MECHANICAL PROPERTIES OF
PONDEROSA PINE FROM
THE BLACK HILLS

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MECHANICAL PROPERTIES OF PONDEROSA PINE
FROM THE BLACK HILLS

By

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Summary

This report presents the results of standard tests of strength and related properties for ponderosa pine (Pinus ponderosa) grown in the Black Hills of South Dakota. Average specific gravity and most strength properties were found to be higher for the ponderosa pine of the Black Hills than the average values published for the species, which are based on earlier tests of wood from other growth areas. Hence, published values of basic stresses for clear wood and working stresses for various grades of structural material can be considered applicable to ponderosa pine grown in the Black Hills.

Introduction

How strong is ponderosa pine from the Black Hills? Are the mechanical properties of Black Hills ponderosa pine typical of the published values for the species -- even though these values were obtained from wood grown in other areas?

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2 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
These questions arise largely because of the wide distribution of ponderosa pine in the western United States. Strength and related properties of the species were established before 1918 from evaluations of ponderosa pine from the Cascades, Sierra Nevadas, and both Northern and Southern Rocky Mountains -- but not the Black Hills. Since this area represents the eastern-most part of the tree's natural growth range and has become commercially important, the mechanical properties of Black Hills ponderosa pine were investigated to compare them with the species standards.

Material

The logs (Shipment 1701) used in this investigation were from trees cut in Pennington County, S. D., under the direction of the Rapid City Research Center of the Rocky Mountain Forest and Range Experiment Station. Complete accounts were recorded on standard forms to describe the selection areas and site characteristics, together with detailed data relating to each sample tree.

The topography was mountainous; soil was generally dry with good natural drainage; and streams had only intermittent flow. Absolute elevation of the collection area was about 4,600 feet. The selected trees were in stands composed almost entirely of ponderosa pine.

No data for average annual rainfall were available for the sample area, but at Rochford, 10 air miles west-northwest of the area, rainfall averages about 21 inches annually. Some logging was done in 1921 and 1929, and the area also shows evidence of some fire damage. Figures 1 and 2 show typical stands of ponderosa pine in the area.

Tests were made on material cut 8 to 16 feet above the stump (c-d bolts) from eight representative trees, and bolts from three additional heights in tree No. 8 were also tested. Figure 3 shows the cross-section of tree No. 3 at the 12-foot height. Figure 4 shows end views of test sticks selected to represent average, slow and fast growth. Tree No. 5 was decayed near the pith, necessitating the elimination of tests from that area.

\[3\] Each 4-foot section of a tree is designated as a "bolt." These are assigned letters a, b, c, etc., commencing at the butt of the tree and proceeding upward.

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The average growth rate of the trees included in this shipment was slower than in five of the six shipments previously tested from other regions, and in some Black Hills trees the growth was exceptionally slow. There was a high percentage of sapwood in the South Dakota logs. Trees were from 10 to 20 inches in diameter at breast height, with merchantable lengths ranging from 40 to 58 feet. Estimated age of the trees ranged from 105 to 203 years.

Test Procedure

This shipment of ponderosa pine was collected, prepared, and tested in accordance with the American Society for Testing Materials' Designation D 143-52, "Standard Methods of Testing Small Clear Specimens of Timber."

The 8-foot double length bolts permitted the usual formation of composite bolts for tests of well-matched material in the green and dried conditions. Sticks to be used for dry specimens were kiln dried under a mild drying schedule to about 12 percent moisture content. Specimens cut from these sticks were conditioned to essentially constant weight at 75° F. and 64 percent humidity before being tested.

Some restrictions were encountered in the selection of test specimens because of the relatively small size of the trees and the presence of knots. Less than the usual four pairs of radial and tangential shrinkage pieces could be obtained. In accordance with standard practices many of the minor tests were made on pieces taken from the ends of uninjured bending specimens. Tests of cleavage and tension perpendicular to the grain were somewhat limited, especially in the dried material. No tests were made of tension parallel to the grain.

Data

Average values are listed in tables 1 and 2 for the principal mechanical properties of individual trees in the Black Hills shipment. Tables 3 and 4 show average values, in both the green condition and at 12 percent moisture content, for shipments of ponderosa pine previously tested, together

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with revised averages for the species after the addition of the Black Hills shipment.

Tables 5 and 6 show the results of tests of wood toughness and nail withdrawal resistance in ponderosa pine from the Black Hills. The toughness tests were made on pieces of wood 0.79 by 0.79 inch in cross-section and 11 inches long. These are the first toughness values available for the species. Nail-pull tests were made on 2- by 2- by 6-inch specimens, using plain nails. Most earlier tests of nail-withdrawal resistance were made with cement-coated nails. Data from one earlier shipment, where both plain and cement-coated nails were used, are included in table 6.

**Discussion**

Although all eight trees tested were from a relatively small area in one section of the Black Hills, there is every reason to believe the shipment can be considered typical of ponderosa pine from that portion of its growth range. Experience has shown that, when typical trees are selected from a representative area, the variability within such a shipment is generally quite large, and approaches the variability of a much larger number of trees taken from widely separated areas within the natural growth range of a species.

Ponderosa pine grows in areas that are widely separated geographically. Under such conditions one might expect trees to differ quite markedly when grown in such scattered areas as the Sierras and Cascade Mountains of the Coastal States, the Northern and Southern Rocky Mountains, and the Black Hills. It is of particular interest, therefore, that Black Hills ponderosa pine, as represented by these tests, differs little from the average of six previous shipments from various areas. The difference is so slight that the revised average values for the species, both green and dry materials, are changed only slightly by addition of this shipment, and then generally upward.

This Black Hills sample grew at a somewhat slower rate than the average of the six previous shipments. The growth rate was about the same for the Black Hills as for material collected in Arizona, and only the growth in the Colorado sample was slower.

Radial and tangential shrinkage averaged about as low for the Black Hills specimens as for any of the four earlier shipments for which such data are available; therefore, these values were lower than the average previously published for the species. Volumetric shrinkage average a little higher than the previous averaged for the species, but the difference is of no consequence.

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The average specific gravity of the Black Hills sample, based on weight when oven-dry and volume when green or at 12 percent moisture content, was higher than four of the earlier shipments, representing Arizona, Montana, and two places in California; was about equal to the Colorado sample; and was lower than the one from Washington. Inasmuch as property values are generally fairly well related to specific gravity, it could be expected that Black Hills ponderosa pine would also compare favorably in strength with material from other areas. The data bear out that supposition.

Tables 1 through 4 show that, in most properties, average values for Black Hills ponderosa pine tended to be higher than those for all previous shipments except the denser sample from Washington, for which data are not available in many properties. The major exceptions to that trend are proportional limit values in compression parallel and perpendicular to the grain. In those cases, the apparently lower average values do not reflect a real reduction in property values but rather a difference due to modifications in testing techniques.

All of the previous shipments of ponderosa pine were tested before 1918. Since then, test methods have been developed that permit more accurate measurement of stress-strain data in static tests. In all species these developments have tended to reduce the apparent values for proportional limit and such associated properties as work to proportional limit.

When this factor is taken into account, it is evident that the properties of Black Hills ponderosa pine compare favorably with those of ponderosa pine grown elsewhere. In static bending tests in the green condition, for example, modulus of rupture is about 10 percent higher for the Black Hills specimens than the average of the previous shipments; modulus of elasticity is about 14 percent higher; work to maximum load is 8 percent higher; and total work is about 60 percent higher. A comparison of values from tests of dry material also shows substantial increases for the Black Hills wood in those properties.

Values for maximum crushing strength, impact bending, hardness, and tension perpendicular to grain are also higher than the previous species averages, both in the green and dry conditions. Shear values in the green condition are about 13 percent higher than the previous average, but about 12 percent lower in the dry condition. On the other hand, cleavage values showed no increase over the previous species average when green, but showed about a 9 percent increase when dry. Such variations among properties are not uncommon and, as a whole, substantiate a generally higher level of property values in the Black Hills material.
Values of fiber stress at proportional limit in compression perpendicular to grain are substantially lower than the previous average for the species for both the green and dry wood. As indicated earlier, there is little doubt that differences in test methods account for these large variations. For example, a recent reevaluation of Douglas-fir properties disclosed that shipments tested under modern methods averaged about 30 percent lower than those tested in earlier years. The current ponderosa pine tests show about the same reduction in relation to the previous species average.

The relatively high values obtained for impact bending from this shipment indicate that its shock resistance is high as compared with that of other shipments of ponderosa pine. Further evidence of shock resistance is afforded by the toughness data (table 5). In common with most softwood species, the tangential toughness (obtained when a specimen is loaded on a tangential face) is higher than the radial toughness (when the load is applied on a radial face). No direct comparison with ponderosa pine from the other areas can be made.

Direct comparisons with other species are also limited by the fact that relatively few toughness tests have been made on specimens of the present standard 0.79 by 0.79 inch cross-sectional size. Tests of shortleaf pine from Alabama and Virginia and loblolly pine from Arkansas yielded toughness values in the neighborhood of 310 to 320 inch-pounds for radial specimens and 440 to 455 inch-pounds for tangential specimens. The average specific gravity of the wood tested varied from about 0.46 to 0.49. While the difference in toughness of ponderosa pine and these southern pines seems quite large, it is known that specific gravity strongly affects toughness, and the averages obtained for Black Hills ponderosa pine are actually somewhat higher than might be anticipated for material having a specific gravity so much lower than that of the southern pine.

Average values for the resistance to nail withdrawal for the Black Hills shipment, as presented in table 6, are for withdrawal of sevenpenny plain sinker nails. Comparative values for that type of nail and for sevenpenny cement-coated nails are also listed for ponderosa pine in the shipment from California. Extensive tests of other species have indicated that differences in moisture content at the 7 to 12 percent moisture level have little effect on resistance to immediate withdrawal of plain nails; however, cement-coated nails are much higher in immediate withdrawal resistance than plain nails, as may be seen from the comparative data for the California shipment where both types of

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nails were tested on the same specimens. Other types of nails and other test conditions will, of course, affect nail-withdrawal loads. The data from current tests are not readily comparable with those for other species, but the results will be useful in making comparisons in future tests conducted under current standard practices.

Average values from three sections of the tree trunk in addition to the standard 8- to 16-foot height (c-d bolts) are listed in tables 1 and 2 for tree No. 8. These represent the 0- to 8-foot height (a-b bolts), the 24- to 32-foot height (g-h bolts), and the 40- to 48-foot height (k-l bolts). The data in tables 1 and 2 show that the 8-foot length next to the stump had a substantially higher specific gravity than the c-d bolts, and tended to have somewhat higher property values. Conversely, the g-h and k-l bolts had lower specific gravity and generally lower property values than the c-d standard. These relations are in agreement with other shipments and species; specific gravity and property levels generally decline with increased height in the tree. However, published data on averages for the species represent only the c-d bolt or nearest equivalent; hence, standard comparisons among or within species must be made for c-d bolts only, and the additional data from other parts of a typical tree serve only as supplementary information.

The Forest Products Laboratory has the responsibility for recommending suitable basic stresses for the clear wood of important structural species, including ponderosa pine. Such basic stresses are derived primarily from average species properties in the green condition; together with suitable allowances for variability, duration of load, loading conditions, a factor of safety, and engineering judgment.

Actual working stresses for various structural grades of any species are derived from basic stresses that represent clear wood; a suitable grade ratio is applied to reflect the extent to which strength-reducing characteristics, such as knots, shake, checks, slope of grain, and the like, are permitted in specified grades.

Conclusions

The data included in this report clearly show that the strength properties of ponderosa pine from the Black Hills approach the best values previously obtained from clear wood of the species, and are generally higher than published average values that are intended to represent the species. In view of these findings, the basic stresses published for ponderosa pine as a whole
can also be considered fully applicable to ponderosa pine grown in the Black Hills. Working stresses for specified grades of ponderosa pine lumber can also be considered applicable to Black Hills material that meets such grade requirements, as grade ratios are independent of species or locality.
### Table 1: Strength and related properties of green and kiln dried ponderosa pine from Pennington County, S. D.

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<tr>
<th>Tree No.</th>
<th>Bolt No.</th>
<th>Shrinkage from green:</th>
<th>Static bending</th>
<th>Impact bending</th>
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**KILN DRIED**

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<th>Impact bending</th>
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Table 2.—Strength and related properties of green and kiln dried ponderosa pine from Pennington County, S. D.

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<th>Shear</th>
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<th>Tension</th>
<th>Perpendicular to grain</th>
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<th>Maximum hardness</th>
<th>Maximum parallel strength</th>
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GREEN

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<td>531</td>
<td>717</td>
<td>582</td>
<td>1,039</td>
<td>550</td>
</tr>
<tr>
<td>3</td>
<td>c-d</td>
<td>3,380</td>
<td>1,393</td>
<td>5,180</td>
<td>495</td>
<td>586</td>
<td>460</td>
<td>1,052</td>
<td>462</td>
</tr>
<tr>
<td>4</td>
<td>c-d</td>
<td>4,130</td>
<td>1,577</td>
<td>5,410</td>
<td>566</td>
<td>644</td>
<td>446</td>
<td>1,130</td>
<td>468</td>
</tr>
<tr>
<td>5</td>
<td>c-d</td>
<td>4,020</td>
<td>1,558</td>
<td>5,840</td>
<td>426</td>
<td>586</td>
<td>493</td>
<td>971</td>
<td>454</td>
</tr>
<tr>
<td>6</td>
<td>c-d</td>
<td>3,620</td>
<td>1,405</td>
<td>5,480</td>
<td>448</td>
<td>577</td>
<td>490</td>
<td>1,094</td>
<td>454</td>
</tr>
<tr>
<td>7</td>
<td>c-d</td>
<td>3,970</td>
<td>1,566</td>
<td>5,580</td>
<td>454</td>
<td>644</td>
<td>475</td>
<td>992</td>
<td>481</td>
</tr>
<tr>
<td>8</td>
<td>c-d</td>
<td>3,850</td>
<td>1,556</td>
<td>5,650</td>
<td>492</td>
<td>630</td>
<td>500</td>
<td>1,034</td>
<td>477</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>3,850</td>
<td>1,556</td>
<td>5,650</td>
<td>492</td>
<td>630</td>
<td>500</td>
<td>1,034</td>
<td>477</td>
</tr>
</tbody>
</table>

KILN DRIED

<table>
<thead>
<tr>
<th>No.</th>
<th>c-d</th>
<th>3,890</th>
<th>1,649</th>
<th>5,900</th>
<th>491</th>
<th>665</th>
<th>560</th>
<th>975</th>
<th>389</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>c-d</td>
<td>3,570</td>
<td>1,533</td>
<td>5,600</td>
<td>523</td>
<td>619</td>
<td>506</td>
<td>1,044</td>
<td>370</td>
</tr>
<tr>
<td>2</td>
<td>c-d</td>
<td>4,060</td>
<td>1,766</td>
<td>6,200</td>
<td>531</td>
<td>717</td>
<td>582</td>
<td>1,039</td>
<td>550</td>
</tr>
<tr>
<td>3</td>
<td>c-d</td>
<td>3,380</td>
<td>1,393</td>
<td>5,180</td>
<td>495</td>
<td>586</td>
<td>460</td>
<td>1,052</td>
<td>462</td>
</tr>
<tr>
<td>4</td>
<td>c-d</td>
<td>4,130</td>
<td>1,577</td>
<td>5,410</td>
<td>566</td>
<td>644</td>
<td>446</td>
<td>1,130</td>
<td>468</td>
</tr>
<tr>
<td>5</td>
<td>c-d</td>
<td>4,020</td>
<td>1,558</td>
<td>5,840</td>
<td>426</td>
<td>586</td>
<td>493</td>
<td>971</td>
<td>454</td>
</tr>
<tr>
<td>6</td>
<td>c-d</td>
<td>3,620</td>
<td>1,405</td>
<td>5,480</td>
<td>448</td>
<td>577</td>
<td>490</td>
<td>1,094</td>
<td>454</td>
</tr>
<tr>
<td>7</td>
<td>c-d</td>
<td>3,970</td>
<td>1,566</td>
<td>5,580</td>
<td>454</td>
<td>644</td>
<td>475</td>
<td>992</td>
<td>481</td>
</tr>
<tr>
<td>8</td>
<td>c-d</td>
<td>3,850</td>
<td>1,556</td>
<td>5,650</td>
<td>492</td>
<td>630</td>
<td>500</td>
<td>1,034</td>
<td>477</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>3,850</td>
<td>1,556</td>
<td>5,650</td>
<td>492</td>
<td>630</td>
<td>500</td>
<td>1,034</td>
<td>477</td>
</tr>
</tbody>
</table>

Average adjusted:

<table>
<thead>
<tr>
<th>No.</th>
<th>c-d</th>
<th>3,700</th>
<th>1,547</th>
<th>5,480</th>
<th>484</th>
<th>618</th>
<th>494</th>
<th>1,017</th>
<th>471</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>a-b</td>
<td>3,350</td>
<td>1,430</td>
<td>5,370</td>
<td>458</td>
<td>639</td>
<td>560</td>
<td>1,158</td>
<td>416</td>
</tr>
<tr>
<td>8</td>
<td>g-h</td>
<td>3,450</td>
<td>1,554</td>
<td>5,380</td>
<td>406</td>
<td>596</td>
<td>428</td>
<td>852</td>
<td>397</td>
</tr>
<tr>
<td>8</td>
<td>k-l</td>
<td>3,070</td>
<td>1,475</td>
<td>5,340</td>
<td>380</td>
<td>533</td>
<td>418</td>
<td>917</td>
<td>352</td>
</tr>
</tbody>
</table>

Rept. No. 2090
| Locality of Number: Rings:Moisture:Specific gravity:Shrinkage from green: Static bending: Impact bending: |
|---------------------------------------------------------------|---------------------------------------------------------------|
| growth of: per: content: ovendry, based on ovendry condition: | Stress: Modulus: Work: Stress: Modulus: Height: |
| Pennington | Co., S. D. | 8 | 22.4 | 127.4 | 0.396 | 0.437 | 9.8 | 3.64 | 5.92 | 3,110 | 5,589 | 1,187 | 0.90 | 5.48 | 20.0 | 7,890 | 0.4 | 1,320 | 24.2 |
| Douglas Co., | Colo. | 5 | 31.9 | 92.7 | 0.391 | 0.435 | 9.9 | 3.8 | 5.8 | 3,310 | 5,469 | 1,053 | 0.99 | 6.00 | 11.9 | 6,910 | 2.2 | 1,203 | 20.0 |
| Stevens Co., | Wash. | 5 | 37.6 | 412.0 | 0.415 | 3,590 | 5,670 | 1,160 |
| Coconino Co., | Ariz. | 5 | 21.4 | 98.5 | 0.353 | 0.395 | 9.2 | 4.1 | 6.4 | 2,660 | 4,760 | 879 | 0.17 | 4.97 | 12.8 | 6,160 | 2.1 | 975 | 17.0 |
| Madera Co., | Calif. | 5 | 13.0 | 125.3 | 0.377 | 0.433 | 11.5 | 4.3 | 7.3 | 3,180 | 5,180 | 1,111 | 1.25 | 4.30 | 15.5 | 7,070 | 2.5 | 1,123 | 21.0 |
| Missoula Co., | Mont. | 5 | 17.9 | 119.4 | 0.371 | 0.425 | 9.3 | 3.5 | 5.9 | 2,950 | 4,950 | 869 | 0.59 | 5.20 | 15.4 | 6,500 | 2.3 | 1,061 | 19.0 |
| Sierra Co., | Calif. | 6 | 12.6 | 75.4 | 0.370 | 0.412 | 8.8 | 3.4 | 6.2 | 3,140 | 4,250 | 779 | 0.74 | 5.10 | 7.77 | 7,080 | 3.4 | 822 | 21.1 |
| Adjusted species: average (weighted): | | 19.4 | 98.4 | 0.381 | 0.424 | 9.7 | 3.8 | 6.0 | 3,100 | 5,130 | 997 | 0.57 | 5.19 | 14.2 | 7,000 | 2.6 | 1,097 | 20.7 |

1 Adjusted to 12 percent moisture content.
2 Weighted species averages include limited tests of shipment from Stevens County, Wash.
Table 4.—Comparison of strength and related properties of ponderosa pine from various areas and revised averages for the species (all c-d bolts)

<table>
<thead>
<tr>
<th>Locality of growth</th>
<th>Moisture content</th>
<th>Compression parallel to grain</th>
<th>Compression perpendicular to grain</th>
<th>Hardness; load required to embed a 0.444-inch shearing split maximum proportional to grain; stress at proportional limit</th>
<th>Cleavage tensile strength</th>
<th>Modulus of elasticity of crushing maximum shear parallel to grain; stress at proportional limit</th>
<th>Max. load to split maximum tensile strength at proportional limit; at proportional limit</th>
<th>End Side Lb.</th>
<th>Side Lb.</th>
<th>P.s.i. per in. of width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennington Co., S. D.</td>
<td>127.4</td>
<td>1,600</td>
<td>1,345</td>
<td>2,640</td>
<td>256</td>
<td>344</td>
<td>347</td>
<td>770</td>
<td>172</td>
<td>353</td>
</tr>
<tr>
<td>Douglas Co., Colo.</td>
<td>92.7</td>
<td>2,240</td>
<td>1,174</td>
<td>2,600</td>
<td>410</td>
<td>315</td>
<td>331</td>
<td>706</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Stevens Co., Wash.</td>
<td>37.6</td>
<td>2,770</td>
<td>299</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coconino Co., Ariz.</td>
<td>198.5</td>
<td>1,870</td>
<td>1,046</td>
<td>2,220</td>
<td>342</td>
<td>310</td>
<td>314</td>
<td>662</td>
<td>166</td>
<td>301</td>
</tr>
<tr>
<td>Madera Co., Calif.</td>
<td>125.3</td>
<td>2,130</td>
<td>1,271</td>
<td>2,420</td>
<td>326</td>
<td>316</td>
<td>314</td>
<td>696</td>
<td>174</td>
<td>241</td>
</tr>
<tr>
<td>Missoula Co., Mont.</td>
<td>119.4</td>
<td>2,050</td>
<td>1,061</td>
<td>2,370</td>
<td>313</td>
<td>308</td>
<td>322</td>
<td>674</td>
<td>176</td>
<td>302</td>
</tr>
<tr>
<td>Sierra Co., Calif.</td>
<td>75.4</td>
<td>2,060</td>
<td>2,060</td>
<td>2,060</td>
<td>428</td>
<td>258</td>
<td>286</td>
<td>682</td>
<td>168</td>
<td>310</td>
</tr>
<tr>
<td>Adjusted species average (weighted)</td>
<td>198.4</td>
<td>1,940</td>
<td>1,197</td>
<td>2,450</td>
<td>335</td>
<td>310</td>
<td>321</td>
<td>704</td>
<td>168</td>
<td>306</td>
</tr>
</tbody>
</table>

1 Adjusted to 12 percent moisture content.
2 Weighted species averages include limited tests of shipment from Stevens County, Wash.

Rept. No. 2090
Table 5.--The results of toughness tests on ponderosa pine from Pennington County, S. D. Specimens 0.79- by 0.79- by 11-inches. Tested on a 9.47-inch span.

<table>
<thead>
<tr>
<th>Tree</th>
<th>Bolt</th>
<th>Loaded on radial face</th>
<th>Loaded on tangential face</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>No.</td>
<td>Number: Moisture: Specific: Toughness</td>
<td>Number: Moisture: Specific: Toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of tests:</td>
<td>of tests:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent</td>
<td>In.-lb.</td>
</tr>
<tr>
<td>1</td>
<td>c-d</td>
<td>1</td>
<td>148.1</td>
</tr>
<tr>
<td>2</td>
<td>c-d</td>
<td>2</td>
<td>116.7</td>
</tr>
<tr>
<td>3</td>
<td>c-d</td>
<td>3</td>
<td>155.6</td>
</tr>
<tr>
<td>4</td>
<td>c-d</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>c-d</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>c-d</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>c-d</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>c-d</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>39</td>
</tr>
<tr>
<td>8</td>
<td>a-b</td>
<td>9</td>
<td>147.2</td>
</tr>
<tr>
<td>8</td>
<td>g-h</td>
<td>10</td>
<td>139.0</td>
</tr>
<tr>
<td>8</td>
<td>k-l</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>a-b</td>
<td>6</td>
<td>11.2</td>
</tr>
<tr>
<td>8</td>
<td>g-h</td>
<td>7</td>
<td>10.9</td>
</tr>
<tr>
<td>8</td>
<td>k-l</td>
<td>10</td>
<td>11.2</td>
</tr>
</tbody>
</table>

**GREEN**

<table>
<thead>
<tr>
<th>Tree</th>
<th>Bolt</th>
<th>Loaded on radial face</th>
<th>Loaded on tangential face</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>No.</td>
<td>Number: Moisture: Specific: Toughness</td>
<td>Number: Moisture: Specific: Toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of tests:</td>
<td>of tests:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent</td>
<td>In.-lb.</td>
</tr>
<tr>
<td>1</td>
<td>c-d</td>
<td>1</td>
<td>148.1</td>
</tr>
<tr>
<td>2</td>
<td>c-d</td>
<td>2</td>
<td>116.7</td>
</tr>
<tr>
<td>3</td>
<td>c-d</td>
<td>3</td>
<td>155.6</td>
</tr>
<tr>
<td>4</td>
<td>c-d</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>c-d</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>c-d</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>c-d</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>c-d</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
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<td>Average</td>
<td>39</td>
</tr>
<tr>
<td>8</td>
<td>a-b</td>
<td>9</td>
<td>147.2</td>
</tr>
<tr>
<td>8</td>
<td>g-h</td>
<td>10</td>
<td>139.0</td>
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<tr>
<td>8</td>
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<td>Average</td>
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</tr>
<tr>
<td>8</td>
<td>a-b</td>
<td>6</td>
<td>11.2</td>
</tr>
<tr>
<td>8</td>
<td>g-h</td>
<td>7</td>
<td>10.9</td>
</tr>
<tr>
<td>8</td>
<td>k-l</td>
<td>10</td>
<td>11.2</td>
</tr>
</tbody>
</table>

**KILN DRIED**

1 Specific gravity based on volume at test and weight when oven-dry.

2 Total toughness -- inch-pounds per specimen.
Table 6.--The results of nail-withdrawal tests on ponderosa pine

<table>
<thead>
<tr>
<th>Tree : Bolt</th>
<th>Green</th>
<th>Kiln dried</th>
</tr>
</thead>
</table>

**PENNINGTON COUNTY, S. D. (BLACK HILLS)**

| 1 : c-d : 0 | 2 : 11.7 : 0.417 : 78 : 115 : 124 |
|---------------|----------------|-------------|-------------|
| 7 : c-d : 5  | 126.5 : 0.400 : 62 : 134 : 130 : 5 : 11.4 : 0.431 : 72 : 99 : 107 |
| Average      | 31 : 119.7 : 0.382 : 65 : 124 : 129 : 40 : 11.6 : 0.424 : 76 : 111 : 113 |

**MADERA COUNTY, CALIF.**


1 Specific gravity based on volume at test and weight when oven-dry.
2 Load in pounds required to remove seven-penny sinker nails immediately after being driven to a 1-1/4-inch penetration. (End, radial, and tangential refer to faces from which nail is withdrawn.)
3 Test material represented 5 trees.
4 Load in pounds required to remove seven-penny cement-coated nails immediately after being driven to a 1-1/4-inch penetration.
Figure 1. -- Typical stand of ponderosa pine in Pennington County, S. D., showing tree No. 8 before it was cut.
Figure 2. --Ponderosa pine trees, numbered 3, 5, 6, and 8 in this investigation, came from this site in the Black Hills.

Z M 108 841
Figure 3.--Cross sectional view of a representative ponderosa pine tree from Pennington County, S. D. (tree No. 3 at the 12-foot height).

ZM 107 919
Figure 4. --Slow, medium, and fast growth is shown, left to right, in these blocks of ponderosa pine from Pennington County, S. D.