THE RELATION OF ENCASED KNOTS, KNOT HOLES, AND INTERGROWN KNOTS IN DOUGLAS FIR DIMENSION STOCK

By
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Approved:

[Signature]
Professor of Forestry
ACKNOWLEDGMENTS

The writer desires to acknowledge his indebtedness to Professor G. Voorhies for his many helpful suggestions. Special thanks are also due to Mr. Donald Boyd for his valued service in preparation and help throughout the running of the tests, and to the Corvallis Lumber Company in assisting in the selection of the samples.

Walter Wojcik
INTRODUCTION

The object of this paper is to show the relation of encased knots, knot holes, and intergrown knots in Douglas Fir dimension stock, and how the results obtained can be applied to the W.C.L.A. #10 Grading Rules for dimension stock in raising the knot size of number one dimension, thereby aiding in the sale of the lower grades.
The Relation of Encased Knots, Knot Holes, and Intergrown Knots in Douglas Fir Dimension Stock.

In determining the relationship of encased knots, knot holes, and intergrown knots in Douglas Fir dimension lumber, the selection of material comes first, and several considerations have to be taken into account such as:

1. Size: 1-5/8" x 5-5/8" x 10' were used as the basis for the test, placed on 9' centers.
2. Surfacing: all material was surfaced four sides.
3. Moisture content: all samples were as nearly 17% m.c. as possible. Accuracy was obtained by testing the moisture content by the oven dry method.
4. Slope of grain: all samples had a slope of grain not more than 1:20.
5. Rings per inch: all pieces had, as nearly as possible, the same number of rings per inch, 8 to 12.
6. Density: all samples had approximately the same percentage of latewood, 25 to 30%.
7. All pieces were flat grain.

In the selection of material, the occurrence of the knots had to be taken into consideration.

Pieces of 1-5/8" x 5-5/8" x 10' were selected, as nearly as possible, as outlined above, with one encased knot within the middle third of the length of the piece and at
the edge of the wide face. The number of pieces and the size of the knots for this type of material was as follows:

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Size of Knot</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1&quot;</td>
</tr>
<tr>
<td>4</td>
<td>1-1/2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2-1/2&quot;</td>
</tr>
</tbody>
</table>

Pieces of 1-5/8" x 5-5/8" x 10' were selected as nearly as possible, as outlined above, with one knot hole within the middle third of the length of the piece and at the edge of the wide face. The number of pieces and the size of the knot holes for this type of material was as follows:

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Size of Knot Hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1&quot;</td>
</tr>
<tr>
<td>4</td>
<td>1-1/2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2-1/2&quot;</td>
</tr>
</tbody>
</table>

Pieces of 1-5/8" x 5-5/8" x 10' were selected as nearly as possible, as outlined above, with one intergrown knot within the middle third of the length of the piece and at the edge of the wide face. The number of pieces and the size of the knot for this type of material was as follows:

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Size of Knot</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1&quot;</td>
</tr>
<tr>
<td>4</td>
<td>1-1/2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>2-1/2&quot;</td>
</tr>
</tbody>
</table>
The type of test was a standard static bending test with third point loading conducted on all pieces. Load was applied at the rate of 0.1 inches per minute by means of a movable head. Loads were noted at 100 pound increments with the corresponding deflection at each interval obtained by means of an attached deflectometer. All tests were continued until the maximum load was reached.

Tests were made on each type of material and for each knot class in that group of material with the encased knot, knot hole, and intergrown knot, as the case may be, placed on the tension side or lower side of the piece.

Tests were made for each knot classification in the three different groups of material; the encased knot, knot hole, and intergrown knot, as the case may be, placed on the compression side or upper part of the piece.

Graphs were prepared for each test, plotting load over deflection in order to determine the proportional limit and fix the maximum load.

The fiber stress at the proportional limit was computed by means of the formula $S_{pl} = \frac{3 \times P \times L}{2 \times b \times h^2}$, where $P$ is the load at the proportional limit, $L$, the length of the sample in inches, $b$, the thickness in inches, and $h$, the width of the sample in inches. Fiber stress at the proportional limit in static bending is the stress that exists in the top and bottom fibers of a beam at the proportional limit load.
Tension stress results when the tendency of the forces is to stretch or pull the body apart. Compression stress results when the tendency of the forces is to compress or crush the body.

The modulus of rupture was computed for each test by means of the formula \( R = \frac{3 \times P' \times L}{2 \times b \times h^2} \), where \( P' \) is the maximum load, \( L \), the length in inches, \( b \), the thickness of the sample, and \( h \), the width of the sample, in inches.

The modulus of rupture as computed from Static Bending Tests, is the computed stress in the top and bottom fibers of a beam at the maximum load, and is a measure of the ability of a beam to support a slowly applied load for a short time.

Modulus of rupture is not a true stress as the formula by which it is computed is based on assumptions that are valid only to the proportional limit. It is, however, a widely accepted term, and values for various species are quite comparable. Since the modulus of rupture is based on the maximum load, which is directly determinable, it can be determined more precisely than proportional limit values. It is used in determining safe working stresses for structural timbers.

The results of the above calculations were averaged for the compression and tension side of the member in each of the knot classes in each of the three groups; encased knots, knot holes, and intergrown knots. The results of the computations for the fiber stress at the proportional limit,
the maximum load, the load at the proportional limit, and the modulus of rupture are presented on the following page in the form of a table.

A set of twenty-nine graphs was prepared as follows:

1. Using the average results of tension tests, a graph was drawn plotting load over deflection to get the proportional limit. This was done for encased knots, knot holes, and intergrown knots for all knot sizes.

2. Using the average results of compression tests, a graph was also drawn plotting load over deflection to get the proportional limit. This was done for encased knots, knot holes, and intergrown knots for all knot sizes.

3. Using the average results of tension and compression tests, a graph was drawn plotting modulus of rupture over encased knot sizes, one for knot hole sizes, and one for intergrown knot sizes, showing a comparison between tension and compression.

4. Another graph, showing all three knot classifications; encased knots, knot holes, and intergrown knots were plotted with the average modulus of rupture of tension and compression over knot size, showing the comparison and the effect of the three classifications. The same procedure
<table>
<thead>
<tr>
<th>Knot Size</th>
<th>P.L. #</th>
<th>M.L. #</th>
<th>Spl. #1 sq.in</th>
<th>M.R. #1 sq.in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; Tens.</td>
<td>1400</td>
<td>1925</td>
<td>1 401</td>
<td>6051</td>
</tr>
<tr>
<td>1&quot; Comp.</td>
<td>2700</td>
<td>3728</td>
<td>6 493</td>
<td>10 470</td>
</tr>
<tr>
<td>1&quot; Av.</td>
<td>2050</td>
<td>2627</td>
<td>6 448</td>
<td>8 261</td>
</tr>
<tr>
<td>1\f{3}&quot; Tens.</td>
<td>1000</td>
<td>1690</td>
<td>3 415</td>
<td>5 312</td>
</tr>
<tr>
<td>1\f{3}&quot; Comp.</td>
<td>1100</td>
<td>1970</td>
<td>3 462</td>
<td>6 197</td>
</tr>
<tr>
<td>1\f{3}&quot; Av.</td>
<td>1050</td>
<td>1830</td>
<td>3 303</td>
<td>5 757</td>
</tr>
<tr>
<td>2&quot; Tens.</td>
<td>900</td>
<td>1665</td>
<td>2 830</td>
<td>4 608</td>
</tr>
<tr>
<td>2&quot; Comp.</td>
<td>1200</td>
<td>2225</td>
<td>3 775</td>
<td>6 970</td>
</tr>
<tr>
<td>2&quot; Av.</td>
<td>1050</td>
<td>1945</td>
<td>3 302</td>
<td>5 789</td>
</tr>
<tr>
<td>2\f{3}&quot; Tens.</td>
<td>2200</td>
<td>2905</td>
<td>3 920</td>
<td>4 569</td>
</tr>
<tr>
<td>2\f{3}&quot; Comp.</td>
<td>900</td>
<td>1000</td>
<td>2 830</td>
<td>3 145</td>
</tr>
<tr>
<td>2\f{3}&quot; Av.</td>
<td>1550</td>
<td>1952</td>
<td>3 875</td>
<td>3 557</td>
</tr>
<tr>
<td>3&quot; Tens.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3&quot; Comp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3&quot; Av.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
was used for the average fiber stress at the proportional limit, plotting the average fiber stress at the proportional limit over the knot size.

Results show that a knot hole is stronger than an intergrown knot in the knot sizes of 1-1/4" to 2-1/4", as there is less distortion of grain in the encased knots and knot holes.

All failures occurred around the knots, as can be observed from illustrations on the following pages. The reason for the failures around the knot is due to the grain distortion caused by the presence of the knot.

Figure 1 shows a 1" encased knot, compression failure. The maximum load was 3630# with a deflection of 3.0". Note the location of the break.

Figure 2 shows a 1-1/2" encased knot, tension failure. The maximum load was 1300# with a deflection of 1.1".

Figure 3 shows a 2" intergrown knot, compression failure. The maximum load was 2300# with a deflection of 2.33". Note the location of the failure.

Figure 4 shows a 2" knot hole, compression failure. The maximum load was 1910# with a deflection of 3.0". Note the failure that occurred.

Figure 5 illustrates the type of machine used for the test. The head for third point loading is not attached. Note the failure of the sample in the machine.
Figure 1.
1" Encased Knot, Compression Failure
Maximum Load 3630 Pounds

Figure 2.
1½" Encased Knot, Compression Failure
Maximum Load 1300 Pounds
Figure 3.
2" Intergrown Knot, Compression Failure
Maximum Load 2300 Pounds

Figure 4.
2" Knot Hole, Compression Failure
Maximum Load 1910 Pounds
Figure 5.
Type of Machine Used
Static Bending.
Third Point Loading
Some of the results of the test proved inaccurate as the number of samples available were not sufficient to give accurate results. This was due to the time, the sample selection, and financial conditions. The selection of samples was the most difficult task of the whole experiment, as it was hard to obtain samples of the desired description as explained before.

As far as the accuracy of the other data is concerned, such things as moisture content, oven dry tests, ring count, slope of grain, and knot size were very satisfactory.

In conclusion, some thought should be given to merchandising in correlation with the test. The merchandising portion of the test has been written in another paper presented by Donald Boyd, but I will cover a few of the major points.

In using lumber where strength is the prime requisite, #2 dimension is satisfactory and better than some #1 stock which allows 1-3/4" intergrown knots, if the knots in #2 dimension are knot holes. This can be seen from the graph in Figure 33 on page 39.

Number 2 dimension can be used in building construction where appearance is not the main attribute of the lumber, such as studding, rafters, joists, and load-bearing members where the span is one-third less than that allowed for #1 dimension containing knots less than 1-1/4" of the intergrown type.
Under present merchandising conditions, #2 and #3 dimension are hard to get rid of as a rule. This is primarily due to the fact that consumers of lumber buy more from the appearance standpoint than from the strength qualities of the wood. If the public can be convinced that #2 is, in some cases, stronger than #1, the lumber industry will profit greatly, and will not have the lower grades of dimension overstocking the yards.

As already explained, the results obtained were not of sufficient accuracy to draw too definite conclusions, but perhaps someone in the near future will take the same project and enlarge on it, and with the use of this data will be able to arrive at definite and accurate conclusions that will prove beneficial to the lumber industry.
Graph showing deflection for loads at 100# intervals. Static Bending.
1" Encased Knot - Tension
3rd Point Loading

Proportional Limit - 1400#
Maximum Load - 1925#

Figure 6
Graph showing deflection for loads at 100# intervals. Static Bending.
1" Encased Knot-Compression
3rd Point Loading

Proportional Limit - 2700#
Maximum Load - 3328#
Graph showing deflection for loads at 100# intervals. Static Bending 1/2" Encased Knobs - Tension 3rd Point Loading

Proportional Limit - 1000#
Maximum Load - 1690#

Deflection (Inches)

Figure 8
Graph showing deflection for loads at 100# intervals. Static Bending. 2" Encased Knot - Tension 3rd Point Loading

Proportional Limit - 900#
Maximum Load - 1465#

Figure 10
Graph showing deflection for loads at 100# intervals. Static Bending 2" Encased Knot - Compression 3rd. Point Loading
Graph showing deflection for loads at 100# intervals. Static Bending. 2½" Encased Knot - Tension 3rd Point Loading
Graph showing deflection for loads at 100# intervals. Static Bending. 2 1/2" Encased Knot - Compression 3rd. Point Loading

Proportional Limit - 900#
Maximum Load - 1000#
Proportional Limit - 1500 #
Maximum Load - 2290 #

Graph showing deflection for loads at 100# intervals. Static Bending.
1" Knot Hole - Tension - 3rd Point Loading

Figure 14
Proportional Limit - 1400#  
Maximum Load - 2085#

Graph showing deflection for loads at 100# intervals. Static Bending.  
1" Knot Hole - Compression  
3rd Point Loading

Figure 15
Graph showing deflection for loads at 100# intervals. Static Bending 1 1/2" Knot Hole - Tension 3rd Point Loading
Graph showing deflection for loads at 100# intervals. Static Bending 1/2" Knot Hole - Compression 3rd. Point Loading

Proportional Limit - 1000#
Maximum Load - 1730#

Figure 17
Proportional Limit - 1000#
Maximum Load - 1762#

Graph showing deflection for loads at 100# intervals. Static Bending.
2" Knob Hole - Tension
3rd. Point Loading

Figure 18
Graph showing deflection for loads at 100# intervals. Static Bending 2" Knot Hole - Compression 3rd Point Loading
Proportional Limit - 900#
Maximum Load - 1450#

Graph showing deflection for loads at 100# intervals. Static Bending.
2½" Knot Hole - Tension - 3rd Point Loading

Figure 20
Graph showing deflection for loads at 100# intervals. Static Bending 2½" Knot Hole - Compression 3rd Point Loading

Proportional Limit - 1100#
Maximum Load - 1728#

Deflection (Inches)

Figure 21
Graph showing deflection for loads at 100# intervals. Static Bending.
1" Intergrown Knot - Tension - 3rd Point Loading

Proportional Limit - 1100#
Maximum Load - 2000#

Figure 22
Graph showing deflection for loads at 100# intervals. Static Bending.
1st Intergrain Knot - Compression - 3rd Point Loading

Proportional Limit - 1400#
Maximum Load - 2480#

Deflection (inches)
Figure 23
Graph showing deflection for loads at 100# intervals. Static Bending 1½" Intergrown Knot-Tension 3rd Point Loading

Proportional Limit - 600#
Maximum Load - 1320#
Proportional Limit - 1400#  
Maximum Load - 2345#  

Graph showing deflection for loads at 100# intervals. Static Bending  
1/2" Intergrained Knot - Compression  
3rd Point Loading  

Figure 25
Graph showing deflection for loads at 100# intervals. Static Bending.
2" Intergrown Knot - Tension
3rd Point Loading

Proportional Limit - 600#
Maximum Load - 1,370#

Deflection (inches)
Figure 26
Graph showing deflection for loads at 100# intervals. Static Bending
2" Intergrown Knot - Compression
3rd. Point Loading

Proportional Limit - 1100#
Maximum Load - 2300#
Graph showing deflection for loads at 100# intervals. Static Bending 2½" Intergrown Knot - Tension 3rd Point Loading

Proportional Limit - 700#
Maximum Load - 925#

Deflection (inches)
Graph showing deflection for loads at 100# intervals. Static Bending.
2½" Intergrown Knot - Compression
3rd Point Loading

Proportional Limit - 1400#
Maximum Load - 2610#
Graph showing a comparison of the Modulus of Rupture for Encased Knots in Tension and Compression.

Figure 30

Modulus of Rupture (Pounds per Square Foot)

Encased Knot-Loop Size (Inches)
Graph showing a comparison of the Modulus of Rupture for Knot Holes in Tension and Compression.

- Compression
- Tension

**Figure 31**

- Modules of Rupture (Pounds per Square Inch)

- Knot Hole-Knot Size (Inches)
Graph showing a comparison of the Modulus of Rupture for Intergrown Knots in Tension and Compression.

Intergrown Knot - Knot Size (Inches)

Figure 32
Graph showing Average Modulus of Rupture for Encased Knots, Intergrown Knots, and Knot Holes. *Samples/Class.
Graph showing Average Fiber Stress for Encased, Intergrown Knots, and Knot Holes. 4 samples per class.
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Figure 13. Graph showing deflection for loads at 100# intervals for a 2-1/2" encased knot in compression.

Figures 14 to 21 inclusive are the same as above except that instead of deflections for loads at 100# intervals for encased knots, they are for knot holes.

Figures 22 to 29 inclusive are the same as above except that instead of deflections for loads at 100# intervals for encased knots, they are for intergrown knots.

Figure 30. Graph showing a comparison of the Modulus of rupture for encased knots in tension and compression.

Figure 31. Graph showing a comparison of the Modulus of rupture for knot holes in tension and compression.

Figure 32. Graph showing a comparison of the Modulus of rupture for intergrown knots in tension and compression.

Figure 33. Graph showing average modulus of rupture for encased, intergrown knots, and knot holes. Average tension and compression.

Figure 34. Graph showing average fiber stress for encased knots, intergrown knots, and knot holes. Average tension and compression.