the tables. This method does not show direct relationship of values, but rather the reliability which can be placed on judging one value to be higher or lower than the like value of another object when using the correlated characteristic as a base of judgment. The formula for this method is:

\[ \text{Coefficient of correlation} = \frac{1-6\sum d^2}{n(n^2-1)} \]

where \( S = \) sum, \( d = \) differences in rank, and \( n = \) number of examples. On the following page is an example of one solution. The coefficient is a number which expresses the degree better than chance (chance is 50%) that can be used to select one characteristic on the basis of another one. For example, a coefficient of +.50 means that, on the average, one characteristic can be found with the correlated one 75% of times tried. A negative correlation means that the
Coefficient of Correlation between
S. G. and Max. Deflection in
Sap-Heart Samples

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>Sample</th>
<th>Deflec.</th>
<th>S.G.</th>
<th>Rank of Deflec.</th>
<th>Rank of S.G.</th>
<th>Dif. in Rank</th>
<th>Diff. Squared</th>
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</table>

Sum = 14.5

\[
14.5 \times 6 = 87.0
\]

\[
9 \times 9 = 81 \quad P = 1 - \frac{87}{720} = 0.38
\]

two things occur together less than once out of twice. Perfect correlation is +1.0. With a correlation of -1.0 the items would never be found together. Correlations do not show cause or effect relationship. They merely show what things occur together and therefore provide a basis for further investigation.
The coefficient of correlation between specific gravity and maximum deflection of all-heart samples was found to be +.88 (from TABLE II, see example on page 11). The coefficient for S. G. and maximum deflection of sap-heart samples was +.83. Both of these are very significant as they indicate a possible method of judging the degree of bending that a piece will undergo before breaking. Specific gravity showed about 0.0 coefficient of correlation with modulus of E. The coefficient was slightly higher between S. G. and Spl, and between S. G. and R, but not enough to be reliably significant. Neither the amount of sapwood nor the rings per inch correlated closely with other values.

CONCLUSIONS

While nine trees or thirty-two samples are not enough to furnish infallible proof on the problem of differences between sapwood and heartwood or between trees, the data from this experiment show several definite trends and may serve as a basis for further investigation. The bending test methods used were not exactly the same as the bending in bows and other implements, but the same kinds of stresses were applied. Since the conditions affecting each sample were relatively uniform, the comparisons are thought to be fairly reliable.

Probably bowyers are justified to some extent in using sapwood on backs of Yew bows for the purpose of preventing fracture. Heartwood is slightly stiffer, but its degree of effect on "cast" is not definitely known. There are greater differences between individual trees than there are between uniform samples of the same tree. In any one type of sample
the maximum deflection is roughly proportional to the specific gravity.

**RECOMMENDATIONS**

Further methodical, well controlled experiments should be made to verify present information. Microscopic studies of Yew might reveal causal factors if the same samples were also mechanically tested. Perhaps testing samples in tension parallel to grain and in compression parallel to grain would shed some light on the problem.

After full information has been gathered, there should be some reliable system devised to test miniature samples from pieces of stock to find out what the timber from any one piece or tree is capable of and how it should be manufactured.
<table>
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<th>Tree No.</th>
<th>Sample</th>
<th>% M.C.</th>
<th>S.G.</th>
<th>% Sapwood</th>
<th>Rings per in.</th>
<th>Max. Deflex.</th>
<th>Sp.</th>
<th>B</th>
<th>E*</th>
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<td>9</td>
<td>G</td>
<td>0.650</td>
<td>0</td>
<td>0.45</td>
<td>11,733</td>
<td>18,000</td>
<td>1,306</td>
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<td>0.45</td>
<td>11,733</td>
<td>18,000</td>
<td>1,306</td>
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<tr>
<td>9</td>
<td>I</td>
<td>0.650</td>
<td>0</td>
<td>0.45</td>
<td>11,733</td>
<td>18,000</td>
<td>1,306</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>A</td>
<td>0.640</td>
<td>0</td>
<td>0.505</td>
<td>11,200</td>
<td>19,600</td>
<td>1,205</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>0.612</td>
<td>30</td>
<td>0.71</td>
<td>11,203</td>
<td>19,685</td>
<td>1,169</td>
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</tr>
</tbody>
</table>

TABLE I

*Last three digits omitted.*
### Tree Averages of Bending Test Results

<table>
<thead>
<tr>
<th>Tree</th>
<th>Samples</th>
<th>Deflec.</th>
<th>Spl</th>
<th>R</th>
<th>E</th>
<th>S.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heart</td>
<td>.697</td>
<td>12,601</td>
<td>20,931</td>
<td>1,403</td>
<td>.737</td>
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<tr>
<td></td>
<td>Sap &amp; Ht.</td>
<td>.772</td>
<td>12,444</td>
<td>20,088</td>
<td>1,304</td>
<td>.694</td>
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<tr>
<td>2</td>
<td>Heart</td>
<td>.58</td>
<td>14,400</td>
<td>23,333</td>
<td>1,564</td>
<td>.702</td>
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<tr>
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<td>Sap &amp; Ht.</td>
<td>.685</td>
<td>11,023</td>
<td>20,603</td>
<td>1,334</td>
<td>.654</td>
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<tr>
<td>4</td>
<td>Heart</td>
<td>.93</td>
<td>6,933</td>
<td>16,133</td>
<td>701</td>
<td>.710</td>
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<td>Sap &amp; Ht.</td>
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<td>16,800</td>
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<td>.610</td>
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<td>Heart</td>
<td>.40</td>
<td>10,633</td>
<td>15,733</td>
<td>1,421</td>
<td>.578</td>
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<tr>
<td></td>
<td>Sap &amp; Ht.</td>
<td>.46</td>
<td>10,933</td>
<td>16,133</td>
<td>1,412</td>
<td>.556</td>
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<td>Heart</td>
<td>.33</td>
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<td>12,600</td>
<td>1,182</td>
<td>.570</td>
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<td>Sap &amp; Ht.</td>
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<td>14,587</td>
<td>1,031</td>
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<tr>
<td>7</td>
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<td>.485</td>
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<td>19,160</td>
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<td>.568</td>
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<tr>
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<td>12,900</td>
<td>20,666</td>
<td>1,390</td>
<td>.543</td>
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<tr>
<td>8</td>
<td>Heart</td>
<td>.472</td>
<td>8,672</td>
<td>15,229</td>
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<td>.649</td>
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<tr>
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<td>Sap &amp; Ht.</td>
<td>.626</td>
<td>8,672</td>
<td>16,412</td>
<td>769</td>
<td>.619</td>
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<tr>
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<td>.600</td>
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<tr>
<td>10</td>
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<td>.505</td>
<td>11,200</td>
<td>19,600</td>
<td>1,204</td>
<td>.640</td>
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<td>.71</td>
<td>11,203</td>
<td>19,685</td>
<td>1,168</td>
<td>.612</td>
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</tbody>
</table>

#### Averages of Totals

<table>
<thead>
<tr>
<th></th>
<th>Deflec.</th>
<th>Spl</th>
<th>R</th>
<th>E</th>
<th>S.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>.547</td>
<td>10,972</td>
<td>17,960</td>
<td>1,226</td>
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<tr>
<td>Sap &amp; Ht.</td>
<td>.623</td>
<td>12,143</td>
<td>18,177</td>
<td>1,188</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II**

SCHOOL OF FORESTRY
OREGON STATE COLLEGE
CORVALLIS, OREGON
Tree Number 1
Sample A

Size = 65/64" x 3/4"
Sapwood = 0%
S. G. = 0.737

Inches of Deflection
Tree Number 1
Sample B

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .737
Tree Number 1
Sample G

Size = 1" x 3/4"
Sapwood = 30%
S. G. = .694
Tree Number 1
Sample D

Size = 1" x 3/4"
Sapwood = 26%
S. G. = .694
Tree Number 1
Sample E

Size = 1" x 3/4"
Sapwood = 30%
S. G. = .694
Tree Number 2
Sample A

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .702
Tree Number 2
Sample B

Size = 65/64" x 3/4"
Sapwood = 35%
S. G. = .654

Inches of Deflection
Tree Number 5
Sample A

Size = 1" x 3/8"
Sapwood = 0%
S. G. = .578

Pounds of Load

Inches of Deflection
Tree Number 5
Sample B

Size = 1\" x 3/4\"
Sapwood = 0%
S. G. = .578

Pounds or Load

Inches of Deflection
Tree Number 5
Sample C

Size = 1" x 3/4"
Sapwood = 45%
S. G. = .566

Inches of Deflection
Tree Number 5  
Sample C 
Size = 1" x 3/4" 
Sapwood = 40\% 
S. G. = .566
Tree Number 6
Sample A

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .570

Inches of Deflection
Tree Number 6
Sample B

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .570

Inches of Deflection
Tree Number 8
Sample D

Size = 1" x 3/4"
Sapwood = 25%
S. C. = .504

Inches of Deflection
Tree Number 7
Sample A

Size = 65/64" x 3/4"
Sapwood = 0%
S. G. = .568

Inches of Deflection
Tree Number 7
Sample B

Size = 1" x 3/4"
Sapwood = 50%
S. G. = .543
Tree Number 8
Sample A

Size = 63/64" x 3/4"
Sapwood = 0%
S. G. = .649

Inches of Deflection
Tree Number 8
Sample B

Size = 63/64" x 46/64"
Sapwood = 35%
S. G. = .619
Tree Number 9
Sample A

Size = 1\" x 3/4\"
Sapwood = 0%
S. C. = .650
Tree Number 9
Sample B

Size = 1" x 5/4"
Sapwood = 0%
S. G. = 0.650
Tree Number 9
Sample C

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .650

Pounds of Load

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Inches of Deflection
Tree Number 9
Sample D

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .650

Inches of Deflection
Tree Number 9
Sample E

Size = 1" x 3/4"
Sapwood = 0%
S. G. = .650

Inches of Deflection
Tree Number 9
Sample G

Size = 1" x 3/4"
Sapwood = 25%
S. G. = .600
Tree Number 9

Sample H

Size = 65/64" x 3/4"

Sapwood = 50%

S. G. = .600

Pounds of Load

Inches of Deflection
Tree Number 9
Sample J

Size = 1" x 3/4"
Sapwood = 28%
S. G. = .600
Tree Number 10
Sample A
Size = 1" x 3/4"
Sapwood = 0%
S. G. = .640
Tree Number 10
Sample B

Size = 65/64" x 3/4"
Sapwood = 30%
S. G. = .612
LITERATURE CITED

1 U. S. F. S. Forest Products Laboratory, Madison, Wisconsin, Technical Note Number 189, revised July, 1936.