SAWING TO REDUCE WARP IN PLANTATION RED PINE STUDS

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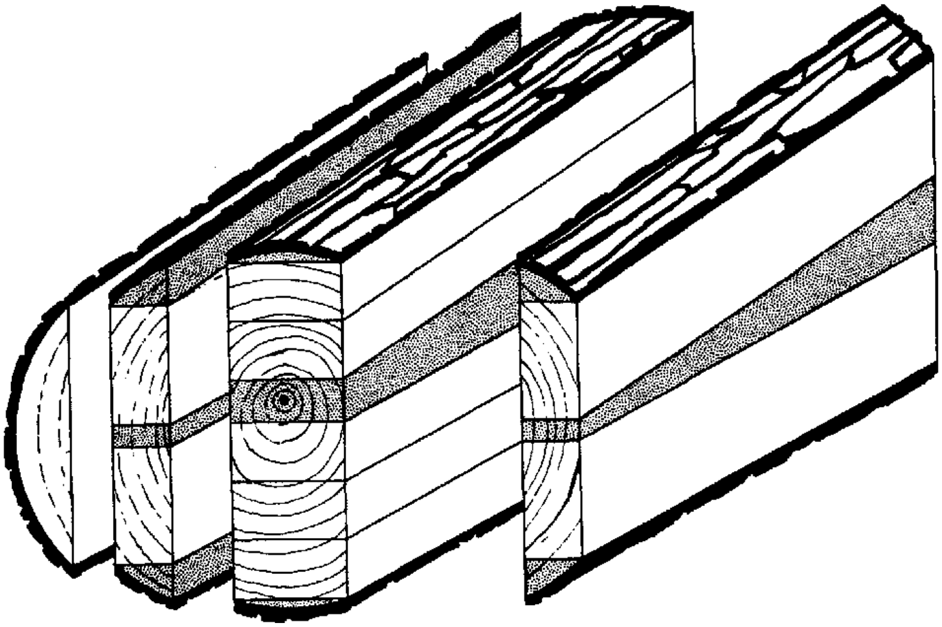

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ABSTRACT

Large volumes of red pine (Pinus resinosa) from plantations in the Lake States and the Northeastern States are about to appear on the saw log market. One of the most important products of small saw logs is studs (2 in. x 4 in. x 8 ft.).

A study has been conducted by the FPL which examines the relationship of two industrial and one FPL sawing method on the subsequent warp in the studs from this species.

Results generally indicate that the species is suitable for studs. There is significantly less warp in studs sawn by the FPL method than the industry methods. Also one of the industry methods is significantly better than the other. The mean crook of studs from butt logs is much greater than in those from upper logs. The opposite is true with respect to twist. Studs sawn from the outside of the log are always lower in warp than from the inner area. This would appear to be the main reason for the superiority of the FPL method over the commercial methods.

When all aspects of warp are considered the best industry method yielded 73 percent from butt logs and 84 percent from upper logs which met the "stud" grade of the new National Grading Rules. Comparable yields by the FPL method were 79 and 87 percent.

SAWING TO REDUCE WARP IN PLANTATION RED PINE STUDS

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INTRODUCTION

All available evidence indicates an increasing demand for lumber in the foreseeable future. The population is continuing to increase and with it the demand for housing. Although substitutes for wood will undoubtedly continue to be used and will probably increase their share of the market, it seems wood will continue to be the mainstay in house construction.

During recent years we have witnessed a major movement of the softwood dimension industry to new species and to trees of relatively small diameter, in the search for sufficient timber to meet demands. Examples of this are the growth of the stud industry in the lodgepole pine and Engelmann spruce areas of the Rocky Mountains.

During the era of the Civilian Conservation Corps (1933–1942) tremendous areas in the Lake States and in the northeastern part of the United States were planted to trees. A high percentage of this planting was to red pine (Pinus resinosa). Statistics (16)[2] show that in the period 1926–1944, a total of 1,392,949 acres was planted in the Lake States alone. No similar figures appear to be available for the northeastern area, but it is probably safe to assume a comparable area in plantations. In the Lake States red pine was used on about 43 percent of the planted area.

Many of these red pine plantations are now reaching small sawlog size (8- to 14-in.-diameter breast high). Thinning of most of the stands is needed and it is likely that during the next few years, enormous volumes of small red pine logs will be available to the sawmilling industry. In addition, planting has continued since 1944 at a high rate in both areas with an even higher percentage of red pine. This would indicate continued availability of small red pine logs.

One of the most likely outlets for these logs is the stud industry. Past research (5, 6) has shown, for other species, a relationship between sawing method and the quality of studs produced. Such information with special reference to red pine will be of significant importance to this new industry.

For these reasons the Forest Products Laboratory has been studying the effects of different sawing methods on the reduction of warp in red pine studs. This is the third in a series of studies involving species important or likely to become important in the stud industry. Species previously examined were loblolly pine (Pinus taeda L.) and lodgepole pine (Pinus contorta Dougl.).

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Forms of Warp

"Warp" (17) denotes any deviation of a piece of lumber from a true or plane surface. Bow, crook, twist, and cup are forms of warp. Bow is a distortion in a board from flatness along its length. Crook is the deviation of a piece of lumber edgewise from a straight line from end to end. Twist is the turning or winding of the edges in a manner that the four corners of any face are not in the same plane. And cup is the deviation flatwise from a straight line across the width of a board. Bow, crook, and twist occur frequently and to a varying degree in nominal 2- by 4-inch studs, Cup is seldom present in sufficient degree to affect either the grade or the use of the stud.

Review of Literature

Many researchers have recognized that the sawing method should be important in reducing potential warp of lumber. Cockrell (1) states: "In butt logs, the combination of highlongitudinal shrinkage near the pith and slight shrinkage or elongation of the wood further out can cause extreme counter tension in seasoning which would result in pronounced warping of boards cut with one edge along the pith. Although the cross grain surrounding knots would, to a lesser degree, affect the slight shrinkage or elongation of the outer wood, no lumber can be safely cut with the pith along one edge without increasing the risk of degrade in seasoning. It would, therefore, be good practice to saw logs, and especially butt logs, so that the pith is approximately in the center of the board or timber."

Differential longitudinal shrinkage during drying has long been recognized as the primary cause of bow and crook, and frequently is a contributing cause of twist. Koehler and others (18) at the Forest Products Laboratory have shown that the normal longitudinal shrinkage of wood is from 0.1 to 0.3 percent. They have noted abnormal longitudinal shrinkage up to 5.78 percent in ponderosa pine (Pinus ponderosa Laws.) compression wood; this is equivalent to a shortening of more than 5 inches in an 8-foot stud.

Excessive longitudinal shrinkage in areas of non-normal wood has been reported by numerous other writers including Cockrell (1, 2), Du Toit (3), King (7, 8), Paul (13), Paul and Sweet (14), and Pillow (15).

King (7,8) concluded that the application of water-repellent chemicals helped reduce distortion in stored southern pine studs but estimated that 80 percent of the warping problem could be eliminated by proper selection of logs and by changing the patterns of sawing.

Kloot and Page (10), in working with radiata pine (Pinus radiata D. Don), suggested that sawing patterns that eliminate the central portion of the log should reduce the warping problem

Paul and Sweet (14) made three recommendations for sawing patterns in southern yellowpine: Control sawing pattern to reduce mixing fast and slow growth or compression and normal wood, and possibly employ taper sawing; cut center of log into boards if wide ringed; and saw crooked logs to have the wide lumber face at right angles to the plane of the crook.

Zobel (19) quoted correspondence from Jennings of Australia as follows: "The existence of the core (juvenile wood formed the first years of growth) must be recognized in the sawing pattern, because it is fundamentally unstable in seasoning, low in mechanical strength and, consequently, very low in value." Zobel also stated, "Sawing of lumber with core wood included invites trouble since it dries differently from other wood, having excessive longitudinal shrinkage and other difficulties."

Kotok (9) investigated the relationship of seven tree characteristics -- general sweep, spiral grain, short butt crook, eccentric pith, stem crook, fluted butt and forked stem--on the grade yields of studs sawed from several diameter classes. He found the presence of eccentric pith, stem crook, fluted butt, or forkedness positively correlated with reduced yields of upper-grade studs. He also reported a positive correlation between increasing log diameter and increasing yield of upper grades,

Malcolm (11, 12) found that average crook and bow deflections in segments of the length of 2x4 studs were markedly lower in studs from upper logs than in those from butt logs in small diameter loblolly pine trees. He also noted that the tendency to crook and bow appeared to decrease progressively with increasing height above the stumps. In addition, he found that certain growth characteristics in the first 4-foot butt length of small-diameter lodgepole pine trees have a strong influence on the severity of crook and bow in studs produced from the butt area, A thorough search of the literature indicates that in 1965 Hallock (5) conducted the first study in which control of the internal characteristics of sawed lumber was attempted by altering the sawing pattern, He reported a significant relationship between sawing method and subsequent warp in loblolly pine studs. However, sawing methods that reduced one form of warp frequently increased others. Because crook was the overriding cause of warp degrade, the sawing method that reduced crook the most was selected as the best overall method.

In 1969, a similar study on lodgepole pine (6) further confirmed the effects of sawing method on warp. Although the findings were generally parallel to those for loblolly pine, the effects were less in magnitude,

CONDUCT OF STUDY

Scope

The subject of this report is the relationshipof warp in red pine studs to sawing methods, to log cross-sectional eccentricity, to position of the stud in the log, to log diameter, to log position in the tree and to presence of compression wood.

Study Design

This study was designed so that a 5 percent difference in yield of "stud" grade studs between any two treatments would be statistically significant at the 0.05 level. To keep thenumber of logs within manageable levels, the investigation was divided into three substudies.

Substudy 1 was of a 4 by 2 by 2 by 2 factorial design (four diameters by two logpositions by two eccentricities by two sawing methods).

Substudy 2 was designed to compare a third sawing method with the two methods investigated in substudy 1 and was of a 3 by 2 by 2 by 1 factorial design (three sawing methods by twologpositions by two eccentricities by one diameter).

Substudy 3 was designed to investigate the effect of the presence of compression wood on warp. It was of a 2 by 2 by 2 by 2 by 1 factorial design (two classes of compression wood by two diameter classes by two sawing methods by two eccentricities by one log position).

In each of the substudies, 15 logs were selected for each factorial combination. These were further randomly divided into three replications of five logs each.

Variables

A primary objective was toprovide information that could be used by sawmill personnel toproduce a product with a lower potential for warp. Thus the selection of variables was confined to the characteristics that are readily identifiable visually.

Log diameter.--It is anticipated that stud mills would use red pine logs similar in size to those used by stud mills in other areas; namely, 6 to 12 inches measured at the top d.i.b. (diameter inside bark).

For the study as a whole this diameter range was divided into four classes: 6 inches (5.1 to 7.0), 8 inches (7.1 to 9.0), 10 inches (9.1 to 11.0), and 12 inches (11.1 to 13.0).

Sawing method.--Most mills that produce studs in quantity use one of two basic sawing methods--conventional or Scragg.

The minimum conventional mill combines a standard log carriage with either a circular or a band headrig, and usually has secondary breakdown equipment such as an edger and a resaw or a gang. The log is placed on the carriage and, by a certain sequence of sawing and turning, it is reduced either to the final product or to flitches and cants for further remanufacture by whatever secondary equipment is available. This basic system is suitable for producing studs by any one of the three methods to be described.

The Scragg system is suitable for producing studs only by methods III and IV (fig. 1). With the Scragg system, the logpasses between successive pairs of parallel (usually circular) saws that

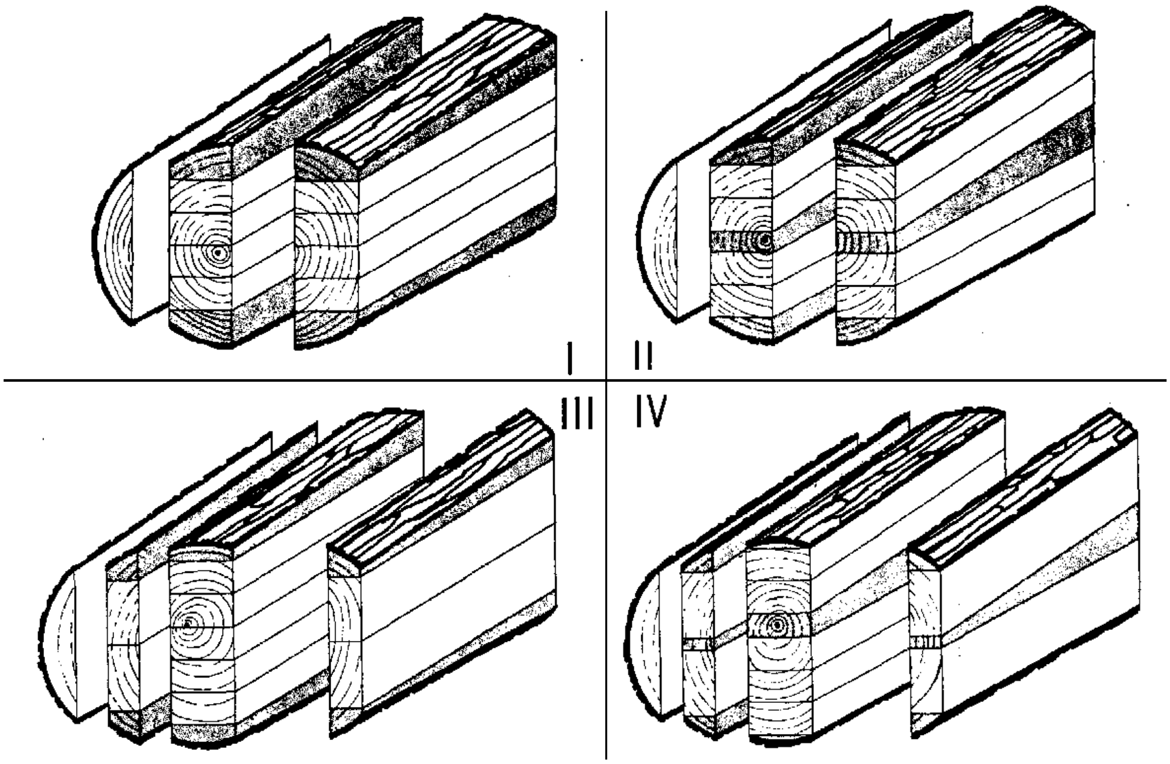

Figure I.--Four sawing methods (on 12-inch diameter class) that can be used to reduce logs to studs. In Methods I and III taper and excess wood (shaded area) are in the slab, whereas in Methods II and IV they are mainly concentrated in a wedge in the pith area.

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remove slabs, 2-inch flitches, and leave a 4-inch cant from the approximate geometric center of the log. The 2-inch flitches are then passed through a circular gang and ripped into stock 4 inches wide. The 4-inch cant is also passed through another section of the circular gang and ripped into stock 2 inches thick Thus the log is usually sawed in a more or less continuous process to yield only studs. This system is ideal for method III and with minor alterations, for method IV.

Method I (fig. 1) in this study is a procedure commonly used at conventional mills with carriage and band or circular headrigs. By this methodany log large enough to develop two adjacent 4-inch cants can be sawed. Characteristically it produces two parallel and adjacent 4-inch cants that tend to have the pith centrally located on the inner wide faces. Each cant is then ripped parallel to its longitudinal axis into 2-by 4-inch stock The taper of the log and all wood not of sufficient size to yield an additional stud is removed in the slabs and edgings. With this method all of the juvenile core (less sawdust) becomes a part of the studs.

Method III (Scragg method) is suitable for logs with diameters of more than 5 inches. When applied to logs under approximately 9.5 inches, a single 4-inch cant is produced that tends to have the pith in its approximate geometric center. With most logs of 10- and 12-inch-diameter classes, an additional 2-inch flitch is developed parallel and adjacent to each wide face of the central 4-inch cant. In this method, all sawing is approximately parallel to the central longitudinal axis of the cant or flitch Thus log taper and excess wood in the cant or flitch are removed as tapered slabs and edgings. The entire juvenile core less sawdust is included in the lumber.

This method has an advantage, theoretically at least, over Method I; it tends to confine the core to fewer studs and to yield a higher percentage of studs with balanced growth stresses in the 4-inch plane, Method IV (FPL improved Scragg method) is a modification of Method 111 that, to our knowledge, has never been used commercially. The 2-inch flitches and 4-inch cant are produced exactly as in Method 111. If the 2-inch flitch is wide enough to yield two studs, these studs are ripped parallel to the adjacent bark edges, and excess wood and taper are removed in the form of a wedge from the longitudinal center of the flitch. If the 2-inch flitch contains only one stud, it is ripped from the longitudinal center of the flitch with taper divided equally between the edgings. The 4-inch cant is ripped into studs parallel to and immediately adjacent to both bark edges. Thus taper and excess wood are removed from the juvenile core area rather than immediately under the bark as in Method III. Often a large part of the juvenile core is thus removed, and the percentage of core wood in all the studs from a given log is reduced. Like Method III, Method IV should yield a higher percentage of studs with balanced growth stresses than Method I. Studs from 2-inch side flitches wide enough to yield two 2 by 4's tend to have less cross grain than similar studs developed in Method111.

The first study on loblolly pine included four sawing methods (fig. 1). Method II was not included in this red pine study because it is not used commercially and did not yield as high grades as the method now most commonly used by industry (Method III).

Eccentricity and Compression wood.--All logs are eccentric; the pith is not inthe exact geometric center. Generally, the more eccentric logs contain moderate-to-heavy concentrations of compression wood on the side with the longer radius (fig. 2). Positioning the log with the compression wood concentrated in the vertical or the horizontal plane as shown in figures 2 and 3 should result in studs with differences in warp tendencies. With vertical positioning the compression wood would tend to occur centrally with reference tothe width of some studs (fig. 2), and with horizontal positioning the compression wood would tend to be concentrated on one edge or face of some studs (fig. 3).

Because the effect of eccentricity may be independent of compression wood, the position of the eccentricity of all logs was controlled for each sawing method. An equal number of the logs in each variable class were sawed with the eccentricity vertical and horizontal.

Logs were also selected for presence or absence of visible compression wood onthe log ends,

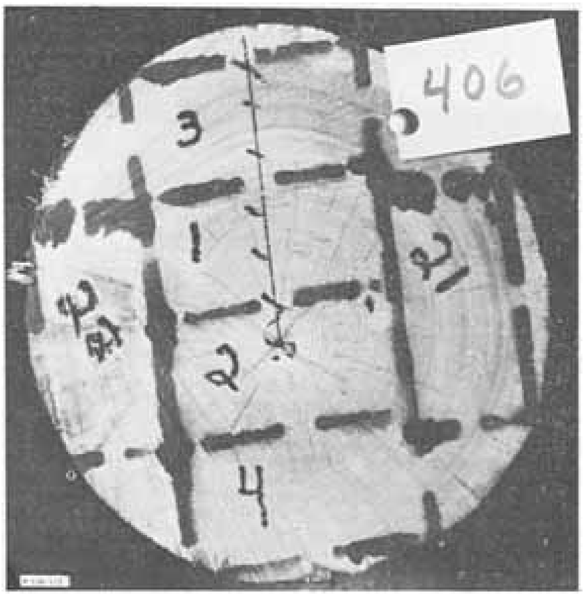

Figure 2.--Cross section with Sawing Method III design applied to 10-inch log; cross-sectional eccentricity in vertical position. Compression wood is shown especially in studs I and 3.

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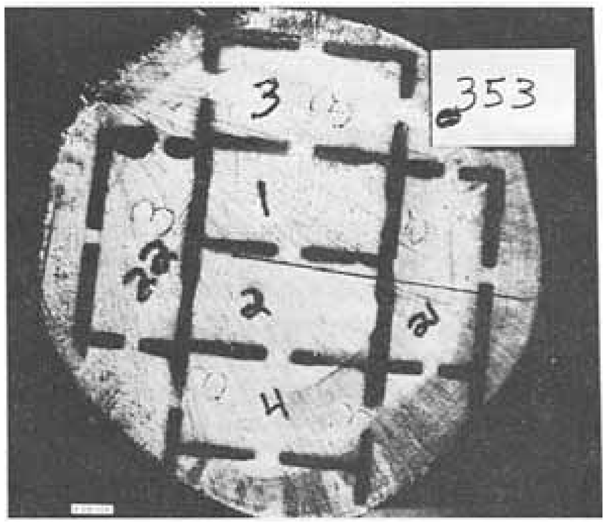

Figure 3.--Cross section with Sawing Method III design applied to IO-inch log; cross-sectional eccentricity in horizontal position.

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Log position.--Because previous research indicated that warp potential of lumber cut from butt logs differs from that from upper logs, log position in the tree was also selected as a variable. In the sawmill it is usually possible to identify the butt logs but not possible to separate the upper logs further, Thus in this investigation all upper logs were combined into a single log position group. The butt logs were defined as the first 8-foot log above the stump, and the upper logs as those from any position above the butt logs.

Stud position.--The position of studs in the logs was classed as either inner or outer. Positions were determined by log diameter and sawing method.

Procedure

Based on the variability noted in two previous studies, the sample size for each of the three substudies was statistically predicted; substudy 1, 480; substudy 2, 180; and substudy 3, 240. Since there were some areas of overlap in the treatments, a total of 660 logs was required rather than the sum of 900 indicated above.

Through the cooperation of the Wisconsin Department of Natural Resources, two plantations were located with trees of suitable diameter to furnish the logs needed in the study. One of these, near Whitehall, Wis., was in private ownership; the other, near Woodruff, was in the Northern Highland State Forest.

Logs for the study were selected and cut by personnel of the Forest Products Laboratory from trees marked for cutting by personnel of the Department of Natural Resources.

There were no log grades for red pine available at the time the logs were cut. Therefore the criteria were similar to those used in the previous investigation on loblolly pine. All the logs chosen had the following general specifications:

1. Sweep of no more than 1 inch in the length of the log (8-1/4 to 8-1/2 ft.).

2. No unsound knots. (An unsound knot is any visible branch, stub, or socket that contains either advanced decay extending to the log heart or any hole larger than 1/4 in. penetrating more than 2 in.) (4).

3. No evidence of decay, shake, or fire scars.

For each log selected, the following information was recorded: Minimum and maximum d.i.b. to nearest 0.1 inch on both ends of the log, compression wood class (compression or normal wood), log position class (butt or upper), andlogdiameter class (6, 8, 10, or 12 in.) based on minimum small end d.i.b. A metal tag bearing the log number was nailed to each end of each log. Logs were assigned a sawing method and an orientation-for-eccentricity class at random.

These logs were shipped to the Laboratory in October and November 1969. Whenever the weather warmed above the freezing point and there was danger of the logs drying out, they were kept under water-spray storage until sawed.

Just before sawing, a thin cross-sectional slice was sawed from the upper end (usually smaller log end) to provide a new, clean surface. The exact sawing pattern was stenciled on the end of each log with paint applied from aerosol cans (fig. 4). A code number was placed on the end of each stud to identify the position of the stud in the log (fig. 5). A card indicating the log number was attached, and the stenciled end of each log was photographed (figs. 2 and 3) for a permanent record.

The logs were sawed on the Laboratory's sawmill. Although completely instrumented for research purposes, this sawmill is a conventional medium- weight circular headsaw type with a setter - controlled, hand - operated - block type carriage. The mill installation is equipped with a light projection sawline indicator which made it possible to position precisely the opening saw cut on any face to coincide with the stenciled sawing pattern.

Logs were placed on the carriage and securely dogged to three headblocks with the stenciled end toward the saw. They were then sawed at a feed rate of about 1/8 inch per tooth, which compares favorably with fast commercial mill production rates. Green rough target size of the nominal 2 by 4 studs was 1-3/4 x 3-7/8 inches.

Immediately after each stud was sawed, it was renumbered on the wide face with both the log and the stud number. The studs were solid stacked until there was a sufficient number for a kiln load. They were covered with polyethylene plastic sheeting at all times toprevent drying. When a kiln load of studs had accumulated, studs were end trimmed to precisely 96 inches.

Experience in the loblolly study had shown that the rough edges and corners of the studs that resulted from sawing sometimes made precise measurement of deflection difficult--especially after kiln drying when the "fuzz" on the studs had stiffened. For this reason all the studs in the green condition were planed lightly to 1-23/32x3-27/32 inches: this was sufficient to remove the "fuzz"

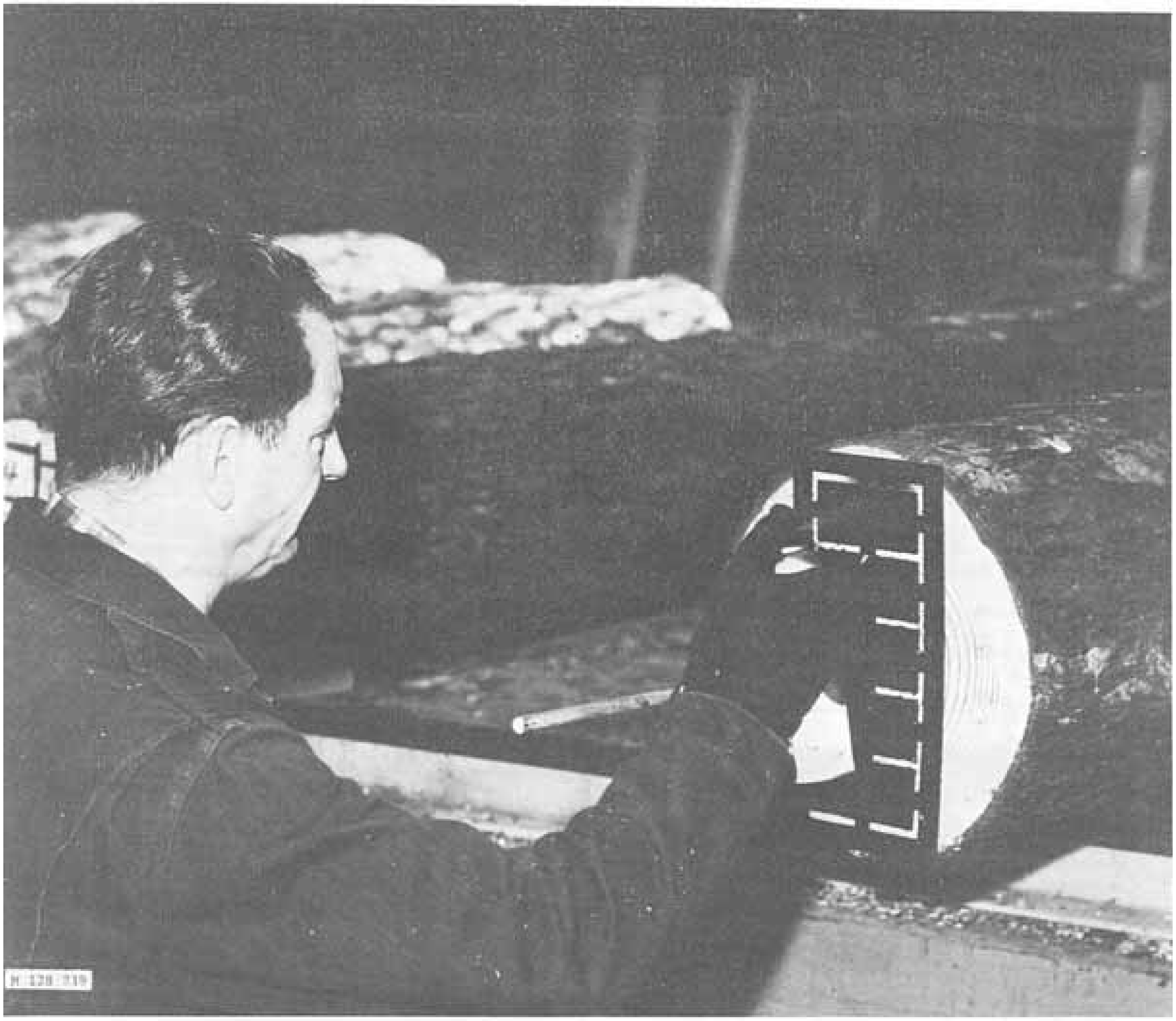

Figure 4.--Stenciling sawing pattern with an aerosol paint spray for center cant on end of log.

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and almost all saw marks.

Each stud was then placed in a box that was constructed to aid in measuring length and deflection. In this operation the length of each stud could be measured to the nearest 1/32 inch (fig. 6). The amounts of crook (fig. 7), bow (fig. 8) and twist (fig. 9) were measured and recorded.

After being measured, the 3,609 studs were dried in the Laboratory's kilns to an average moisture content of 12 percent.

On removal from the kiln, the studs were allowed to cool for one day and were thenremeasured for length, crook, bow, and twist. The length of the studs that showed crook and bow was defined as the length of the chord connecting the ends on the concave face. This is a measure of the maximum usable length of the stud if it were cut squarely and parallel on both ends.

Moisture content measurements taken at this time on 5 percent of the studs with an electric resistance -type moisture meter showed that average moisture content was at or slightly below 12 percent. When all kiln-dried studs had been remeasured, they were planed on four sides in a standard molder to finished dimensions (1-1/2 by 3-1/2 in.).

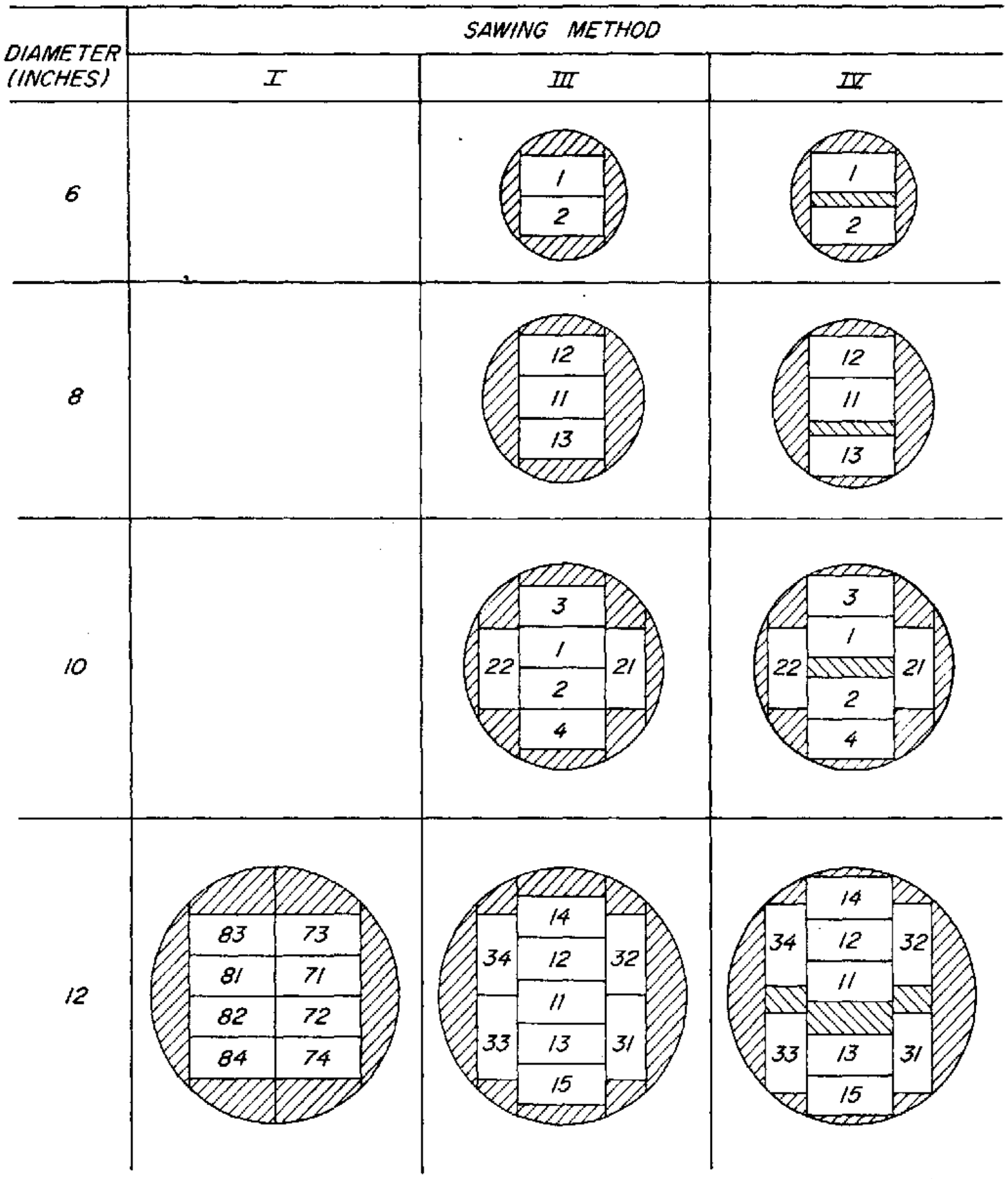

Figure 5. --Numbering system used to identify studs and their positions in a log.

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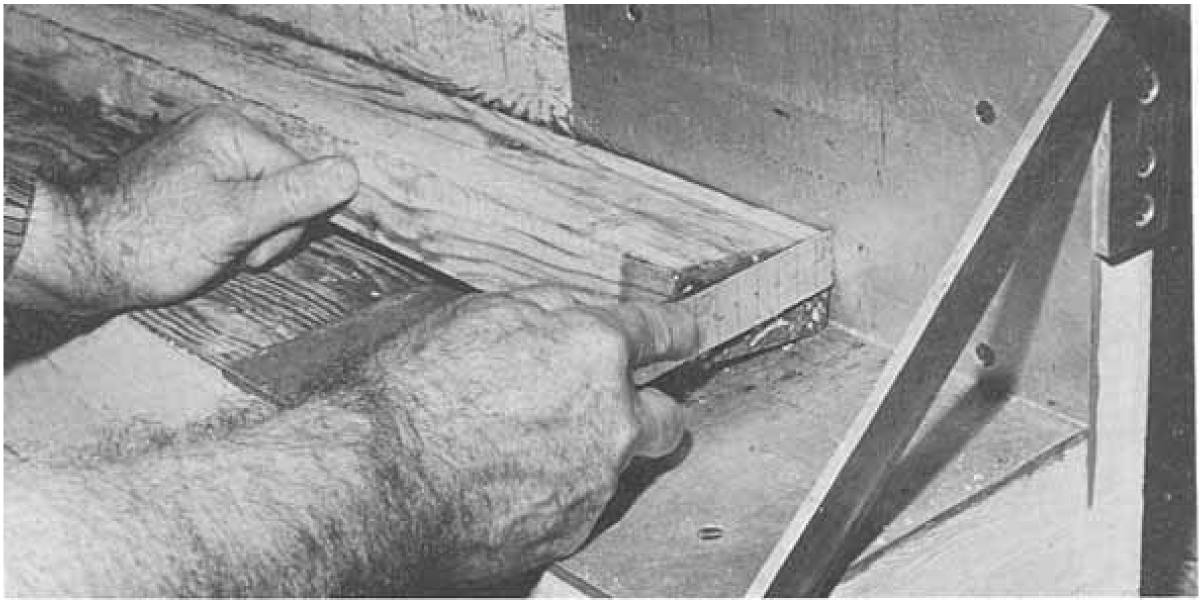

Figure 6.--Measuring the length of a stud; metal panel immediately behind stud is graduated in increments of 1/32 inch.

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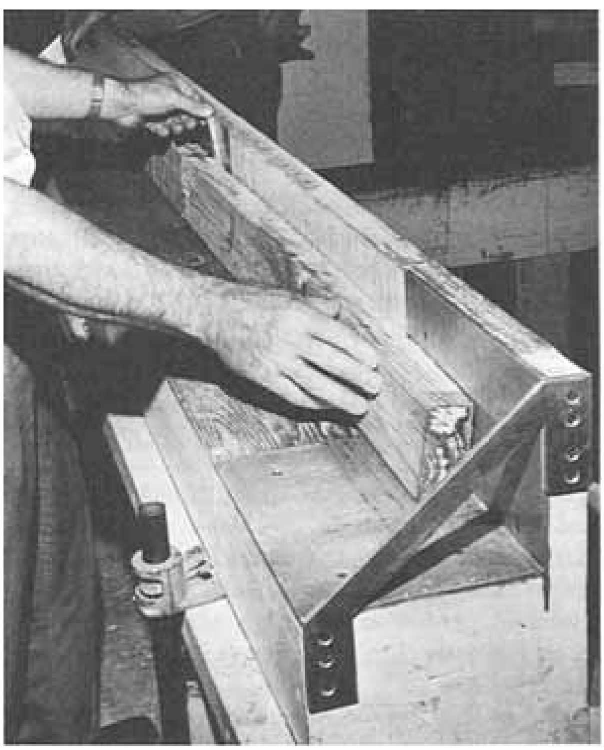

Figure 7.--Measuring crook in a stud; amount of deflection is read on a tapered wedge gage.

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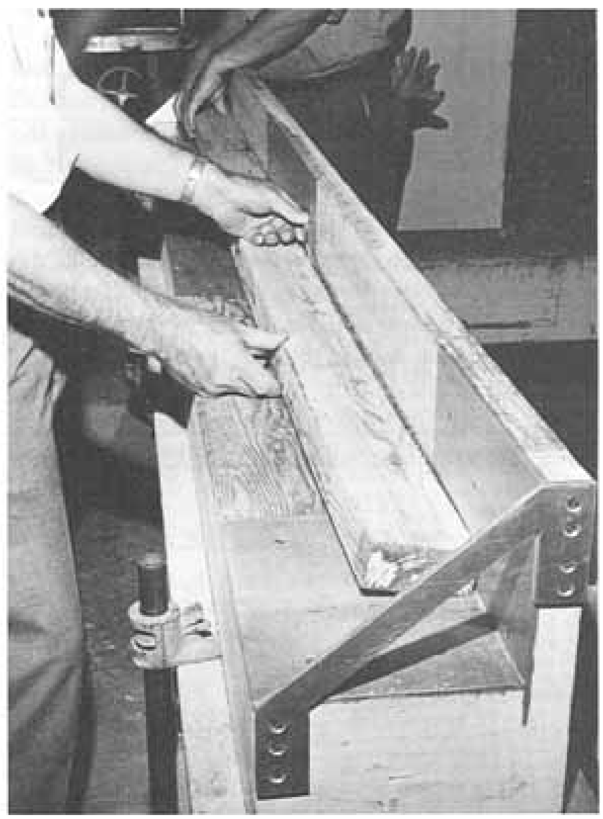

Figure 8.--Measuring bow in a stud.

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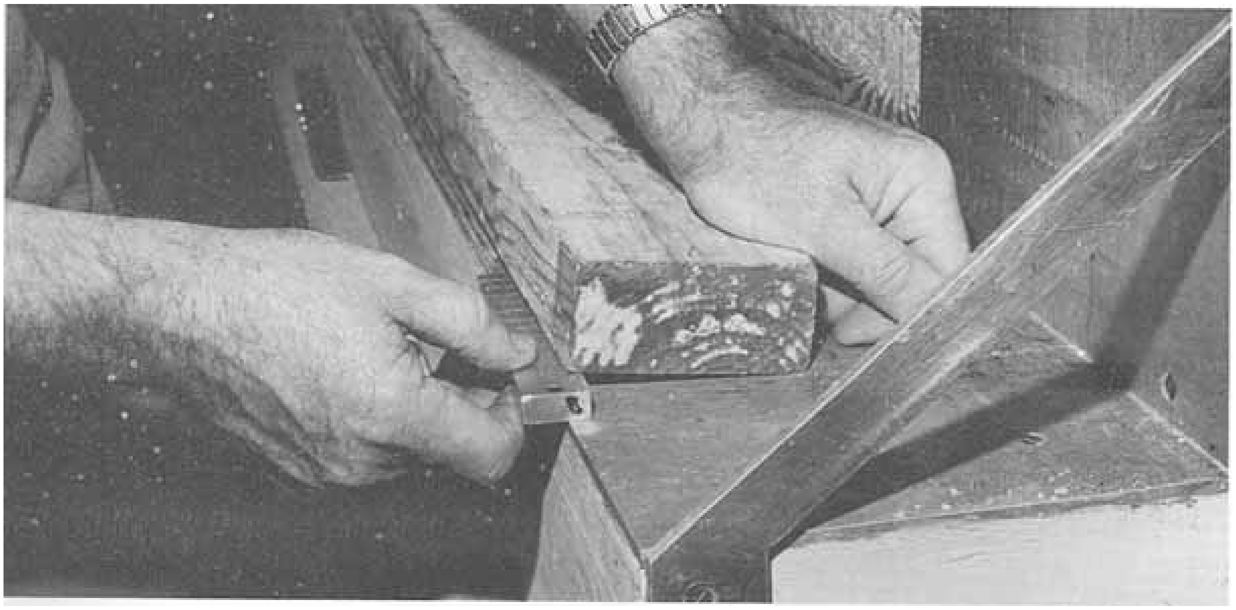

Figure 9.--Measuring twist in a stud; end of stud not shown is held flat to the table.

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Analysis of Data

All data were punched on cards, and analyses were made on the Laboratory's computer. In most analyses, two criteria were used to evaluate the relationships of the variables to the amount of warp: The percentage of studs that met the "stud" grade limitation of the Northern Hardwood and Pine Manufacturers Association (table 1); and the mean crook, bow, or twist for each treatment or for a combination of independent variables. Each criterion was tested by analysis of variance procedures.

All effects reported here were statistically significant at the 0.05 level unless otherwise noted.

Table 1.--Warp limitations for stud grades[1]

Grade	Crook	Bow	Twist
	In.	In.	In.
Stud	0 - 8/32	0 - 24/32	0 - 12/32
Below grade	9/32 - or more	25/32 - or more	13/32 - or more

[1]According to the National Grading Rules for Dimension Lumber. Product Standard 20-70 (American Softwood Lumber Standard) which has been accepted by the Northern Hardwood and Pine Manufacturers Association.

RESULTS AND DISCUSSION

Results are presented here by substudies, except for the effects of positions of studs in logs, which are discussed after Substudy 3. Sawing Methods III and IV (the commercial Scragg method and the FPL-improved Scragg method) are covered under all substudies. Substudy 2 includes all three sawing methods. The other variables are discussed under the substudies in which they were investigated.

Substudy I

In this study, examination was made of the relationship of Sawing Methods III and IV, of butt and upper logs of 6-, 8-, 10-, and 12-inch-diameter classes and of horizontal andvertical eccentricities to the subsequent warp in dry studs. Yields by percent of "stud" grade studs are shown in tables 2 through 5, and mean warp in tables 6 and 7.

Sawing methods.--Sawing Method IV resulted in a higher percentage of "stud" grade studs than Method III when crook was measured (table 2, 87.8 vs. 84.2 pct.). It was also superior at the 0.01 level when all warp was evaluated (table 5, 82.7 vs. 78.3 pct.).

The term "all warp" used throughout this report means the grade of the stud determined by considering the warp aspect that relegates a stud to its lowest grade classification. Thus, a stud with "stud" grade crook, "stud" grade bow, and below grade twist is below grade in terms of "all warp." The grade assigned under "all warp" is equivalent to its commercial grade.

Sawing Method IV was also superior to Method III in reducing twist, but the difference (table 4) was not quite significant at the 0.05 level.

Most of the increase inthe yield of "stud" grade studs by Method IV when crook is considered, is in studs from butt logs (table 2, butt logs 81.9 vs. 76.2 and upper logs 93.6 vs. 92.4 pct.). However, this interaction between sawing method and log position was just short of significant at the 0.05 level.

When bow and twist are considered, differences between Methods III and IV in the yield of "stud" grade studs were not significant. However, Method IV was superior in both cases (tables 3 and 4). These are very insensitive criteria because the bow limitations, 24/32 inch, and the twist limitations, 12/32 inch, for "stud" grade are very large, and few studs fail to make the grade. An interaction between sawing method and diameter is indicated by the fact that Method IV is better than Method III in yield of studs meeting "stud" grade from 6-inch-diameter logs (table 4), but shows almost no difference for the other diameters.

In addition to the percentage of studs making stud grade, these data were also analyzed in terms of mean warp. In some ways, this criterion more accurately reflects the true effect of the variables

Table.2.--Percent yield of "stud" grade studs meeting warp limits for crook (Substudy 1)

Diameter	Eccentricity	Butts III	Butts IV	Uppers III	Uppers IV	All logs[1] III	All logs[1] IV	Average all logs Methods III and IV
In.								
6	Vertical	71.9	89.7	100.0	100.0	86.6	94.9	90.7
	Horizontal	71.0	80.0	96.9	96.7	84.1	88.3	86.2
	Combined	71.4	84.7	98.5	98.3	85.4	91.6	88.5
8	Vertical	69.5	76.4	96.9	95.2	83.9	86.3	85.1
	Horizontal	74.6	76.2	98.2	97.0	85.5	86.9	86.2
	Combined	72.2	76.3	97.5	96.1	84.7	86.6	85.6
10	Vertical	75.3	78.4	91.8	98.9	83.8	88.9	86.3
	Horizontal	83.3	85.4	100.0	98.9	92.0	91.9	91.9
	Combined	79.1	82.1	95.8	98.9	87.7	90.4	89.0
12	Vertical	80.6	80.9	81.0	90.4	80.8	85.5	83.1
	Horizontal	74.1	86.6	90.2	84.4	81.8	85.5	83.6
	Combined	77.3	83.8	85.7	87.3	81.3	35.5	83.4
All[1]	Vertical	76.1	80.2	89.7	94.8	82.9	87.6	
	Horizontal	76.3	83.6	95.4	92.4	85.6	87.9	
	Combined	76.2	81.9	92.4	93.6	84.2	87.8	
	Combined[1]	79.1		93.0				

[1]Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

on warp in studs.

Sawing Method IV was superior to Method III in reducing the mean crook per stud (4.4/32 vs. 5.2/32). Most of this superiority was due to studs from butt logs (5.5/32 vs. 7.2/32 in. for butts compared to 3.2/32 vs. 3.3/32 in. for uppers) indicating an interaction between sawing method and log position (table 6).

When mean bow is considered, sawing method is not significant. Logs sawn with vertical eccentricity had a significantly lower mean bow when sawn by Method IV (6.2/32 in.) than when sawn by Method III (7.4/32 in,). Horizontal eccentricity showed no significant difference in bow between Method III (6.7/32 in.) and Method IV (table 7, 6.9/32 in.).

Mean twist was effectively reduced by Method IV (4.8/32 in.) as compared to Method III(5.6/32 in., table 6), a difference that is significant at the 0.01 level. This superiority was much more marked in studs sawn from logs with horizontal eccentricity than vertical eccentricity (table 7). indicating an interaction between sawing method and position of the eccentricity.

Log position (butts vs. uppers).--Log position had a significant effect (0.01 level) on the yield of studs meeting the "stud" grade warp limitation for crook, bow, twist, and all warp. Considering only crook, 79.1 percent of the studs from butt logs met "stud" grade requirements while 93.0 percent of those from upper logs did so (table 2). For bow, 96.7 percent of those from butts and 99.9 percent (table 3) from uppers met the requirements. Butt logs were superior to upper logs in yield of "stud" grade studs when twist is the criterion (97.6 pct. vs. 91.6 pct., table 4).

When all forms of warp are considered together, the superiority of studs sawn from upper logs

Table 3.--Percent yield of "stud" grade studs meeting warp limits for bow (Substudy 1)

Diameter	Eccentricity	Sawing Methods for-- Butts III	Butts IV	Uppers III	Uppers IV	All logs[1] III	All logs[1] IV	Average all logs Methods III and IV
In.								
6	Vertical	96.9	96.5	100.0	100.0	98.5	98.3	98.4
	Horizontal	93.5	96.7	100.0	100.0	96.8	98.3	97.5
	Combined	95.2	96.6	100.0	100.0	97.7	98.3	98.0
8	Vertical	93.2	96.4	100.0	100.0	96.8	98.3	97.5
	Horizontal	97.0	95.2	100.0	100.0	98.4	97.7	98.0
	Combined	95.2	95.8	100.0	100.0	97.6	98.0	97.8
10	Vertical	93.5	94.3	100.0	100.0	96.9	97.2	97.0
	Horizontal	94.0	95.8	100.0	100.0	97.1	97.8	97.4
	Combined	93.8	95.1	100.0	100.0	97.0	97.5	97.2
12	Vertical	97.0	100.0	100.0	100.0	98.4	100.0	99.2
	Horizontal	100.0	98.5	100.0	99.2	100.0	98.8	99.4
	Combined	98.5	99.2	100.0	99.6	99.2	99.4	99.3
All[1]	Vertical	95.3	97.4	100.0	100.0	97.6	98.7	
	Horizontal	97.2	96.9	100.0	99.7	98.5	98.3	
	Combined	96.2	97.1	100.0	99.8	98.1	98.5	
	Combined[1]	96.7		99.9				

[1] Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

with respect to crook is partially offset by the superiority of butts with respect to twist. Uppers, are however, superior by a margin of 85.4 percent to 75.7 percent for butts (table 5).

The advantage of butt logs over uppers in terms of reduced twist occurs primarily in the smaller diameters. For the larger diameter classes there is not much difference between logs from the two positions. This interaction was significant at the 0.01 level.

Another interaction was noted between log position and diameter when considering all-warp yields. Although upper logs were superior to butt logs in all size classes, the difference was much greater in the 8- and 10-inch-than in the 6- and 12-inch-diameter classes. This interaction appears to be illogical and probably is a chance occurrence.

The results when mean deflection is used as a criterion for evaluating warp are shown in table 6 and figure 10. Log position is significant at the 0.01 level in influencing crook, bow, and twist. Studs sawn from butt logs had more crook and bow than those from upper logs. When twist is considered, the situation is reversed with studs from uppers showing higher mean deflection than from butts (table 6).

Also significant at the 0.01 level for all three aspects of warp was an interaction between log position and diameter. Crook in studs from butt logs decreased with increased diameter, but the opposite was true in studs from upper logs. Bow in studs from butt logs also decreased with diameter, but was unaffected by diameter in upper logs (table 6). Studs from both butt and upper logs developed less twist as diameter increased. In

Table 4.--Percent yield of "stud" grade studs meeting warp limits for twist (Substudy 1)

Diameter	Eccentricity	Sawing Methods for: Butts III	Butts IV	Uppers III	Uppers IV	All logs[1] III	All logs[1] IV	Average all logs Methods III and IV
In.								
6	Vertical	87.5	93.1	62.9	70.0	74.6	81.4	78.0
	Horizontal	93.5	96.7	65.6	90.0	79.4	93.3	86.3
	Combined	90.5	94.9	64.2	80.0	76.9	87.4	82.1
8	Vertical	94.9	98.2	87.7	83.9	91.1	90.6	90.8
	Horizontal	95.5	96.8	86.0	94.0	91.1	95.4	93.2
	Combined	95.2	97.5	86.9	89.1	91.1	93.1	92.1
10	Vertical	100.0	96.6	96.9	94.6	98.4	95.6	97.0
	Horizontal	97.6	99.0	95.6	96.7	96.6	97.8	97.2
	Combined	98.9	97.8	96.3	95.6	97.5	96.7	97.1
12	Vertical	99.2	100.0	95.9	97.6	97.6	98.8	98.2
	Horizontal	97.8	98.5	95.1	92.2	96.5	95.4	95.9
	Combined	98.5	99.2	95.5	94.9	97.1	97.1	97.1
All[1]	Vertical	97.5	98.0	90.9	91.3	94.2	94.6	
	Horizontal	96.8	98.1	90.4	93.6	93.7	95.9	
	Combined	97.2	98.1	90.7	92.5	93.9	95.2	
	Combined[1]	97.6		91.6				

[1] Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

each diameter class studs from upper logs had greater twist but the difference in twist between studs from butt and upper logs decreased with increasing diameter (table 6).

Diameter.--Diameter had a significant effect at the 0.01 level on the percentage of studs meeting the twist and all-warp requirements of the "stud" grade. In the 6-inch-diameter class 82.1 percent of the studs met the twist requirements compared to 97.1 percent in the 12-inch class (table 4). Similar results were noted where all-warp was the criterion (table 5, 70.2 pct. for 6 in. vs. 80.8 pct. for 12 in.).

If mean warp of the stud is used as a criterion, both bow and twist were significantly (0.01 level) affected by log diameter. Mean twist decreased from 7.7/32 inch in the 6-inch-diameter class to 3.3/32 inch in the 12-inch-diameter class, A similar relationship exists for mean bow (table 6) decreasing from 8.3/32 in the 6-inch class to 5.4/32 in the 12-inch class.

Interactions between diameter and log position have already been noted.

Eccentricity position. -- Eccentricity was found to have no effect on warp when measured by the percent of studs meetingthe "stud" grade requirements. When the more sensitive mean warp is used as the measure, twist for horizontal eccentricity is significantly below that of vertical eccentricity (table 7, 4.9/32 in. vs. 5.4/32 in.).

An interaction between sawing method and eccentricity in relation to mean bow has already been discussed.

Table 5.--Percent yield of "stud" grade studs meeting all warp limits (crook, bow, twist) (Substudy 1)

Diameter	Eccentricity	Sawing Methods for --						Average all logs Methods III and IV
		Butts		Uppers		All logs[1]		
		III	IV	III	IV	III	IV	
In.								
6	Vertical	59.4	79.3	62.9	70.0	61.2	74.6	67.9
	Horizontal	67.7	73.3	62.5	86.7	65.1	80.0	72.5
	Combined	63.5	76.3	62.7	78.3	63.1	77.3	70.2
8	Vertical	64.4	74.5	86.2	80.6	75.8	77.7	76.7
	Horizontal	70.1	71.4	86.0	91.0	77.4	81.5	79.4
	Combined	67.5	72.9	86.1	86.0	76.6	79.8	78.2
10	Vertical	71.0	72.7	88.8	93.5	80.6	83.3	81.9
	Horizontal	82.1	82.3	95.6	95.6	89.1	88.7	88.9
	Combined	76.3	77.7	92.1	94.5	84.4	86.1	85.2
12	Vertical	78.4	80.9	78.5	88.8	78.4	84.8	81.6
	Horizontal	71.8	83.6	86.2	78.9	78.7	81.3	80.0
	Combined	75.1	82.3	82.4	83.8	78.6	83.0	80.8
All[1]	Vertical	71.7	77.2	81.5	86.7	76.6	82.0	
	Horizontal	73.8	79.9	86.5	87.0	80.0	83.4	
	Combined	72.8	78.6	83.9	86.9	78.3	82.7	
	Combined[1]	75.7		85.4				

[1] Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

Table 6.--Mean warp in increments of 1/32 inch by diameter classes of butt and upper logs for Sawing Methods III and IV[1] (Substudy 1)

Diameter	Crook			Bow			Twist		
	Butts	Uppers	All	Butts	Uppers	All	Butts	Uppers	All
In.									
SAWING METHOD III									
6	8.9	2.3	5.6	12.5	4.2	8.4	5.9	10.9	8.4
8	6.9	2.6	4.6	10.3	2.9	6.6	4.7	7.0	5.9
10	6.5	3.3	4.9	10.6	3.9	7.3	3.9	4.7	4.3
12	6.2	4.9	5.6	7.2	4.6	5.9	3.2	4.1	3.6
All	7.2	3.3	5.2	10.1	3.9	7.0	4.4	6.7	5.6
SAWING METHOD IV									
6	5.3	2.5	3.9	12.0	4.6	8.3	4.9	9.1	7.0
8	6.8	2.7	4.8	10.4	3.4	6.9	4.2	5.8	5.0
10	5.4	2.9	4.1	8.7	3.4	6.1	3.7	4.6	4.1
12	4.6	4.8	4.7	5.7	4.2	5.0	2.4	3.6	3.0
All	5.5	3.2	4.4	9.2	3.9	6.6	3.8	5.8	4.8
COMBINED SAWING METHODS III and IV									
6	7.1	2.4	4.8	12.3	4.4	8.3	5.4	10.0	7.7
8	6.9	2.6	4.8	10.3	3.2	6.8	4.5	6.4	5.4
10	5.9	3.1	4.5	9.7	3.7	6.7	3.8	4.6	4.2
12	5.4	4.8	5.1	6.4	4.4	5.4	2.8	3.9	3.3
All	6.3	3.3	4.8	9.7	3.9	6.8	4.1	6.2	5.1

[1] Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

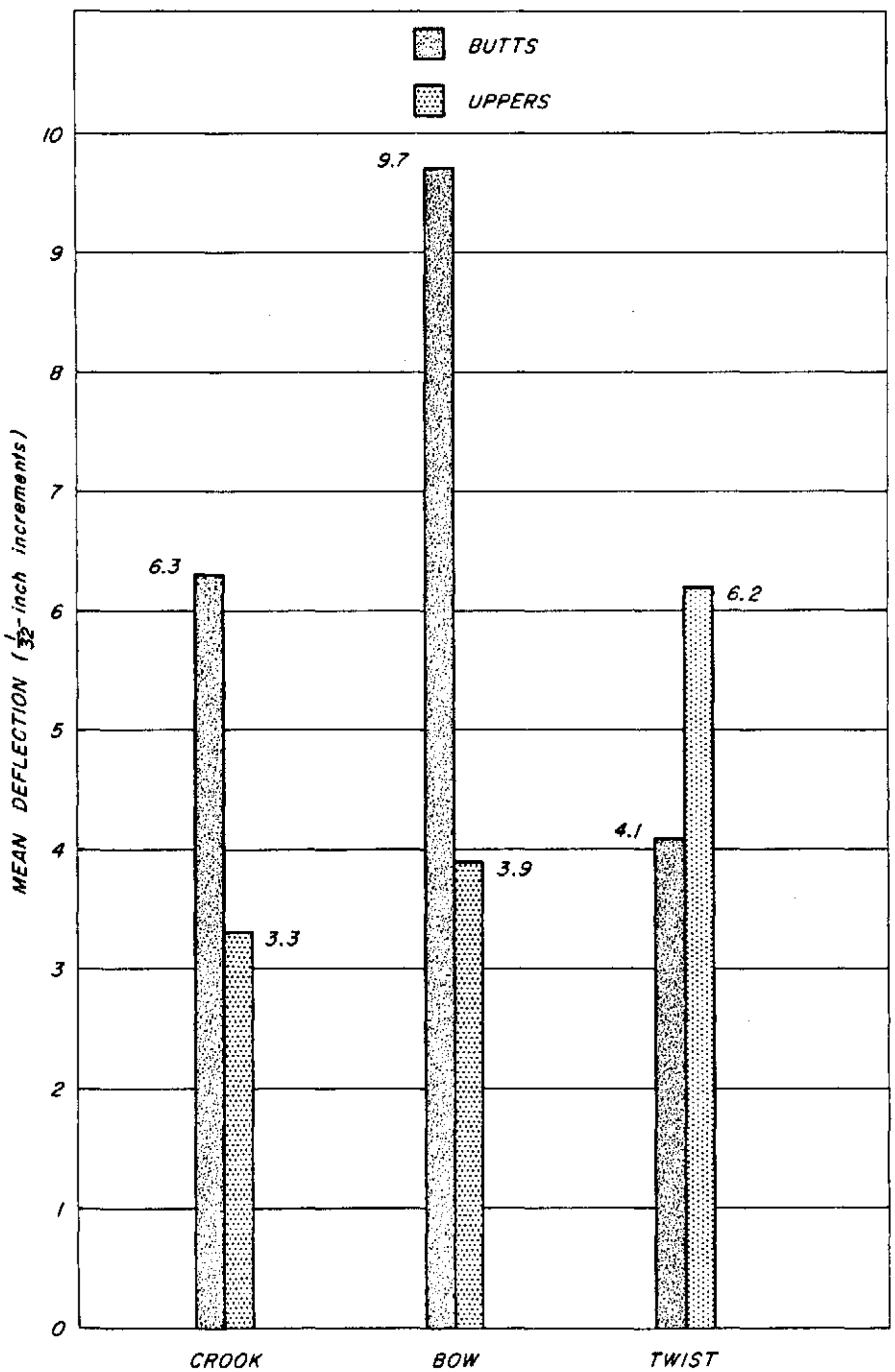

Figure 10.--Effect of log position on crook, bow, and twist for mean warp of all studs.

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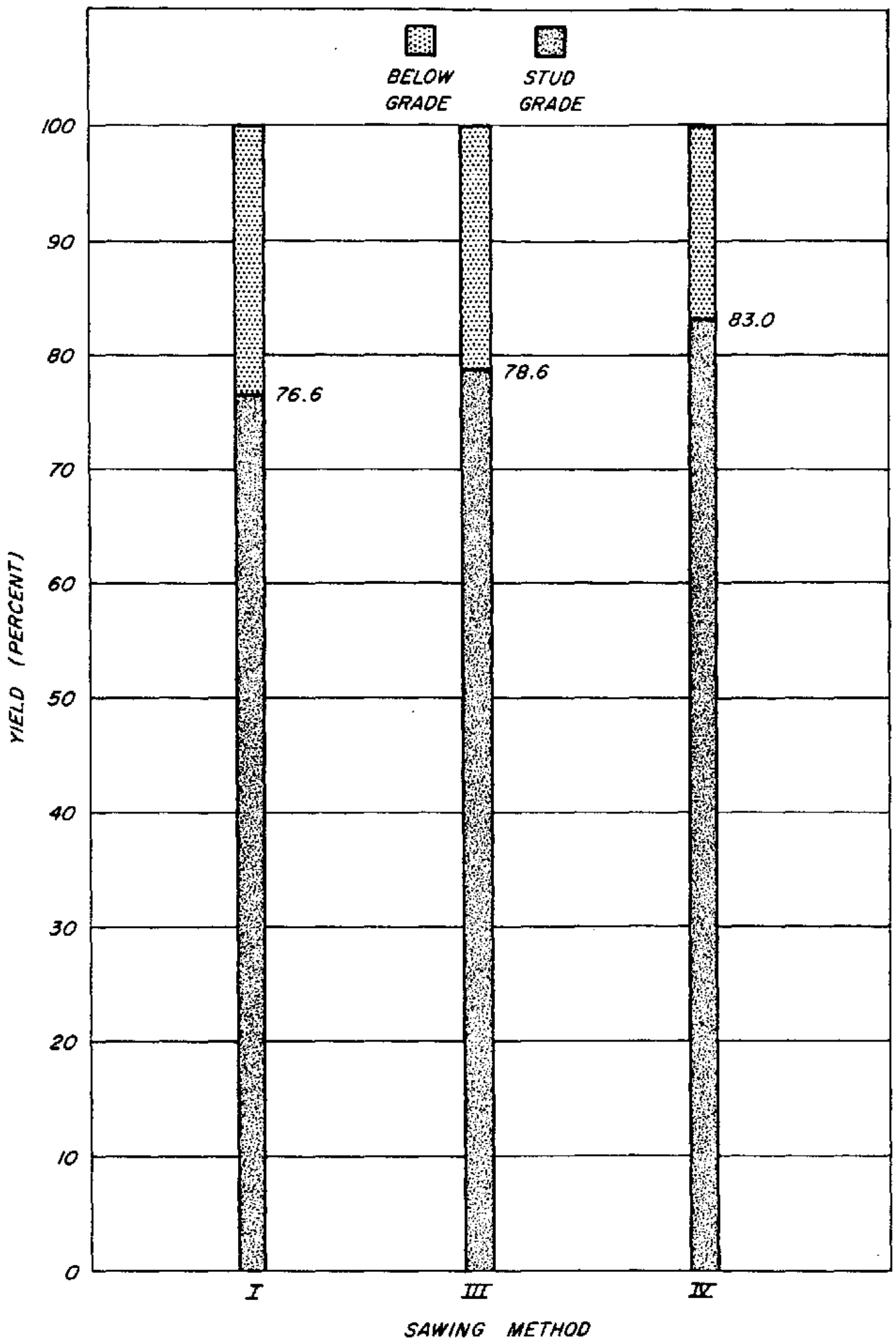

Figure 11.--Percent yields for sawing methods of studs meeting "stud" grade (National Grading Rules) from 12-inch logs (butts and uppers) in substudy 2.

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Table 7.--Mean warp in increments of 1/32 inch by eccentricity classes of butt and upper logs for Sawing Methods III and IV[1] (Substudy 1)

Eccentricity	Crook			Bow			Twist		
	Butts	Uppers	All	Butts	Uppers	All	Butts	Uppers	All
SAWING METHOD III									
Vertical	7.6	3.7	5.7	10.8	4.0	7.4	4.4	6.8	5.6
Horizontal	6.7	2.8	4.8	9.5	3.9	6.7	4.5	6.6	5.5
SAWING METHOD IV									
Vertical	5.7	2.9	4.3	8.9	3.6	6.2	4.2	6.2	5.2
Horizontal	5.3	3.6	4.5	9.5	4.2	6.9	3.3	5.3	4.3
COMBINED SAWING METHOD III and IV									
Vertical	6.7	3.3	5.0	9.8	3.8	6.8	4.3	6.5	5.4
Horizontal	6.0	3.2	4.6	9.5	4.0	6.8	3.9	6.0	4.9

[1]Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

Substudy 2

Substudy 2 was a comparison of Sawing Method I with Methods 111 and IV in butt and upper logs of horizontal and vertical eccentricities in only the 12-inch-diameter class. Yields in percent of studs meeting "stud" grade requirements are shown in table 8 and figure 11. Values for mean crook, bow, and twist are given in tables 9 and 10.

Sawing Method I versus Methods III and IV.--In terms of the percent of studs which met "stud" grade requirements for crook, both Methods III and IV gave better recoveries than Method1 (table 8, Method I, 77.5 pct.; Method III, 81.5 pct.; Method IV, 85.6 pct.). The same relationship was also found in terms of studs meeting all-warp limits ofthe "stud" grade (76.6, 78.7, and 83.0 pct., respectively). However, neither of these relationships was statistically significant.

In terms of mean warp of the studs, Sawing Method III yielded studs with more bow (5.9/32 in.) than Method I (5.1/32 in.), or Method IV (5.0/32 in.). Sawing Method IV proved best in reducing twist with a mean of 3.0/32 inch compared to 3.6/32 inch for Method III and 3.7/32 inch for Method I (table 9).

Studs sawn from butt logs showed the least crook when sawn by Method IV and did not appear to be affected by the eccentricity position (table 10) as compared to those from Methods III and I. Studs sawn from upper logs did appear to be influenced by eccentricity. When upper logs were sawn with the eccentricity vertical, Sawing Method IV resulted in studs with the least crook and Method III with the greatest. Quite different results were obtained, however, when upper logs were sawn with the eccentricity horizontal: Method III produced the least crook, followed by Method1

Table 8.--Percent yields of "stud" grade studs from 12-inch-diameter logs[1] (Substudy 2)

Sawing Method	Eccentricity in--								
	Butts			Uppers			All logs		
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined
				CROOK					
I	60.8	67.5	64.2	92.4	89.2	90.8	76.6	78.3	77.5
III	80.6	74.1	77.3	81.0	90.2	85.7	80.8	82.1	81.5
IV	80.9	86.6	83.8	90.4	84.4	87.3	85.6	85.5	85.6
All	74.1	76.1	75.1	87.9	87.9	87.9	81.0	82.0	81.5
				BOW					
I	100.0	98.3	99.2	100.0	100.0	100.0	100.0	99.1	99.6
III	97.0	100.0	98.5	100.0	100.0	100.0	98.5	100.0	99.2
IV	100.0	98.5	99.2	100.0	99.2	99.6	100.0	98.8	99.4
All	99.0	98.9	99.0	100.0	99.7	99.9	99.6	99.2	99.4
				TWIST					
I	99.2	99.2	99.2	99.1	97.5	98.3	99.1	98.3	98.8
III	99.2	97.8	98.5	95.9	95.1	95.5	97.6	96.4	97.0
IV	100.0	98.5	99.2	97.6	92.2	94.9	98.8	95.3	97.1
All	99.5	98.5	99.0	97.5	94.9	96.2	98.5	96.7	97.6
				ALL WARP					
I	60.8	66.7	63.7	92.4	86.7	89.5	76.6	76.7	76.6
III	78.4	71.8	75.1	78.5	86.2	82.4	78.4	79.0	78.7
IV	80.9	83.6	82.3	88.8	78.9	83.8	84.8	81.2	83.0
All	73.4	74.0	73.7	86.6	83.9	85.2	80.0	78.9	79.4

[1]Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

and Method IV (table 10).

Log position--There was no statistically significant difference in the yield of studs meeting the "stud" grade warp limits from butt and upper logs. It should be noted, however, that upper logs in every case (table 8) produced a higher percentage of studs meeting the "stud" grade requirement for both crook and all-warp than butt logs.

Mean warp of studs showed that log position influenced all forms of warp. These relationships were significant at the 0.01 level. Studs from butt logs were found to have a greater mean crook than those from upper logs. A similar relationship was noted for bow. When twist was measured, however, studs from butts showed less than those from uppers (table 10).

An interaction between log position and eccentricity was noted when measured by mean bow. Studs sawn from butt logs with the eccentricity horizontal had less bow than those sawn with the eccentricity vertical. Just the opposite situation is noted in upper logs, with the studs sawn from

Table 9.--Mean warp in increments of 1/32 inch in studs from 12-inch logs[1] (Substudy 2)

Warp	Log position	Sawing Method I	III	IV	All
Crook	Butts	7.5	6.2	4.6	6.1
	Uppers	4.3	4.9	4.8	4.7
	All	5.9	5.6	4.7	--
Bow	Butts	5.7	7.2	5.7	6.2
	Uppers	4.5	4.6	4.2	4.3
	All	5.1	5.9	5.0	--
Twist	Butts	3.4	3.2	2.4	3.0
	Uppers	4.0	4.1	3.6	3.9
	All	3.7	3.6	3.0	--

[1]Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

vertical eccentricity logs showing lower mean bow than those from horizontal eccentricity logs (table 10).

Eccentricity.--Eccentricity by itself was not a factor in influencing either the percentage of studs meeting the stud grade requirement or mean warp. In combination with log position it is a factor in an interaction already described.

Substudy 3

Examined in this study was the relationship of the presence or absence of compression wood visually evident on the log ends, of 8- and 10-inch-diameter butt logs, of Sawing Methods III and IV, and of horizontal and vertical eccentricities to the subsequent warp in dry studs. Yields of "stud" grade studs are shown in table 11, and mean warp values are presented in table 12.

Compression wood.--Although the presence of compression wood reduced the percentage of studs meeting the "stud" grade requirements, results were statistically significant only in the case of bow, Logs without visible compression wood yielded 95.2 percent "stud" grade compared to 92.1 percent from logs with evident compression wood (table 11).

When mean warp was used as the criterion for evaluation, compression wood in combination with sawing method appeared to affect the severity of bow. In studs sawn from logs with compression wood, Sawing Method IV effectively reduced the mean bow to less than that of Sawing Method III (table 12). In logs without compression wood, there was very little difference between mean bow from Sawing Methods III and IV.

Sawing method.--Sawing Method IV yielded a higher percentage of studs meeting "stud" grade requirements for crook than did Method III. Method IV was also superior in bow and twist but the difference here was not significant (table 11).

Sawing Method IV was superior to Method III when evaluated by mean bow and by mean twist (table 12).

Diameter.--Ten-inch-diameter logs yielded a higher percentage of studs meeting the crook, bow, twist, and all-warp limitations of "stud" grade than did 8-inch logs, but the difference was not statistically significant.

Studs from 10-inch-diameter logs had less mean bow than studs from 8-inch logs. This was also true for twist, which was found to be significant at the 0.01 level (table 12).

Eccentricity.--Eccentricity had no significant effect on either the yield of "stud" grade studs or their mean crook (table 13).

Table 10.--Mean warp in increments of 1/32 inch in studs from 12-inch logs[1] (Substudy 2)

Warp	Eccentricity	Sawing Method I	III	IV	All
		BUTTS			
Crook	Vertical	7.9	6.2	5.1	6.4
	Horizontal	7.2	6.4	4.3	5.9
	All	7.5	6.2	4.6	6.1
Bow	Vertical	5.6	7.9	6.1	6.5
	Horizontal	5.8	6.6	5.3	5.8
	All	5.7	7.2	5.7	6.2
Twist	Vertical	3.7	2.9	2.7	3.1
	Horizontal	3.1	3.5	2.1	2.9
	All	3.4	3.2	2.4	3.0
		UPPERS			
Crook	Vertical	4.1	6.1	3.4	4.5
	Horizontal	4.5	3.7	6.3	4.8
	All	4.3	4.9	4.8	4.7
Bow	Vertical	4.1	4.9	3.3	4.1
	Horizontal	5.0	4.3	5.3	4.8
	All	4.5	4.6	4.2	4.4
Twist	Vertical	3.7	3.8	3.4	3.6
	Horizontal	4.4	4.4	4.0	4.2
	All	4.0	4.1	3.6	3.9

[1] Averages in "All" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

Table 11.--Percent yield of studs from 8- and 10-inch logs meeting stud grade warp limits[1] (Substudy 3)

Diameter	Compression wood	Sawing Method III				Sawing Method IV				Combined Sawing Methods III and IV			
		Crook	Bow	Twist	All warp	Crook	Bow	Twist	All warp	Crook	Bow	Twist	All warp
In.													
8	Yes	69.3	88.2	96.1	61.4	74.6	91.2	98.2	68.4	71.9	89.7	97.1	64.9
	No	71.9	97.4	94.7	68.4	78.9	94.3	98.4	75.6	75.4	95.8	96.5	72.0
	All	70.6	92.8	95.4	64.9	76.7	92.8	98.3	72.0	73.6	92.8	96.8	68.4
10	Yes	74.8	91.8	98.3	70.3	83.4	97.2	98.3	80.1	79.1	94.5	98.3	75.2
	No	78.4	94.0	97.8	72.4	85.1	95.4	97.7	81.6	81.7	94.7	97.7	77.0
	All	76.6	92.9	98.0	71.3	84.2	96.3	98.0	80.8	80.4	94.6	98.0	76.0
All	Yes	72.0	90.0	97.2	65.8	79.0	94.2	98.2	74.2	75.5	92.1	97.7	70.0
	No	75.1	95.7	96.2	70.4	82.0	94.8	98.0	78.6	78.5	95.2	97.1	74.5
	All	73.6	92.8	96.7	68.1	80.5	94.5	98.1	76.4	77.0	93.6	97.4	72.2

[1]Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

Relationship of Position of Stud in Log to Warp

Table 14 shows the percentage of studs from the inner and the outer areas of the log which met the limits of “stud” grade for crook, bow, twist, and all-warp by diameter and by sawing method.

For Method I, studs Nos. 71, 72, 81, and 82 were considered inner. For Methods III and IV, stud numbers considered inner were as follows: 8-inch, No. 11; 10-inch, Nos. 1 and 2; 12-inch, Nos. 11, 12, and 13 (fig. 5). All other studs were considered outer. A separation of the studs from 6-inch logs into inner and outer categories was not possible because only two studs were involved, and both were in approximately the same relative position in the log.

For Methods III and IV, the increased yield of studs from the outer area meeting the “stud” grade crook limits was significantly higher (0.01 level) than from the inner area (table 14). The difference between the percentage of inner and outer studs meeting the crook limits decreased with increasing diameter. A similar relationship existed for log position also with uppers showing more favorable results.

The position of the stud in the log did not seem to affect the percentage of studs meeting the bow limits of “stud” grade. However, this probably really reflects the very liberal bow limits resulting in 90 to 100 percent compliance of the studs in all categories.

Twist in studs sawn by Methods III and IV was significantly more severe (0.01 level) from the inner area in terms of the percentage of studs meeting the twist limits of “stud” grade. Using the same criterion, the inner studs from small logs twisted significantly more (0.01 level) than from the larger logs. Similarly, inner studs from upper logs twisted significantly more (0.01 level) than those from butt logs when compared to outer studs from the same respective log position (table 14).

When all aspects of warp are considered together, a significantly higher (0.01 level) percentage of those from the outer area, when sawn by Methods III and IV, meet the all-warp “stud” grade limits. Significantly fewer (0.01 level) studs from the inner area of small logs meet the stud grade requirements than from the same area in larger logs (table 14).

A substantially lower percentage of studs from

Table 12.--Mean warp in increments of 1/32 inch in studs from 8- and 10-inch logs[1] (Substudy 3)

Diameter	Compression wood	Sawing Method III: Crook	Sawing Method III: Bow	Sawing Method III: Twist	Sawing Method IV: Crook	Sawing Method IV: Bow	Sawing Method IV: Twist	Combined Sawing Methods III and IV: Crook	Combined Sawing Methods III and IV: Bow	Combined Sawing Methods III and IV: Twist
In.										
8	Yes	7.8	13.2	5.1	6.4	9.8	4.3	7.1	11.5	4.7
	No	6.5	8.9	5.0	6.2	10.8	4.2	6.4	9.9	4.6
	All	7.1	11.1	5.1	6.3	10.3	4.3	6.7	10.7	4.7
10	Yes	7.8	10.5	4.1	4.9	7.5	3.4	6.3	9.0	3.8
	No	6.2	9.7	3.7	4.3	8.4	3.6	5.2	9.1	3.6
	All	7.0	10.1	3.9	4.6	8.0	3.5	5.8	9.1	3.7
All	Yes	7.8	11.9	4.6	5.7	8.6	3.9	6.7	10.2	4.3
	No	6.3	9.3	4.4	5.3	9.6	3.9	5.8	9.5	4.1
	All	7.1	10.6	4.5	5.5	9.1	3.9	6.3	9.9	4.2

[1] Averages in "All" and "Combined" columns are not necessarily the arithmetic mean of the other tabular values because they are weighted by the actual number of studs in each class.

Table 13.--Mean warp and percent "stud" grade yield for crook in studs from 8- and 10-inch logs (Substudy 3)

Diameter	Compression wood	Eccentricity	Mean crook	Stud grade
In.				Pct.
8	Yes	Vertical	7.7	65.2
		Horizontal	6.5	78.3
	No	Vertical	6.2	80.5
		Horizontal	6.5	70.8
10	Yes	Vertical	5.4	80.0
		Horizontal	7.2	77.4
	No	Vertical	6.4	76.2
		Horizontal	4.1	87.1

the inner area as compared to the outer area of 12-inch-diameter butt logs sawn by Method I met the croak requirements of "stud" grade, but the difference was not statistically significant. The stud position in the log did not appear to affect the incidence or severity of bow. It may have a slight effect on twist in upper logs but is not statistically significant (table 14).

Table 14.--Percent yield of "stud" grade studs €or inner and outer positions

Diameter	Sawing Method	Crook Inner	Crook Outer	Bow Inner	Bow Outer	Twist Inner	Twist Outer	All warp Inner	All warp Outer
In.									
				BUTTS					
8	III	27	84	92	94	85	98	20	79
	IV	51	89	93	93	95	100	44	85
10	III	56	84	96	91	93	100	50	79
	IV	70	90	94	97	95	99	64	88
12	III	71	80	99	98	97	99	68	79
	IV	81	85	99	99	98	100	78	85
All	III and IV	59	86	96	96	94	100	54	82
				UPPERS					
8	III	92	100	100	100	46	99	46	99
	IV	83	99	100	100	65	96	52	95
10	III	90	98	100	100	85	100	75	98
	IV	98	99	100	100	85	100	83	99
12	III	83	87	100	100	87	100	74	87
	IV	82	90	100	99	85	100	72	90
All	III and IV	88	96	100	100	76	99	67	95
				BUTTS AND UPPERS					
8	III and IV	63	93	96	97	73	98	41	90
10	III and IV	78	93	98	97	90	100	68	91
12	III and IV	80	86	99	99	92	100	73	85
All	III and IV	73	91	98	98	85	99	60	88
				BUTTS					
12	I	43	85	100	98	98	100	43	84
				UPPERS					
12	I	91	91	100	100	96	100	88	91
				BUTTS AND UPPERS					
12	I	67	83	100	99	97	100	65	87

SUMMARY

Large volumes of plantation-grown red pine logs will soon be available to Lake States and Northeastern sawmills. This study investigated the relations of sawing method and other related variables to the warp in nominal 2-inch by 4-inch studs sawn from these logs. Other variables included the position of the stud in the log, log diameter, log position in the tree, the presence of compression wood in the log and the rotational position of the log cross-sectional eccentricity with respect to the sawing pattern.

A total of 660 logs were sawn into 3,609 studs on the sawmill at the Forest Products Laboratory; the studs were kiln dried to an average moisture content of 12 percent. After drying the studs were measured and evaluated to determine crook, bow, and twist. Both mean warp and percentage of studs meeting the "stud" grade warp requirements of the new National Grading Rules were used as evaluation criteria.

Diameters used were 6-, 8-, 10-, and 12-inches inside bark on the small end of the log. Logs were classified as butts or uppers. Compression wood logs were those with sufficient compression wood to be visible on one or both ends.

Logs were sawn according to two commercial and one experimental sawing method with each applied to an equal number of logs in which eccentricity (longest radius) was oriented horizontally and vertically.

The experimental sawing method proved superior to the regular Scragg method in terms of the percentage of studs meeting the "stud" grade warp requirements, Both methods were superior to the conventional method. Similar results were also indicated when mean warp was used as a criterion. The experimental sawing method proved especially effective in reducing crook and twist but had little effect on bow.

More studs from upper logs met crook and bow limits of "stud" grade than from butts; the reverse was true when considering twist. The same relationship was observed when mean warp was evaluated.

Diameter affected the percentage of studs meeting all of the warp limits of "stud" grade with the larger diameters giving the higher recoveries. Diameter had a similar effect on mean bow and twist.

The position of the eccentricity when sawing did not seem to have any significant effect on either grade yields or mean warp.

Although the presence of compression wood in the log consistently reduced the yield of studs meeting the crook, bow, and twist limits of "stud" grade, it was significant only in the case of bow. Evaluation based on mean warp gave similar results.

Studs from the inner area of the log consistently showed more severe crook and twist but bow appeared to be unaffected. When all facets of warp were considered, a substantially higher percentage of the studs from the outer area met the "stud" grade criteria than from the inner area.

Recommendations to the Industry

From this research the following recommendations are made to sawmills producing studs from plantation-grown red pine logs.

1 Use of the FPL improved Scragg sawing method should be seriously considered. This practice can result in at least 5 percent greater recovery of "stud" grade studs than either of the other commonly used methods.

2. If crook is a major problem, it can be reduced by sawing only upper logs. Butt logs could be cut longer and sawn into dimension lumber 6 inches and wider which has less inherent tendency to warp.

3 If twist is a major problem, it can be reduced by increasing the percentage of butt logs and by increasing the average diameter of the log mix

4. Rotating the logs to any special position relative to eccentricity will probably have little effect on warp.

LITERATURE CITED

1. Cockrell, R. A.
   1943. Some observations on density and shrinkage of ponderosa pine wood. Amer. Soc. Mech. Engin. Trans. 65: 729-739, 10 pp., illus.
2. ______
   1949. Further observations on longitudinal shrinkage of softwoods. Forest Prod. Res. Soc. Proc. 1949. 455-459.
3. Du Toit, A. J.
   1963. A study of the influence of compression wood on the warping of Pinus radiata D. Don. timber. S. African Forestry J. No. 44: 11-15.
4. Englerth, G. H., and Smith, W. R.
   1954. Guide for grading southern pine logs. Southeastern Forest Exp. Sta., Asheville, N.C. July.
5. Hallock, H.
   1965. Sawing to reduce warp of loblolly pine studs. U.S. Forest Serv. Res. Pap. FPL 51, 52 pp., illus. Forest Prod. Lab., Madison, Wis.
6. ______
   1969. Sawing to reduce warp of lodgepole pine studs. U.S. Forest Serv. Res. Pap. FPL 102, 32 pp., illus. Forest Prod. Lab., Madison, Wis.
7. King, Woodrow W.
   1954. Cause of and remedy for warped southern yellow pine 2 x 4's. Texas Forest Serv. Circ. No. 37, 19 pp., illus.
8. ______
   1954. Alleviating bow and crook in southern yellow pine dimension with chemicals. Forest Prod. J. IV(5): 271-276.
9. Kotok, E. S.
   1967. Tree characteristics influence 2 x 4 stud yield of lodgepole pine. U.S. Forest Serv. Res. Note INT-63, 8 pp., Intermountain Forest and Range Exp. Sta., Ogden, Utah.
10. Kloot, N. H., and Page, M. W.
    1959. A study of distortion in radiata pine scantlings. Commonwealth Sci. and Ind. Res. Organ. Div. Forest Prod. Tech. Pap. No. 7, Melbourne, Australia, 24 pp.
11. Malcolm, F. B.
    1968. Warp in studs from small-diameter loblolly pine. Southern Lumberman Vol. 216 No. 2687.
12. ______
    1968. Sacrificing short butt logs to chips may reduce lodgepole stud warping. Forest Industries 95(5).
13. Paul, Benson H.
    1960. The juvenile core in conifers. Tappi 43(1): 1-2.
14. Paul, Benson H., and Sweet, C. V.
    1956. Quality control in manufacture of lumber from second growth. Rep. 1781, U.S. Forest Prod. Lab., Madison, Wis.
15. Pillow, M. Y.
    1930. Compression wood cause of bowing and twisting. Wood Working Ind. 8(5): 26-27.
16. Rudolf, Paul.
    1950. Forest plantations in the Lake States. USDA Tech. Bull. 1010, USDA, Washington, D.C.
17. U.S. Forest Products Laboratory
    1955. Wood handbook, U.S. Dept. Agr., Agr. Handbook No. 72, 528 pp.
18. ______
    1960. Longitudinal shrinkage of wood. Rep. 1093, U.S. Forest Prod. Lab., Madison, Wis.
19. Zobel, B., Webb, C., and Henson, F.
    1959. Core or juvenile wood of loblolly and slash pine trees. Tappi 42(5): 345-356.

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