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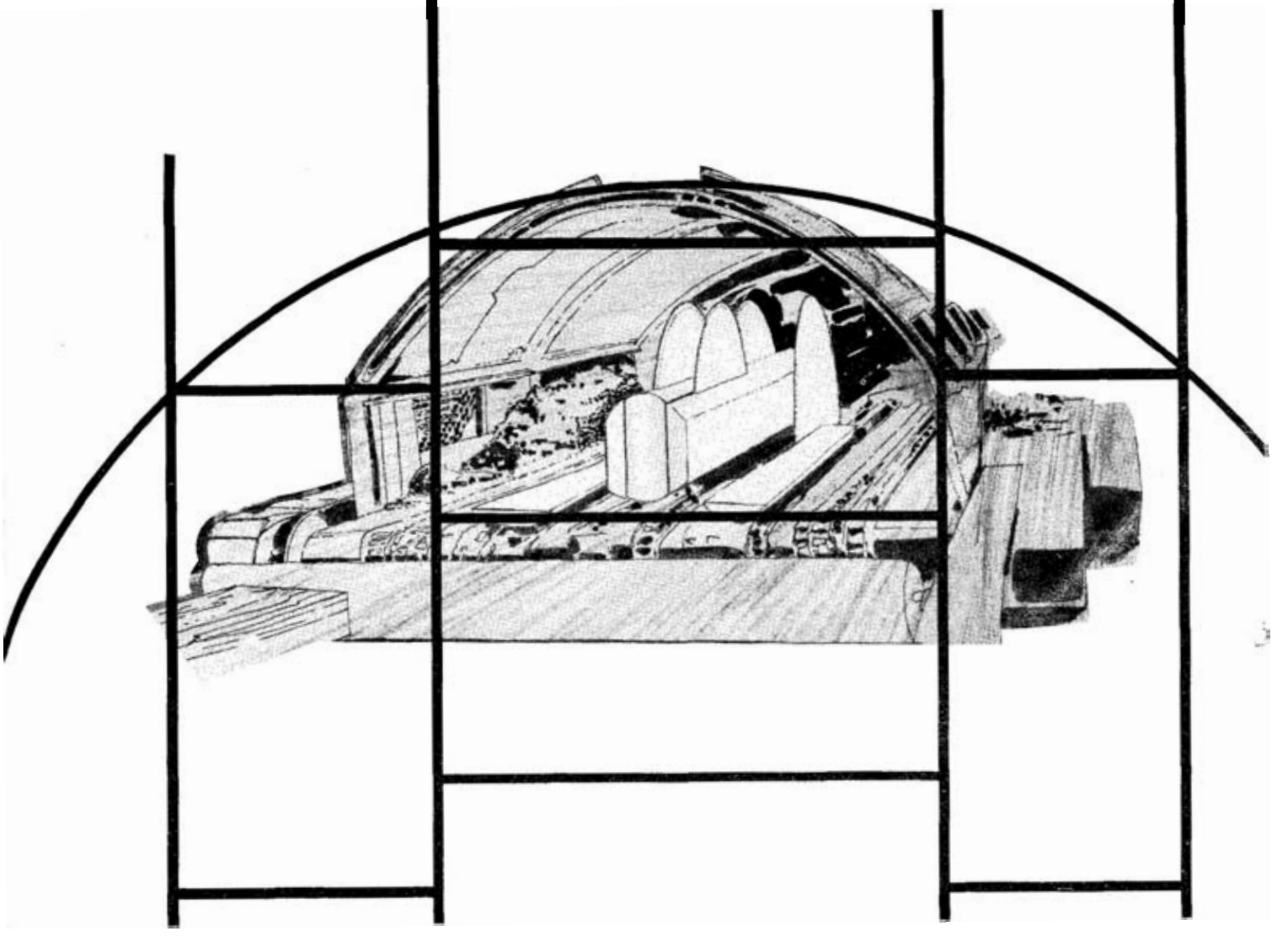
SAWING TO REDUCE WARP OF LOBLOLLY PINE STUDS



SUMMARY

Sawing and related variables are investigated in relation to warp of 2- by 4-inch studs sawn from small loblolly pine logs. Included were sawing method, position of the stud in the log, rotational position of log eccentricity, log diameter, log position in the tree, juvenile core diameter, and presence of compression wood in the log.

A total of 432 logs were sawn into 2,342 studs on the Forest Products Laboratory mill and kiln dried to an average moisture content of 12 percent. After studs were dried and planed, they were measured and evaluated to determine crook, bow, twist, moisture content, length, and grade,

Diameters used were 6, 8, 10, and 12 inches (inside bark) on the small end. Logs were classified as butts or uppers. Compression wood logs were those with sufficient compression wood to he visible on one or both log ends. Logs were sawn according to two commercial and two experimental sawing methods or patterns, each applied to logs whose eccentricity was oriented horizontally and vertically.

The four sawing methods influenced the three aspects of warp differently. Some reduced crook and increased bow while others resulted in the opposite situation. Crook was the overriding aspect of warp in meeting Southern Pine Inspection Bureau grades. One of the experimental sawing methods, Method IV, proved best in reducing crook and thus was best in overall control of warp.

With slight variations, crook and bow of studs significantly decreased with increased distance from the center of the log, both for butt and upper logs. This same relationship exists for twist in upper logs.

Consistently less warp resulted by orienting log eccentricity horizontally when sawing butt logs, and vertically when sawing upper logs.

Studs from butt logs developed considerably more crook and bow than those from upper logs. For twist the reverse was true. Log diameter appeared to have a definite influence on warp in upper logs, but not in butt logs.

Presence of compression wood resulted in significantly more warp in studs from both butt and upper logs. No significant relation was found between juvenile core diameter and the degree of warp of the studs.

In addition a 10 percent sample was strapped in two packages and stored for 90 days in a shed to evaluate changes occurring in storage. The majority of these studs increased in length, increased in crook, decreased in bow, and increased in twist. While decreased length is generally associated with increased warp as would be expected, the reverse also occurred with some 25 percent of the studs.

Analysis of all data indicated a new sawing method, the FPL Improved Method, would be better than the four used in this study. Procedures are given for sawing logs of various sizes with this new method.

A section outlining the direct commercial application of this research concludes the paper.

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The U.S. Forest Products Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

SAWING TO REDUCE WARP OF LOBLOLLY PINE STUDS

by HIRAM HALLOCK, Technologist

FOREST PRODUCTS LABORATORY
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

In the lumber market today, emphasis on high-quality items often results in the rejection of warped pieces of lumber. Not only is there greater awareness of warp, but some evidence of more warp occurring in recent years. If research can discover means of preventing ox reducing warp, it will. be of great value to both industry and consumers,

One of the reasons for 'increasing warp is the change in American forests from old-growth trees to second growth. Second growth, with its faster growth rate and generally small diameter, yields lumber with much higher warping tendencies. That warp in second growth is a greater problem than in old growth is evident from an examination of grading rules published by the various associations of lumber manufacturers. In most grading rules, specific limits on warp have only been included in recent years.

In the past, researchers have tried to reduce warp through improved lumber piling methods, including edge stacking of dimension and drying under restraint. Air drying practices and kiln schedules have been rather thoroughly investigated. Although information from these studies has helped to reduce the problem, it remains a serious one.

For all these reasons, the role of sawing in preventing warp was investigated at the Forest Products Laboratory. Because of the importance of loblolly pine among the southern pines, this was chosen as the species to consides. In the sizes of loblolly pine (Pinus taeda) trees often cut commercially, studs are potentially important products. Therefore this study is confined to warp in studs sawn from small loblolly pine logs.

Forms of Warp

Warp (17)[1] is the general term used to describe any deviation of a piece of lumber from a true or plane surface. It includes bow, crook, twist, and cup. Bow is defined as distortion in a board from lengthwise flatness but not across its faces. 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 such that the four corners of any face are not in the same plane. Cup is a deviation flatwise from a straight line across the width of a board. Bow, crook, and twist occur frequently and to a varying degree in 2- by 4-inch studs. Cup is seldom present in sufficient degree to affect either grade or utility of the stud.

Review of Literature

Apparently a major portion of the excessive warping problems of dimension from second

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

growth arises from the silvicultural conditions under which the trees are grown. This is especially true of the southern pines. Several investigators have concluded that the only real solution lies in improved silvicultural practices which will control the stocking and thus the growth rate, especially during the early years of the life of the tree. Industry is, however, faced with the immediate and probably continuing problem of how to reduce unfavorable effects of such characteristics as juvenile core and compression wood to their least degrading denominator.

Many investigators studying the relation of lumber characteristics to warp or degrade have recognized that the sawing method should play an important role in the reduction of potential warp. Cockrell (2) states, "In butt logs, the combination of high longitudinal 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 os 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."

A thorough search of the literature indicates no study has been made in which the characteristics of the sawn lumber were controlled by controlling and altering the sawing pattern. Nevertheless, the value of this approach is indicated by some related studies.

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 at the Forest Products Laboratory (18) have shown the normal longitudinal shrinkage of wood to be 0.1 to 0.3 percent. Abnormal longitudinal shrinkage up to 5.78 percent has been noted in ponderosa pine (Pinus ponderosa) 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 have also been reported by numerous other writers including Cockrell (2, 3), Du Toit (4), King (8, 9), Paul (12), Paul and Sweet (13), and Pillow (14).

King (8, 9) concluded that the application of water-repellent chemicals helps to reduce distortion in stored southern pine studs but estimates that 80 percent of the warping problem could be eliminated by proper selection of logs and changed sawing patterns.

Kloot and Page (10) in working with radiata pine (Pinus radiata) suggest that sawing schedules eliminating the central portion of the log should reduce the warping problem.

Paul and Sweet (13) make three recommendations with reference to sawing patterns in southern yellow pine: (1) control sawing pattern to reduce mixing fast and slow growth or compression and normal wood--also the possibility of taper sawing; (2) cut center of log into boards if wide ringed: and (3) saw crooked logs so that the wide lumber face is at right angles to the plane of the crook

Zobel (19) quotes correspondence from Jennings of Australia as follows: "The existence of the core 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 states, Sawing of lumber with core wood included invites trouble since it dries differently from other wood, having excessive longitudinal shrinkage and other difficulties."

CONDUCT OF STUDY

Scope

This study was divided into several aspects. Reported in this paper is the investigation of the relationships between warp in loblolly pine studs and sawing methods, log cross sectional eccentricity, position of the stud in the log, log diameter, log position in the tree, juvenile core diameter, and presence of compression wood.

Several other types of information of particular interest to the mill operator were developed during the study and are reported here. Among these are sawing accuracy, oversizing to compensate for shrinkage and sawing variability, and the effect on warp of long-term storage of strapped lumber packages.

Other fundamental information such as the

occurrence and measurement of growth stresses will be published at a later date.

Variables

A primary objective of this study was to provide information that could be used by sawmill personnel to produce a product with lower potential warp. Thus it was necessary to use as log variables only characteristics readily identifiable at a glance.

Log size.--Most of the southern pine sawmills concentrating on the production of studs are using small logs in the range of 6 to 12 inches, top d.i.b. (diameter inside bark). These logs are frequently, though not always, selected from the general run of pulpwood. For this study it was decided to use equal numbers of logs from the top d.i.b. ranges of 6 inch (5.6 - 6.5), 8 inch (7.6 - 8.5), 10 inch (9.6 - 10.5), and 12 inch (11.6 - 12.5). It was felt that the omission of the 7-, 9-, and 11-inch diameter would reduce the sample size without obscuring any trends that might be related to diameter.

Sawing method.--Four sawing methods (designated as Methods I, II, III, and IV in fig. 1) were employed to convert the logs to 2x4 studs.

Most mills producing studs in quantity fall into one of two basic types--conventional or Scragg.

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

The Scragg system is suited to the production of studs only by Methods III and IV. With this Scragg system, the log passes between successive pairs of parallel (usually circular) saws which remove slabs, 2-inch flitches, and leave a 4-inch cant from the approximate geometric center of the log. The 2-inch flitches arc 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 wide, The log thus is usually sawn to yield only studs in a more or

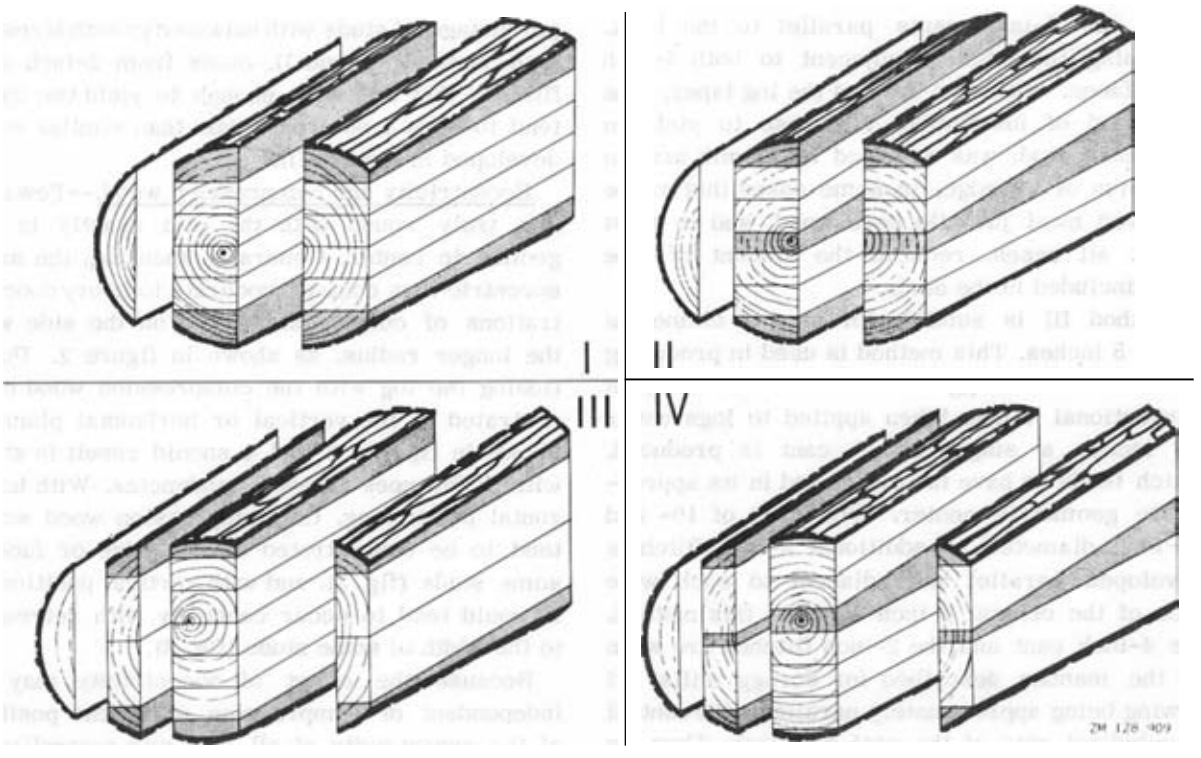

Figure 1.--The four sawing methods used in this study as applied to the 12-inch diameter class. In Methods I and III taper and excess wood (shaded area) are in the slab while En Methods II and IV they are mainly concentrated in a wedge from the pith area.

less continuous process. This system is ideal for Method III and with minor alterations for Method IV.

Method I (fig, 1) is commonly used at conventional mills with carriage and band or circular headrigs. It can saw any log large enough to develop two adjacent 4-inch cants. In this study it was used to saw one-fourth of the 10- and 12-inch d.i.b. logs. Characteristically it produces two parallel and adjacent 4-inch cants which tend to have the pith centrally located on one of their 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. When this method is used all of the juvenile core (leas sawdust) becomes a part of the studs.

Method II is a modification of Method I, not used commercially, and subject to the same diameter limitations. The modification is based on the hypothesis that warp potential would be reduced by reducing the degree of cross grain and the amount of juvenile wood present in the sawn stock. The 4-inch cants were developed parallel to the pith as in Method I. The difference is that, in Method II, the studs were ripped from the 4-inch cants parallel to the bark, beginning immediately adjacent to both 4-inch bark faces. With this method the log taper, plus the wood of insufficient thickness to yield an additional stud, was removed in the pith area in the form of a wedge. In some cases this wedge removed most juvenile core wood, and in most if not all cases, reduced the amount of core wood included in the studs,

Method III is suitable for logs of diameters above 5 inches, This method is used in producing studs at all Scragg mills and occasionally at conventional mills. When applied to logs under 10 inches a single 4-inch cant is produced, which tends to have the pith boxed in its approximate geometric center. With logs of 10- and 12-inch diameter an additional 2-inch flitch is developed parallel and adjacent to each wide face of the central 4-inch cant. In this method, the 4-inch cant and the 2-inch flitches are sawn in the manner described for Scragg mills, all sawing being 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 in the form of 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 and possibly II; 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 is a modification of Method III that, to our knowledge, has never been in commercial use. The 2-inch flitches and 4-inch cant are produced exactly as in Method III. If the 2-inch flitch is wide enough to yield two studs, these 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 in all cases the percentage of core wood in 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 Methods I and II. Studs from 2-inch side flitches that are wide enough to yield two 2x4's tend to have less cross grain than similar studs developed in Method III.

Eccentricity and compression wood.--Few logs are truly round with the pith exactly in the geometric center. Generally speaking, the more eccentric logs contain moderate to heavy concentrations of compression wood on the side with the longer radius, as shown in figure 2. Positioning the log with the compression wood concentrated in the vertical or horizontal plane as shown in figures 3 and 4 should result in studs with differences in warp tendencies. With horizontal positioning, the compression wood would tend to be concentrated on one edge or face of some studs (fig. 3), and with vertical. positioning it would tend to occur centrally with reference to the width of some studs (fig, 4).

Because the effect of eccentricity may be independent of compression wood, the position of the eccentricity of all logs was controlled in relation to the application of each sawing method. Half of the logs in each variable class were

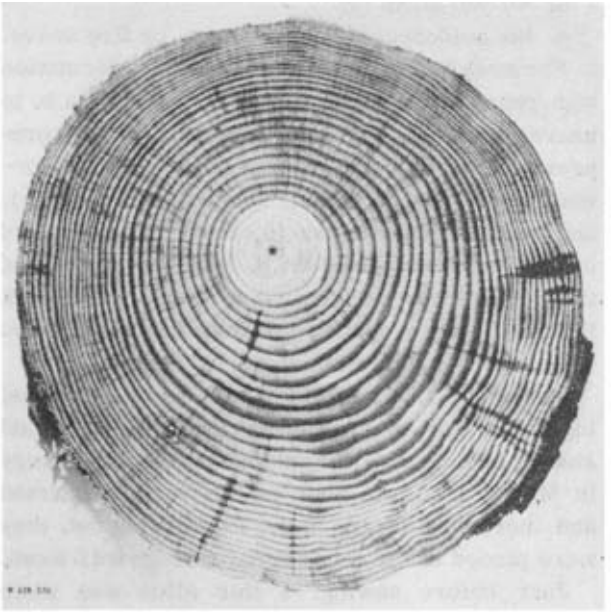

Figure 2.--Eccentric cross section of a log showing heavy concentration of compression wood in the quadrant bisected by the longest radius. ZM 128 220

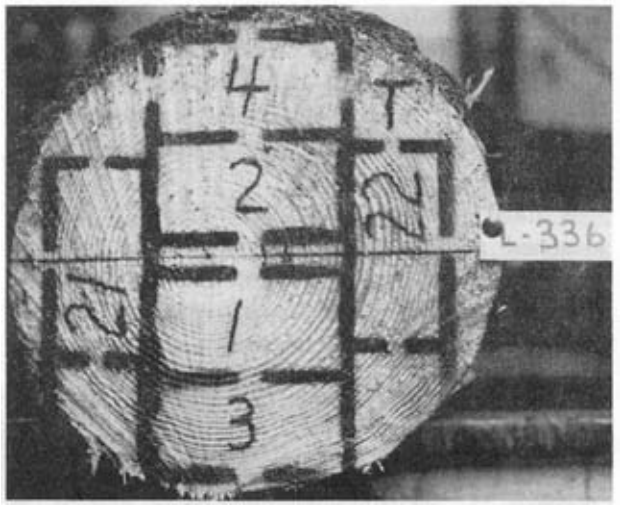

Figure 3.--SawingMethod IV applied to a 10-inch log with the radial eccentricity concentrated in the horizontal position. Compression wood occurs in studs 1, 2, and 22.

sawn with the eccentricity vertical and one-half horizontal. This might be considered as doubling the number of sawing methods but the author prefers to consider it as a separate controlled variable.

Logs were also chosen on the basis of presence or absence of compression wood visible on the log ends.

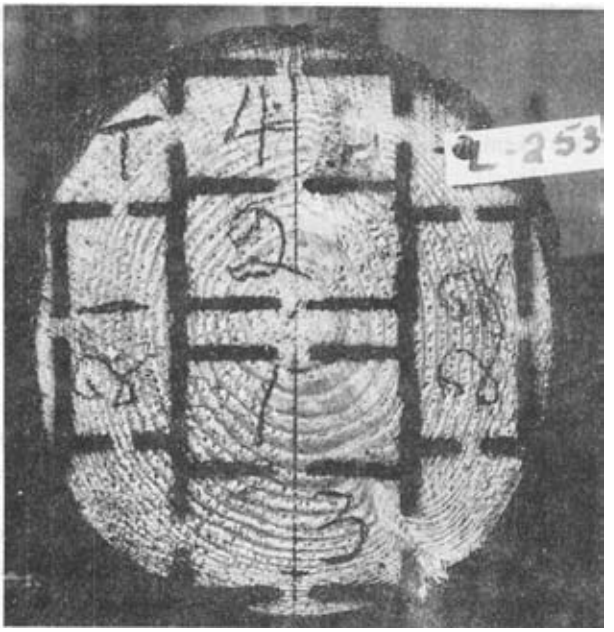

Figure 4.--Sawing Method IV applied to a 10-inch log with the radial eccentricity in the vertical position. Compression wood is confined to studs 1 and 3.

Log position.--Because previous research has indicated that warp potential of lumber cut from the butt log differs from that cut from the upper logs, log position in the tree was also selected as a variable. In the mill it is usually possible to identify the butt logs but not possible to separate the upper logs further. Thus in this study all upper logs were combined into a single log position group. Equal numbers of butt and upper logs were selected. The butt logs were defined as the first 8-foot log above the stump and the upper logs were obtained at any position above the butt logs. Points at which the upper logs were to be bucked were actually selected to yield logs with the desired top d.i.b. measurements.

Juvenile wood.--Loblolly pine, like all conifers, contains juvenile core wood in varying amounts. If initial stocking is heavy, or the tree grows in the partial shade of the forest, radial growth is slowed, and the: juvenile core may be 1 inch or less in diameter. If stocking is low and other growth factors are favorable, the core may be 5 or more inches in diameter.

The original plan was to select logs so that one-half of them would have juvenile cores over 3 inches in diameter and the other half less than 3 inches. However, it became impractical, after

finding logs having the desired combination of the other variables, to further select them on the basis of core diameter. As a result, this variable was dropped from the log selection criteria but was retained in the analysis.

Procedure

On the basis of work by Kloot and Page (10) on *Pinus radiata*, the requirements for the total sample size were estimated at 432 logs. This allowed a minimum of three logs in each variable class.

Through the cooperation of the Southeastern Forest Experiment Station the study logs were obtained in January and February 1963 from the Hitchiti Experimental Forest near Macon, Ga. The loblolly pine in this area is largely of "old field" origin. Many of the stands are composed of trees in the range of 6 inches to 14 inches d.b.h. The trees are of reasonably good form, and examination of several hundred increment cores and log ends indicates that stocking has been sufficiently heavy to eliminate most of the exceptionally fast growth frequently noted in stands of this type.

Topography in this area is gently rolling but a slope in excess of 15 percent is seldom encountered. Soil is generally red clay and shows evidence of moderate to severe erosion before having been abandoned to its present forest cover. Stand volumes in the area from which the study logs were selected were in the range of 5,000 to 15,000 board feet per acre. Most trees were in an age range of 20 to 50 years with a few individuals as low as 15 and some as high as 80.

Increment cores at breast height were taken from the lower side of the lean of all trees prior to felling, and were evaluated by light transmission (15) for presence and severity of compression wood. If the core was favorable, the tree was felled. As many logs were obtained from each tree as possible. In some cases a 10-inch butt log and an 8- and a 6-inch upper log came from a single tree. It was actually necessary to fell about 265 trees to obtain the required 432 logs.

All the study logs were chosen from logs having 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 feet).
2. No unsound knots (5).
3. No bad knots (5).
4. 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 wood or normal wood). log position class (butt or upper), and log diameter class (6, 8, 10, or 12) 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 to a sawing method and eccentricity orientation class at random

The study logs, together with some additional logs for use in perfecting the stenciling and sawing techniques, were shipped to the Laboratory in March 1963. As soon as the weather warmed and there was danger of the logs drying out, they were placed under water spray storage until sawn.

Just before sawing, a thin slice was sawn from the upper end (usually smallest log end) to provide a new, clear surface on which to stencil the sawing pattern, number the studs, count growth rings, determine the longest diameter and make a photographic record. Full-size stencils made it possible to stencil the exact sawing pattern on the end of each log. Black paint applied from aerosol cans worked very well (fig. 5). Then, a code number was placed on the end of each stud to identify the position of the stud in the log (fig. 6).

A card indicating the log number was then attached and the stenciled end of each log was photographed (figs. 3 and 4) for a permanent record. These photographs proved invaluable in later identifying all studs whose numbers were

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Figure 5.--Stenciling the sawing pattern for the center can: on the end of a log with an aerosol paint spray.

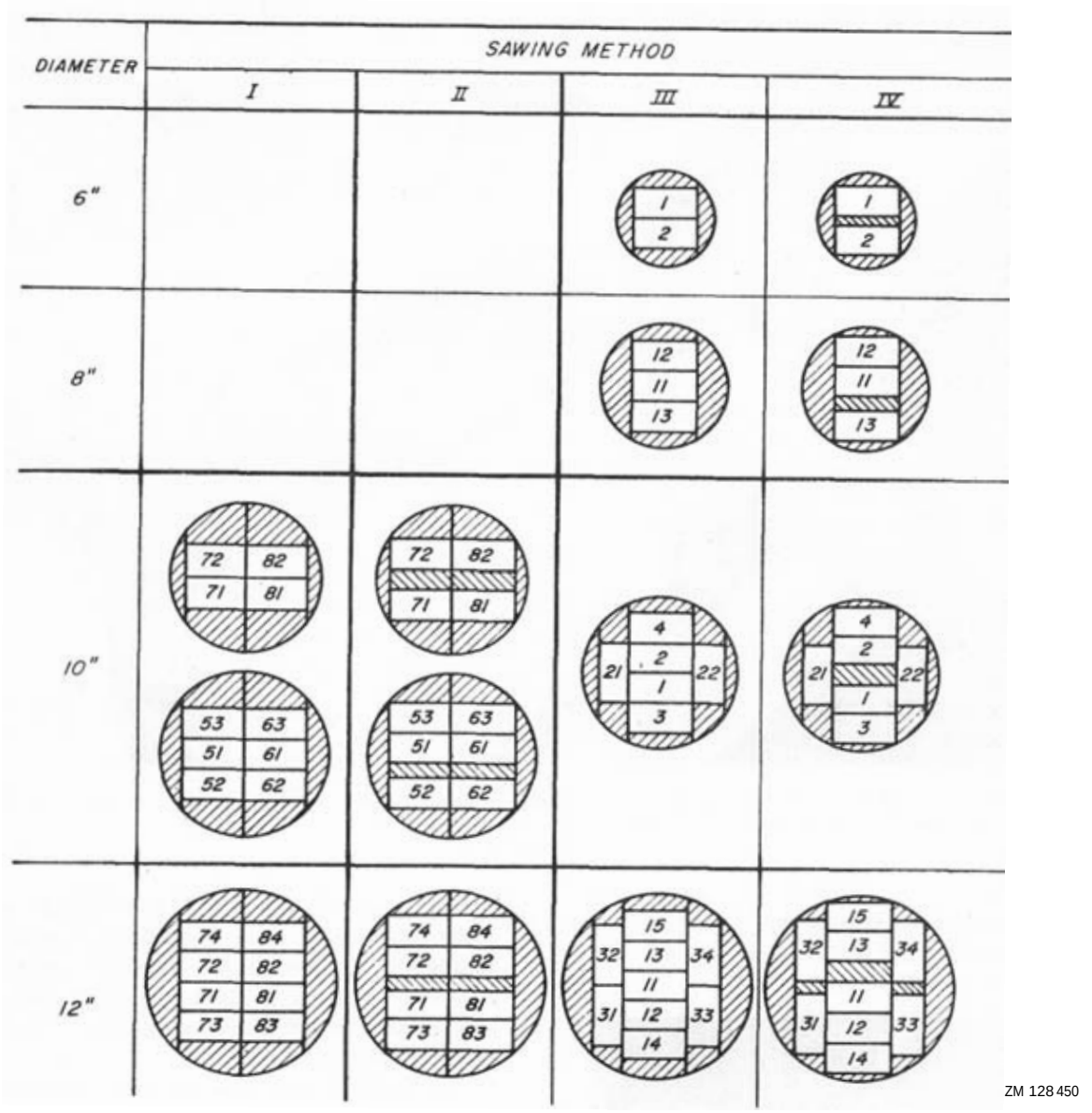

Figure 6.--The numbering system used to identify studs and their position in the log

either incorrect or missing (although only 30 studs of the 2,342 sawn in this study were improperly identified or unidentified).

The logs were sawn on the Laboratory's research sawmill. This sawmill, although completely instrumented for research purposes, is otherwise a conventional medium-weight circular headsaw type with a setter controlled, hand-operated-blocks type of carriage. The mill. installation is equipped with a sawline indicator of the light projection type, 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 the three headblocks with the stenciled end toward the saw. They were then sawn at a feed rate of about 1/8 inch per tooth, which compares favorably with fast commercial mill production rates. Target size of the 2x4 studs was 1-7/8 by 4 inches. This is the size recommended by Cahal (1).

Immediately after each stud was sawed, it was renumbered on the 4-inch face with both the log and stud number. The studs were solid stacked until there was a sufficient number far a kiln load. They were covered with polyethylene plastic sheeting at all times to prevent drying.

When a kiln load of studs had accumulated,

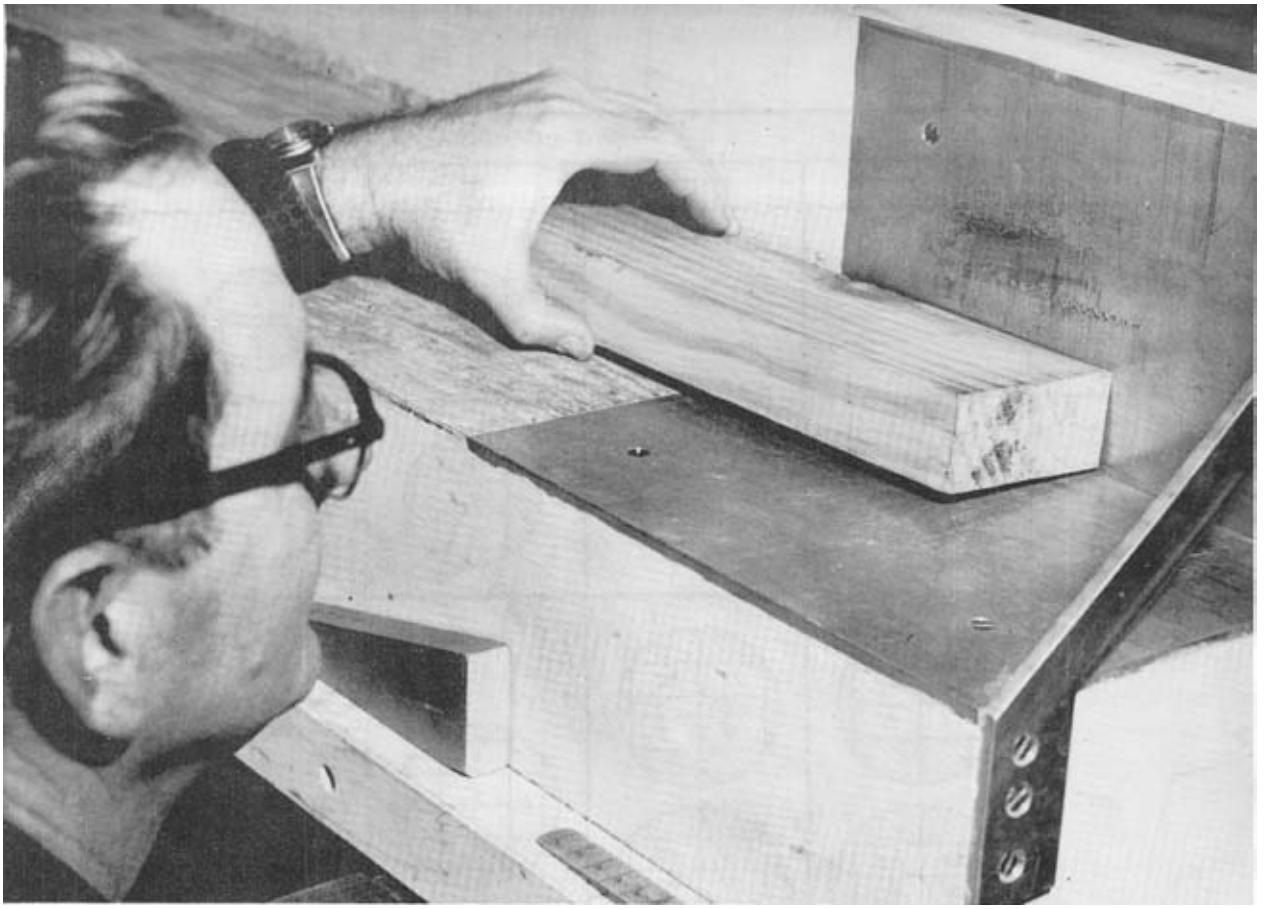

Figure 7.--Measuring the length of a stud. Metal panel immediately back of stud is graduated in increments of 1/32 inch.

Figure 8.--Measuring the crook in a stud. Amount of deflection is read on a tapered wedge gage.

studs were end trimmed to precisely 96 inches. Then each stud was placed in a length and deflection measuring box specially constructed for the purpose. In this operation the stud's length was measured to the nearest 1/32 inch as shown in figure 7.

The four faces of each stud were then numbered in such a way that the position of each face relative to the center of the log was indicated. The amount of crook and bow (measured as in figs. 8 and 9) was represented by another code number. Combinations of the two numbers then indicate the amount and direction of the deflection. Twist was measured (fig. 10) and recorded to show degree and direction of rotation.

At this time the maximum and minimum thickness and width of each stud was also determined and recorded.

After being measured, the studs were dried in 10 separate kiln runs in one of two small experimental kilns to an average moisture content of 12 percent.

The basic kiln schedule used for all the runs approximated the kiln schedules used commer-

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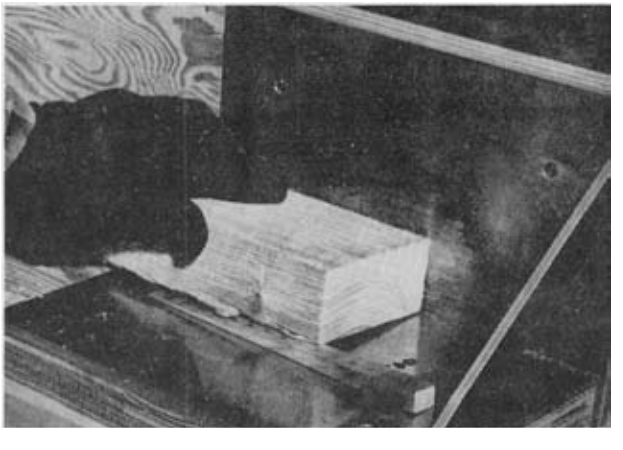
Figure 9.--Measuring the bow in a stud.

cially for drying 2-inch southern pine. Most runs were dried by a schedule that accomplishes most of the drying to an average moisture content of about 12 percent in 144 hours.

A typical set of drying curves is shown in figure 11. The drying of the entering-air samples

Figure 10.--Measuring the twist in a stud. Other end of the stud is held flat to the table.



is representative of the drying of studs along the side plenum chambers or next to the booster (reheat) coil in a commercial kiln. The samples on the leaving-air side represent an expected drying curve for the middle of a kiln truck load 8 feet wide.

After kiln drying, the studs were allowed to cool for 1 day and were then remeasured for length, crook, bow, and twist. The length of those studs that showed crook and bow was defined to be the length of the chord connecting the ends on the concave face. This is a measure of the usable length the stud would have if it were cut squarely and parallel on both ends.

Moisture content measurements were also taken at this time, using an electric resistance-type moisture meter. When the kiln-dried studs had all been remeasured, they were planed on four sides to standard finished dimensions (1-5/8 by 3-5/8 inches). After planing, they were again measured for moisture content, length, crook, bow, and twist (fig. 12). In addition, the planing was evaluated in terms of SPIB (Southern Pine Inspection Bureau) specifications (16) for both the face and the edge. A grade value was also assigned, based on the knot characteristics according to the SPIB specifications.

Ten percent of the studs were randomly selected for the 90-day storage test. These 233 studs were carefully piled into two packages, each strapped with three bands of 3/4- x 0.035-inch steel. The banding was pulled as tightly as possible, using commercial strapping tools, to restrain a large part of the crook, how, and twist. The packages were then placed in a dry open storage shed and allowed to stand 90 days to simulate conditions frequently encountered in the normal merchandising of lumber. After the 90-day storage period, the studs were unstrapped and allowed to stand for 2 days to permit stresses within the studs to reach a state of equilibrium. Then studs were remeasured for moisture content, crook, bow, twist, and length.

Considerable additional data were taken by other personnel from the Laboratory at all stages of this study. This information is to be used in studies on relationships of tree characteristics to compression wood occurrence in logs and lumber; the interrelationships of spiral grain and twist in lumber; the stiffness of lumber as related to sawing methods, specific

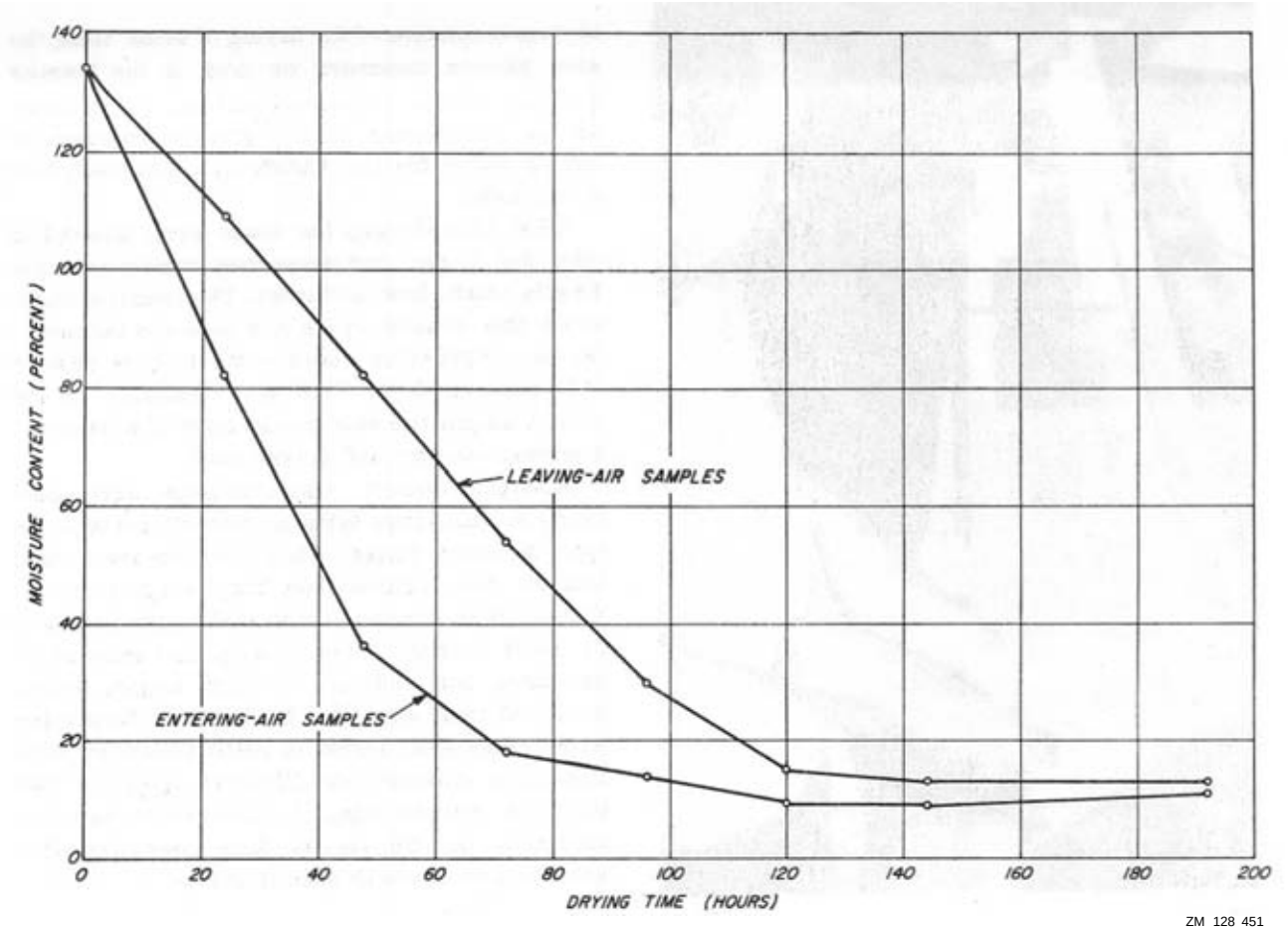


Figure 11.--Typical drying curves for a single kiln load of study studs.

Figure 12.--Measurement of warp and length (left) and moisture content of the planed studs (right). ZM 125 942

gravity, and other factors: and the relationship of warp tendencies of lumber to exact longitudinal position in the tree. These studies are being completed.

ANALYSIS OF DATA

All data for this study were transferred to punch cards. Programs were prepared for the analysis of the data on the Laboratory's IBM 1620 computer. The analysis was divided into the following aspects:

1. Effect of sawing method on volume recovery.
2. Effect of sawing method on dimensional variation.
3. Comparison of all sawing methods by each warp aspect.
4. Comparison of all warp aspects by each sawing method.
5. Effect of position of the stud in the log to each warp aspect.
6. Effect of log diameter on warp.
7. Effect of compression wood and cross sectional eccentricity on warp,
8. Effect of log position on warp.
9. Effect of juvenile core diameter on warp.
10. The range and distribution of moisture content after kiln drying.
11. Effect of 90-day restrained storage on warp, stud length, and moisture content.

Because a primary objective of this study was to evaluate warp relationships to sawing; methods, primary analysis of data was in terms of yields in the various SPIB grades. These grades were based solely on limitations for all aspects of warp and its three components: crook, bow, and twist (table 1). In this manner each stud could be classified in a "go" or "no-go" status, Variations in the proportion of acceptable studs by various classes of the factors investigated were evaluated by chi-square tests.

Also analysis of variance was made to test the effects of log diameter (8 and 12 inches only), log position, stud position in the log, sawing method (III and IV only), and their interactions on the mean crook, bow. and twist of the studs.

Results were sometimes different when mean values for warp were used as a criterion rather than yields of studs equal to or better than various levels of warp as prescribed by the individual SPIB grades, A hypothetical example indicates why this might be:

Table I.--Warp limitations for SPIB grades of 2x4 lumber 8 feet in length

Grade	Maximum allowable warp		
	Crook	Bow	Twist
Stud	6/32	12/32	8/32
No. 1 Dimension	9/32	18/32	12/32
No. 2 Dimension	12/32	24/32	16/32
No. 3 Dimension	18/32	36/32	24/32
No. 4 Dimension[1]	...	...	...

[1] No specific limits. Piece must be three-fourths usable when cut in not more than three lengths 24 inches or longer.

As shown in table 1, the maximum crook allowed in an 8-foot stud of No. 1 Dimension is 9/32 inch. Assume measurement of two 10-stud samples show the following degree of crook: first sample 9/32, 8/32, 7/32, 6/32, 5/32, 8/32, 6/32, 5/32, 9/32, and 27/32 inches; second sample 1/32, 10/32, 11/32, 12/32, 10/32, 11/32, 12/32, 10/32, 10/32, and 3/32. The mean crook is 9/32 inch for both samples but in the first case 9 out of 10 studs are grade No. 1 Dimension while in the second case only 2 out of 10 make this same grade.

DISCUSSION

Results of the study are discussed under topical headings corresponding to the 11 aspects into which the analysis was divided. Summary tables that present the yields of studs by all sawing methods, log diameters, compression wood classes, radial eccentricity classes, log positions, and SPIB grades for all aspects of warp are contained in the Appendix.

1. Effect of Sawing Method on Volume Recovery

In most mills that manufacture 2x4 studs, they are the principal product. All other things being equal, a sawing method that converts the

greatest percentage of the log to studs is most desirable.

Geometrically, certain sawing methods can convert a larger part of the volume of a log to studs than others. This is especially true in logs of relatively small diameters. In a previous study by Hallock (6), it was demonstrated that the diameters at which these changes in recovery occur are critical. For this reason, each of the present diameter classes has also been divided in the analysis of volume yields. For example the 6-inch diameter class is subdivided into the 5.6– to 6.0–inch and 6.1– to 6.5-inch groups,

Sawing Methods I and II will produce identical volume yields; so will Methods III and IV. Consequently, their yields have been combined for this analysis into Methods I–II and Methods III–IV.

Yields in board feet of studs obtained are shown in table 2 for each diameter class and for the combined sawing methods. No recoveries are shown for Methods I–II for 6– and 8-inch diameter classes as it is not possible to apply these methods to logs much smaller than 9.6 inches. Table 2 and figure, 13 show the overrun percentages obtained for Scribner Decimal C and International 1/4-inch log rules. The overrun for Scribner rule ranges from +111.4 percent for the 6–inch diameter class sawn by Methods III–IV to -24.7 percent for the 9.6- to 10.0-inch group sawn by Methods 1-11. By International rule, the overruns range from +10.7 percent for the 8.1- to 8.5-inch group sawn by Methods III–IV to –24.7 percent for the 9.6– to 10.0-inch group sawn by Methods I–II.

Note in table 2 and figure 14 that, in all diameter classes except the 6 inch, recovery increases from the lower half to the upper half of the diameter class. This is particularly evident in the 10–inch class sawn by Methods I–II in which the average yield in studs increases from 22.6 to 30 board feet, or an increaae of 3217 percent,

Another measure of the efficiency of the

Table 2.––Lumberrecovery[1] and overrun by log diameters and sawing methods[2]

Diameter classes	Log scale			Methods I-II				Methods III-IV			Superiority of Methods III-IV over Methods I-II
	Scribner decimal C	International	Yield	Percentages of log end in lumber	Overrun		Yield	Percentages of log end in lumber	Overrun		
					Scribner decimal C	International			Scribner decimal C	International	
Inches	Bd. ft.	Bd. ft.	Bd. ft.	Percent	Bd. ft.	Bd. ft.	Bd. ft.	Percent	Bd. ft.	Bd. ft.	Percent
6	5	10			--	--	10.7	53.4	+111.4	+7.0	--
5.6-6.0			--	--			10.7	57.0	+111.4	+7.0	--
6.1-6.5			--	--			10.7	48.3	+111.4	+7.0	--
8	10	15			--	--	16.3	45.3	+63.0	+8.5	--
7.6-8.0			--	--			16.0	47.1	+60.0	+6.7	--
8.1-8.5			--	--			16.6	43.0	+66.0	+10.7	--
10	30	30	26.3	46.7	-12.3	-12.3	31.9	57.0	+6.3	+6.3	+21.3
9.6-10.0			22.6	42.0	-24.7	-24.7	31.8	59.3	+6.0	+6.0	+40.6
10.1-10.5			30.0	50.6	0.0	0.0	32.0	54.1	+6.7	+6.7	+6.6
12	40	45	41.7	51.6	+4.3	-7.3	47.2	58.6	+18.0	+4.9	+12.5
11.6-12.0			40.8	52.4	+2.0	-9.3	46.5	59.7	+16.2	+3.3	+14.0
12.1-12.5			42.7	50.5	+6.8	-5.1	48.0	56.8	+20.0	+6.7	+12.4

[1] Yields are shown in terms of 2x4 studs only.

[2] Because recovery for a given log is identical for Methods I and II, they are combined into I-II; Methods III and IV are treated the same way.

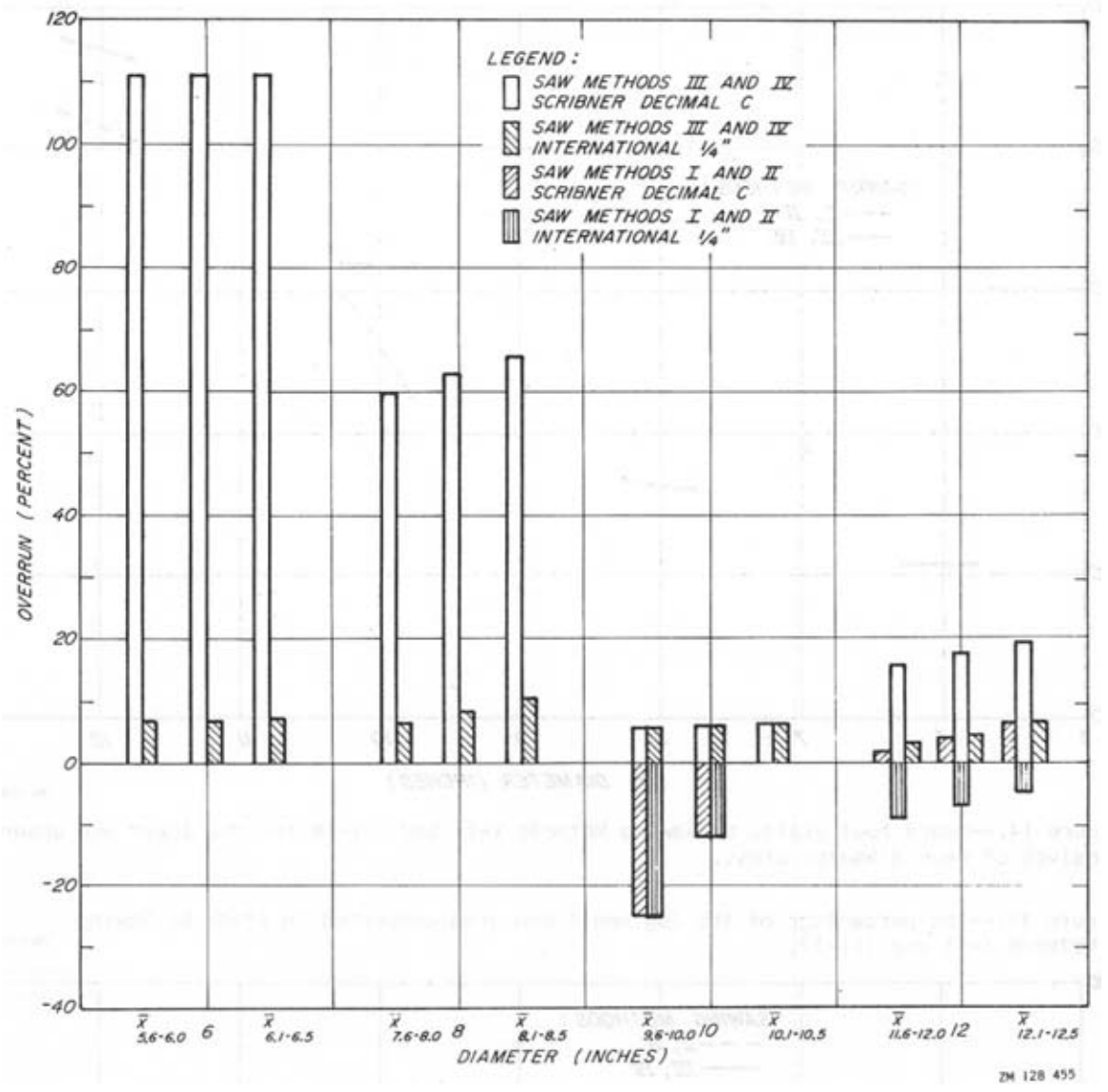


Figure 13.--Lumber overrun for logs of various diameters when sawn into studs by Methods I—II and III-IV compared to log scale by the Scribner Decimal C and International 1/4-inch log rules.

sawing method is to express the combined end area of the studs in terms of the percentage of the small end area of the log, shown in table 2 and figure 15. Values ranged from a low of 42 percent for 9.6- to 10.0-inch logs sawn by Methods 1-11, to a high of 59.7 percent when 11.6- to 12.0-inch logs are sawn by Methods III-IV.

Sawing Methods III-IV always produced greater recoveries of studs, both in terms of board foot and cross sectional area, than did Methods I-II. The superiority of Methods III-IV (table 2), ranged from a low of 6.6 percent for the 10.1- to 10.5-inch group to 40.6 percent in the 9.6- to 10.0-inch group.

2. Effect of Sawing Method on Sawing Variation

Several factors contribute to the variation in accuracy of sawn lumber. Among these are width of the sawn face and spring of the cant as a result of the release of growth stresses.

In Sawing Methods I and II the log, after slabbing, was divided into two cants approximately along a plane in line with the pith. The log was securely restrained by three or more headblocks to avoid distortion during the cutting. Otherwise,

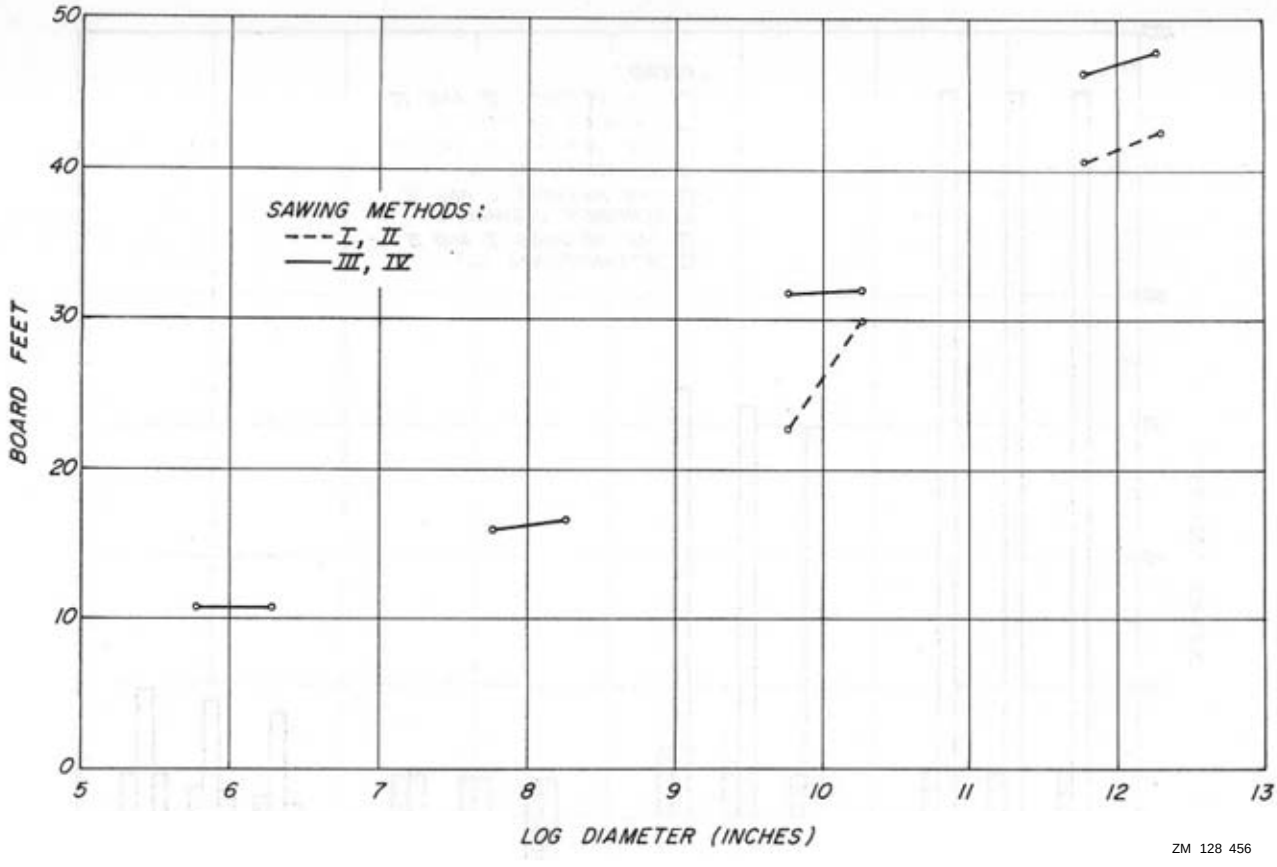
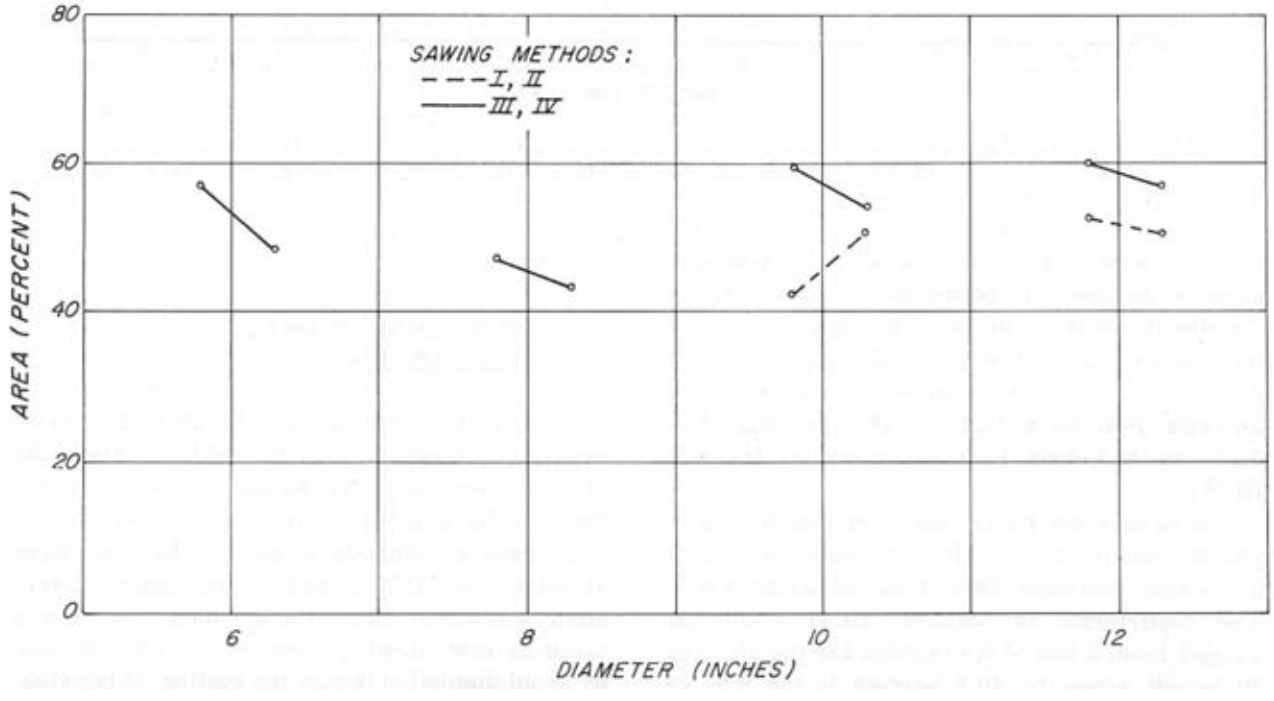


Figure 14.--Board foot yields by Sawing Methods 1—11and Ill–IV for the lower and upper halves of each diameter class.

Figure 15.--The percentage of the log small end area converted to studs by Sawing Methods I—IIand Ill–IV.



any growth stresses, as they are released by the cant-dividing sawline, would distort that end of the log already divided and cause deviation from the intended line of cut.

The width of the face in this cant-dividing cut is usually nearly equal to the full diameter of the log (fig, 1).

In Methods III and IV, slabs and 2-inch flitches were removed from opposite faces of the log, leaving a central 4-inch cant in which the growth stresses tend to be balanced. The maximumwidth of face sawn in this case is from 1 to 3 inches narrower than the log diameter. Thus it could be hypothesized that the studs sawn by Methods III and IV might be more accurate than by Methods I and11.

In this study, two measures of sawing accuracy were used. One of these was the maximum difference in width (or thickness) of a given board, which is often referred to as "within-board variation." The other was the difference between the average width or thickness of the board (defined as the average of the maximum and minimum) and the target width (or thickness). This second measure is referred to here as "between-board variation."

Variation within boards and between boards by sawing methods is summarized in figure 16 for both thickness and width, Within-board data show that, for thickness, no more than 2/32 variation existed for 92.8 percent of studs sawn by Methods I and II compared to 94.2 percent by Methods III and IV, For width, the cumulative values at the 3/32 variation level are 97.5 percent for Methods I and II and 96.8 percent for Methods III and IV. There does not appear to be a significant difference in within-board variation related to sawing methods.

In between-board variation, Methods I and II seem to give slightly better results than Methods III and IV, although the reason is obscure. Yields of studs from Methods I and II with no more than ±1/32 variation are 7.0 percent better for thickness and 5.6 percent better for width than from Methods III and IV.

Note the following sawing accuracy factors in producing 2,342 studs from 432 logs:

1. Between-board thickness variation for 95.9 percent of the studs was no greater than ±1.5/32.
2. Between-board width variation for 95.0 percent of the studs was no greater than 22/32.
3. Within-board thickness variation for 93.5 percent of the studs was no greater than 2/32.

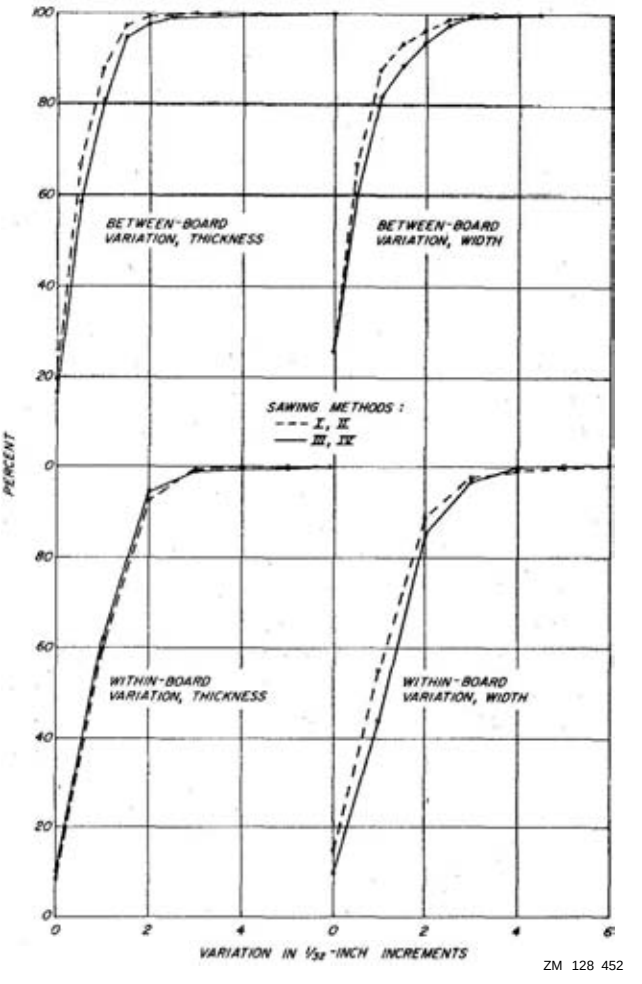


Figure 16.--The effect of sawing method on sawing variation.

4. Within-board width variation for 97.2 percent of the studs was no greater than 3/32.

Planing the studs after they were dried indicated that a green target size of 1-7/8 by 4 inches was adequate for satisfactory dry surfacing to 1-5/8 by 3-5/8 inches when reasonable sawing accuracy standards were maintained. The small percentage of studs that were not planed satisfactorily (by SPIB standards) exhibited warp in amounts that would preclude their being in any grade above No. 4 Dimension.

3, Comparison of All Sawing Methods in Relation to Each Warp Aspect

The sawing methods under study affect the relative amounts or combinations of the warp-influencing factors of juvenile core, compression wood, and log eccentricity in each stud. The effect of each method on each form of warp was

evaluated by comparing yields in terms of cumulative percentages of studs that meet increasing 1/32-inch increments of warp within the variation range of the data.

Figures 17 and 18 compare all sawing methods in terms of crook, figures 19 and 20 make the comparison for bow, and the comparison for twist is shown in figures 21 and 22. All curves have been hand fitted.

Crook.--The superiority of Method IV in reducing the amount of crook in studs from butt logs (fig. 17) is striking, when compared to Methods I or II. Its superiority over Method III is important in reducing the percent of studs with more than 6/32-inch crook. As an example, at the crook limitation of 6/32 inch in 'Stud" grade, Method IV yields 76.7 percent, Method III 72.3 percent, Method II 50.8 percent and Method I 42.8 percent.

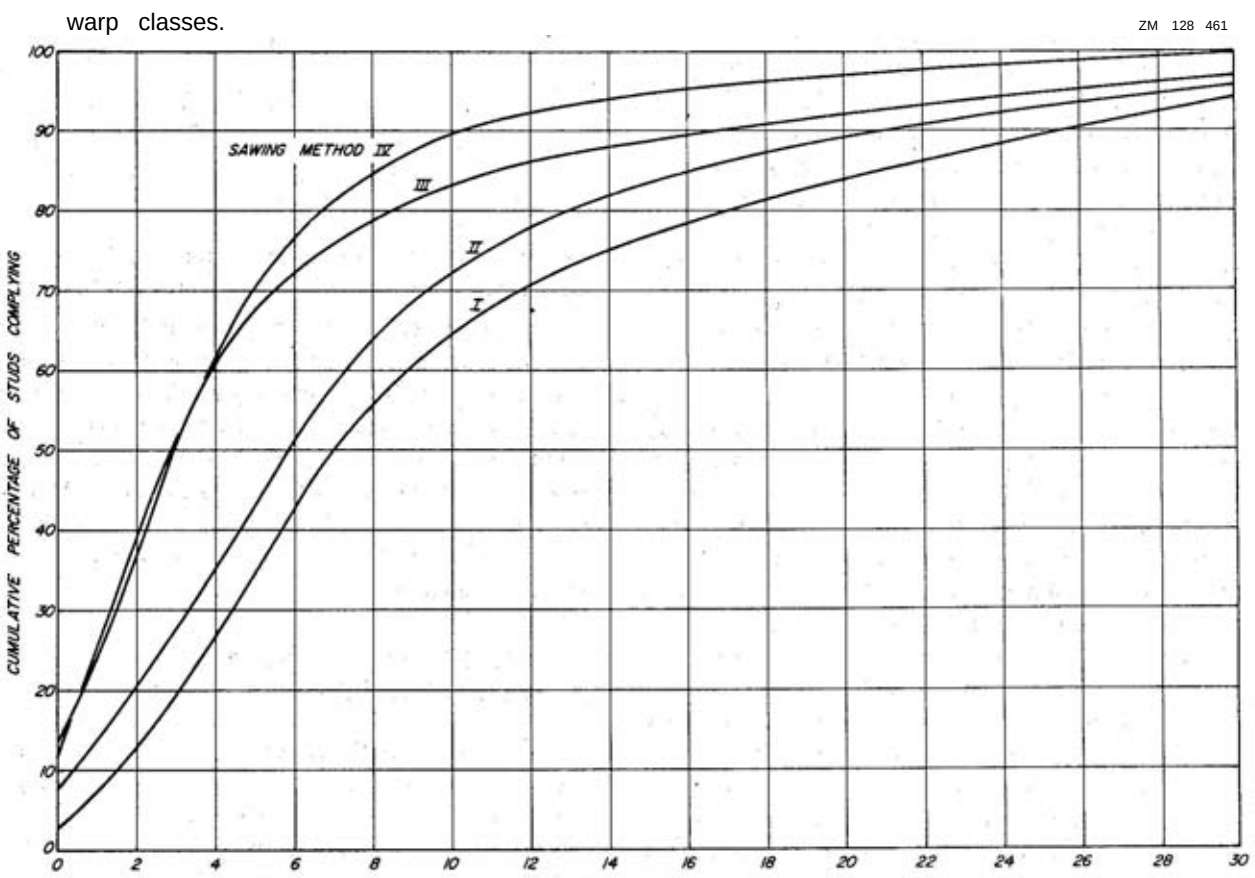
For butt logs, chi-square analysis at the 6/32-inch crook level (for "Stud" grade) indicates that yields from Methods III and IV are significantly better than from Methods I or II at the 0.01 level. The differences between Methods I and II and between Methods III and IV were not significant at the 0.05 level,

Yields from upper logs (fig. 18) do not indicate a superiority for any one sawing method. What is indicated is that either Method III or IV is superior to Method I or 11. Also Method II is superior to Method I in reducing the percentage of studs with a crook of less than 10/32 inch. At the 6/32-crook level ("Stud" grade) yields for Method IV are 89.6 percent, Method III 89.2 percent, Method II 84.4 percent, and Method I 77.0 percent.

Chi-square tests indicated that, at the 6/32-crook level, yields from upper logs by either Method III or IV were significantly better (0.01 level) than by Methods I and II. Yields from Method II over Method I were not significant at the 0.05 level. No significant differences existed between Methods III and IV.

Bow.--Similar comparisons of the sawing methods in terms of bow in studs from butt logs

Figure 17.--Crook in butt logs of combined diameters sawn by four methods. Yields are in terms of the cumulative percentages of studs meeting successive 1/32-inch increment warp classes.



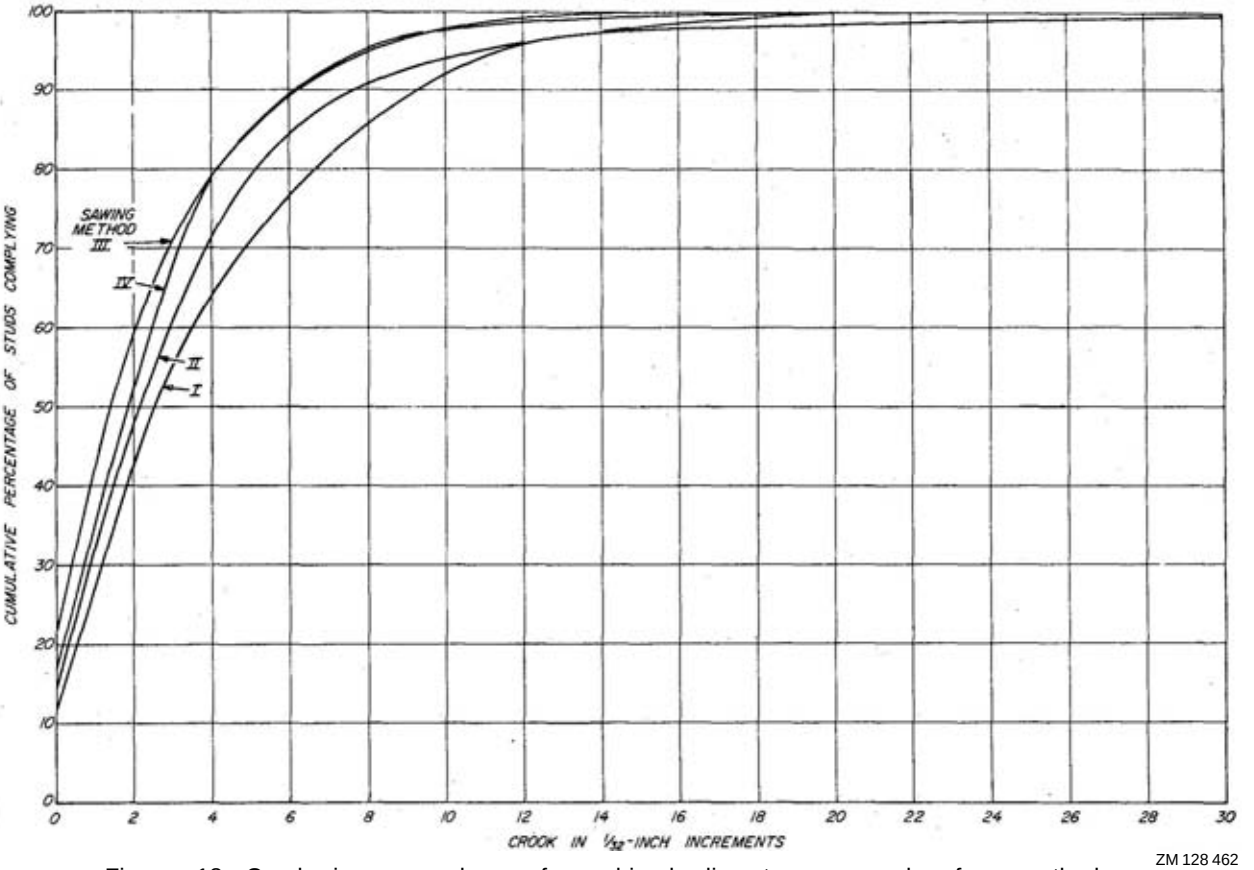


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Figure 18.--Crook in upper logs of combined diameters sawn by four methods.

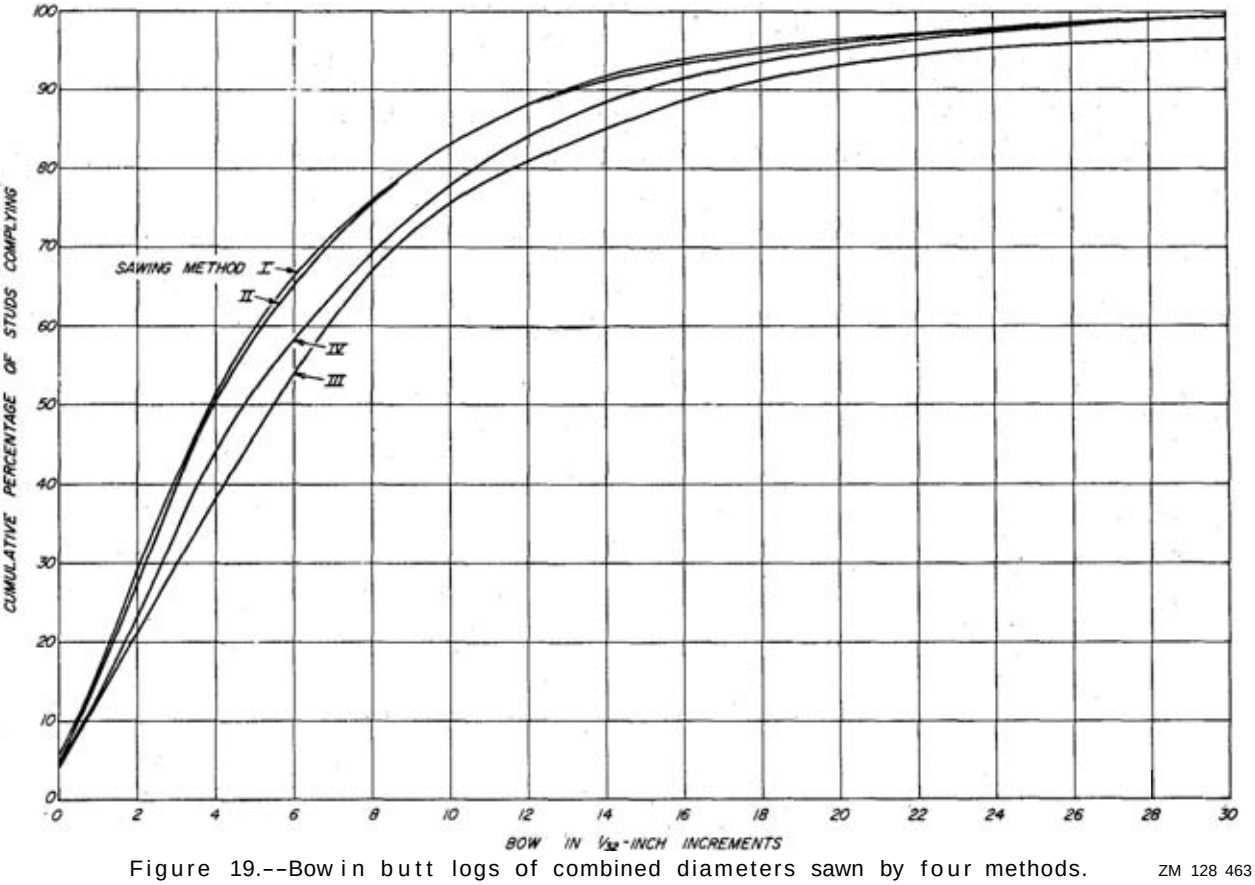

Figure 19.--Bow in butt logs of combined diameters sawn by four methods.

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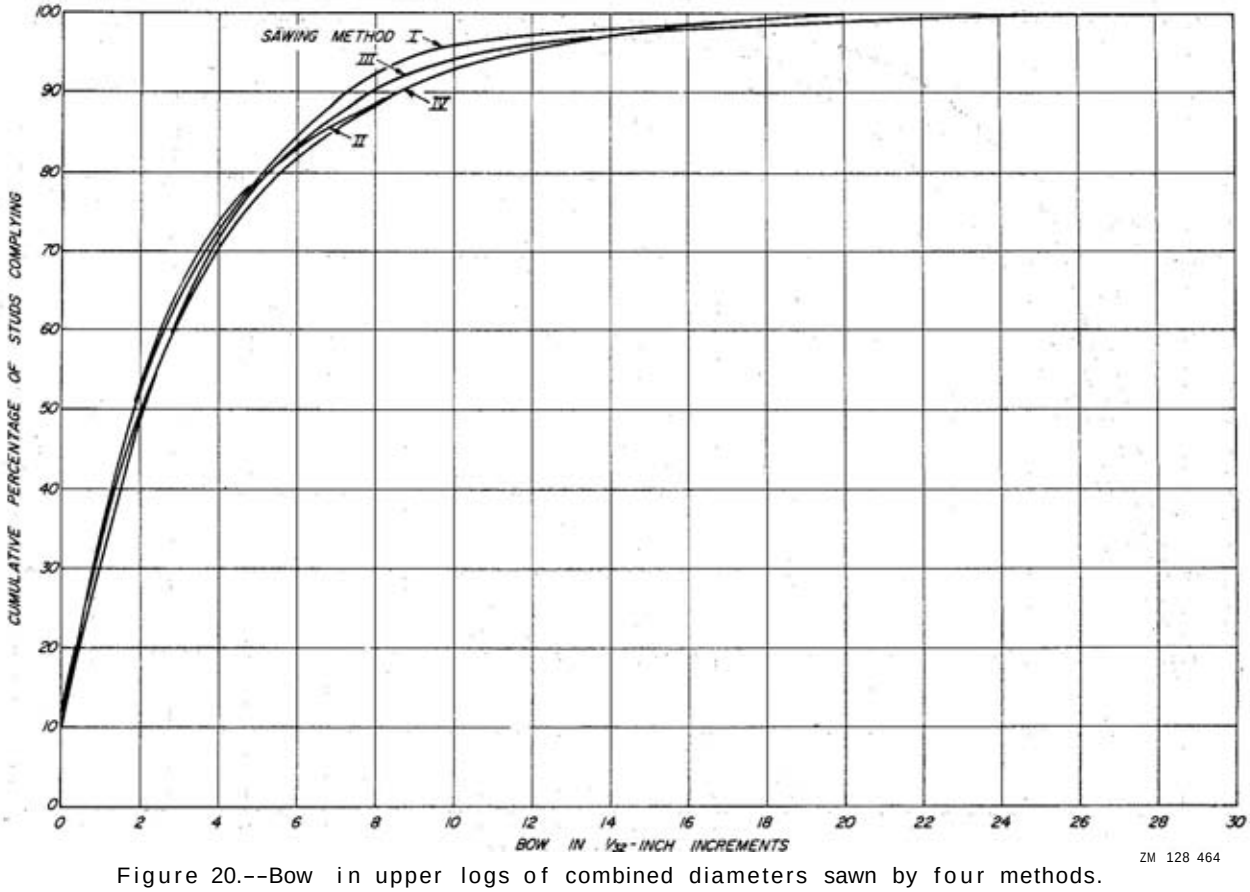


Figure 20.--Bow in upper logs of combined diameters sawn by four methods.

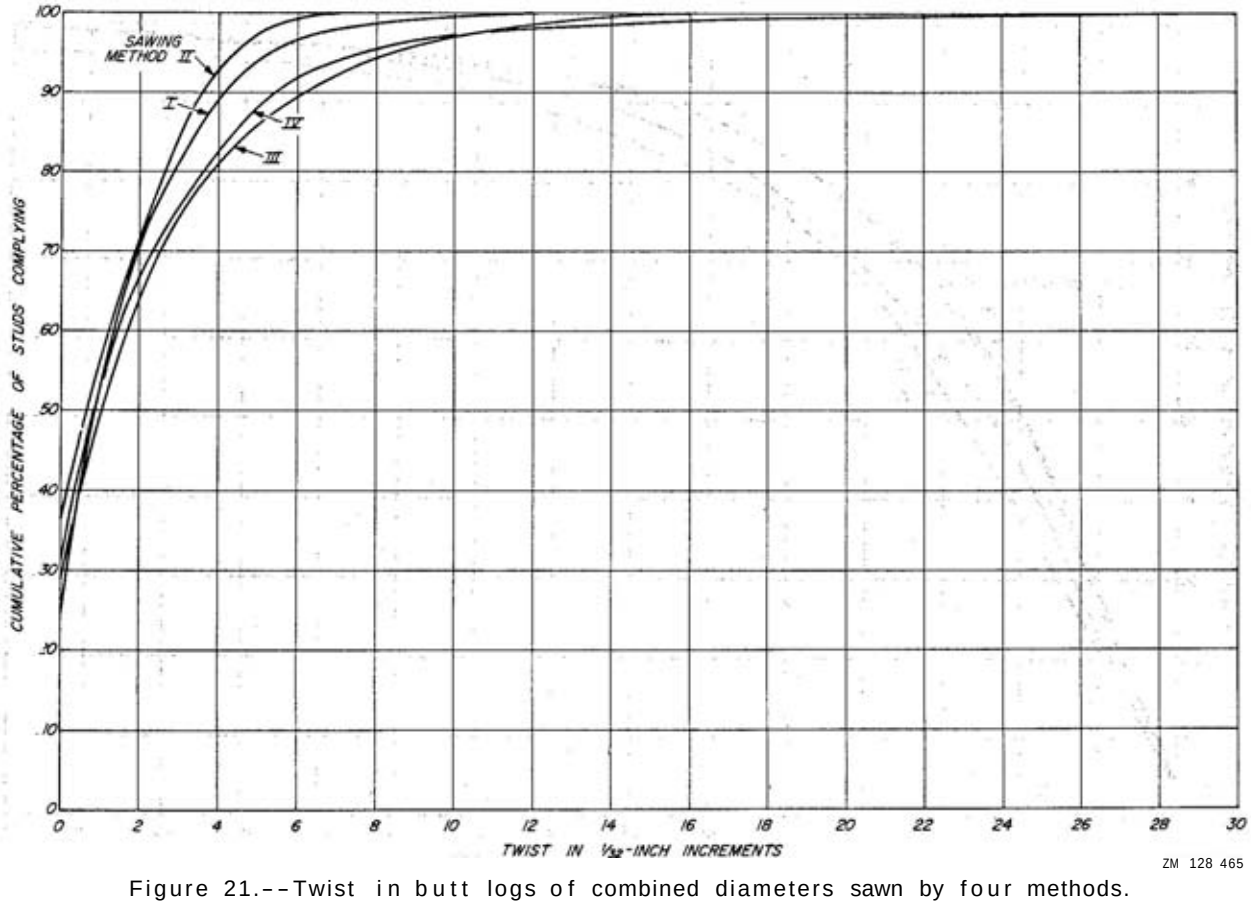


Figure 21.--Twist in butt logs of combined diameters sawn by four methods.

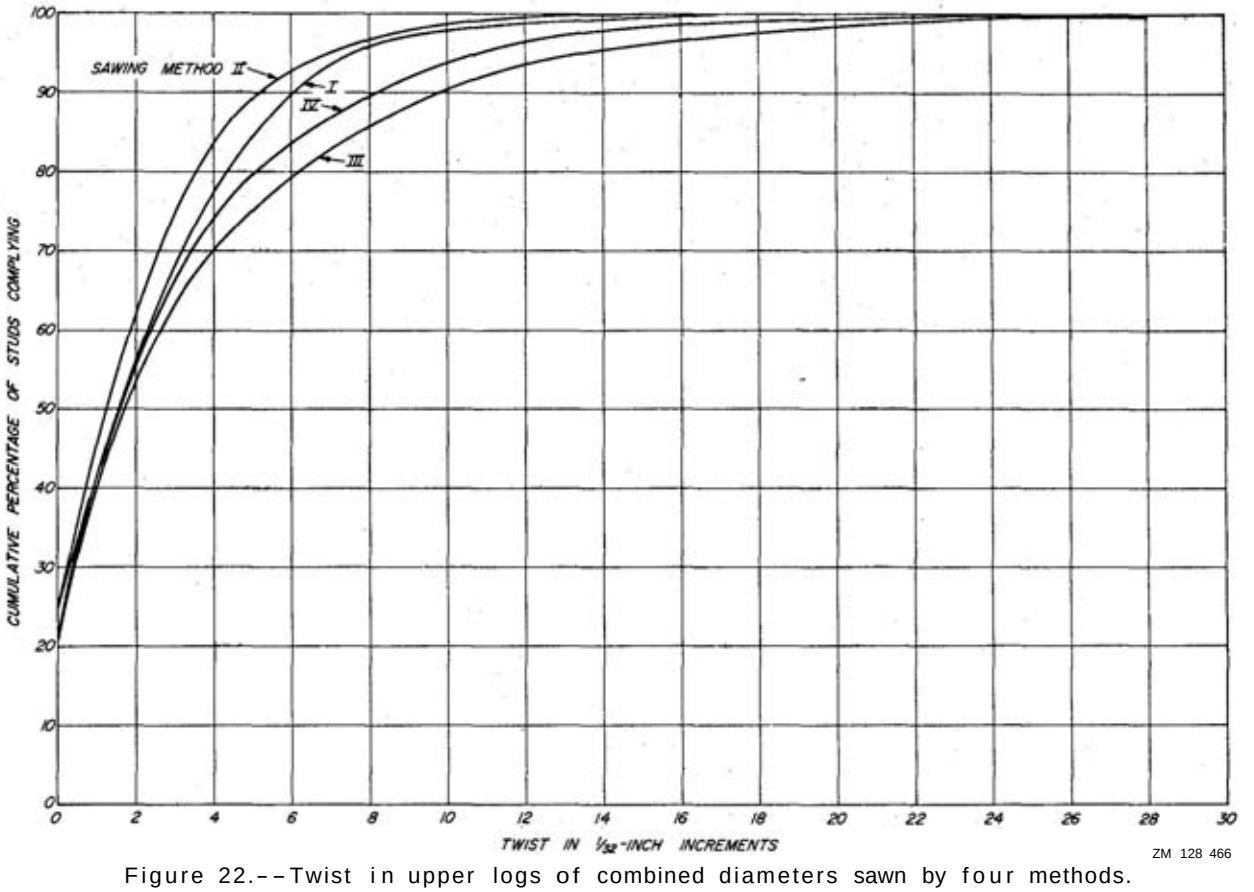


Figure 22.--Twist in upper logs of combined diameters sawn by four methods.

(fig. 19) show a superiority of Methods I and II over Method IV, which in turn is superior to Method 111. Little difference was found between Methods I and 11. At the 12/32-inch bow level ('Stud" grade) yields from Methods I and II are both 88.2 percent, Method IV 84.0 percent, and Method III 80.8 percent.

Chi-square tests of the proportions of studs with 12/32 bow or less indicated the superiority of Methods I and II over Method III to be significant at the 0.05 level, No significance was indicated for Methods I and II over Method IV, or for Method IV over Method III.

Similar comparisons for sawing methods on upper logs in terms of yields for bow (fig. 20) indicate little difference. In the range of 6/32 through 12/32 inches of bow, Method I was slightly superior, reaching a maximum difference of 2.2 percent over second place Method 111.

Chi-square tests indicated no statistical significance in the difference in bow between any of the sawing methods on upper logs.

Twist.--When the sawing methods were analyzed in terms of their influence on twist in butt logs (fig. 21) Method II was superior to Method I, which in turn was superior to Methods IV and 111. At the 8/32-twist level ("Stud" grade) yields by Method II were 100.0 percent, Method I 97.8 percent, Method IV 94.0 percent, and Method III 92.0 percent.

At the 8/32-twist level for butt logs Methods II and I were found to be significantly better at the 0.05 level than Method III. Both were also very close to showing significance at the 0.05 level over Method IV.

In upper logs (fig. 22) ranking was the same for the four sawing methods as with butt logs. At the 8/32 level the yield for Method II is 96.8 percent, Method I 95.9 percent, Method IV 89.4 percent, and Method III 85.7 percent.

Chi-square tests of the proportions of studs with 8/32-inch twist or less showed Method II to be significantly better than Method IV at the 0.05 level and Method III at the 0.01 level. The difference between Methods I and III was significant at the 0.05 level.

4. Comparison of All Warp Aspects in Relation to Each Sawing Method

Sawing methods influenced the individual aspects of warp differently. Some methods reduced crook but increased bow while others reduced bow but increased crook.

Figures 23 to 26 show the performance of sawing methods on the three aspects of warp, (crook, bow, and twist) for both butt and upper logs.

When logs are sawn by Method I, measured warp ,is lowest for twist in butt logs, then twist in upper logs, bow in upper logs, crook in upper logs, bow in butt logs, and highest warp in crook for butt logs (fig. 23).

Similar evaluation of Method II indicates measured warp as lowest for twist in butt logs, then twist in upper logs, crook in upper logs, bow in upper logs, bow in butt logs, and highest warp in crook for butt logs (fig. 24).

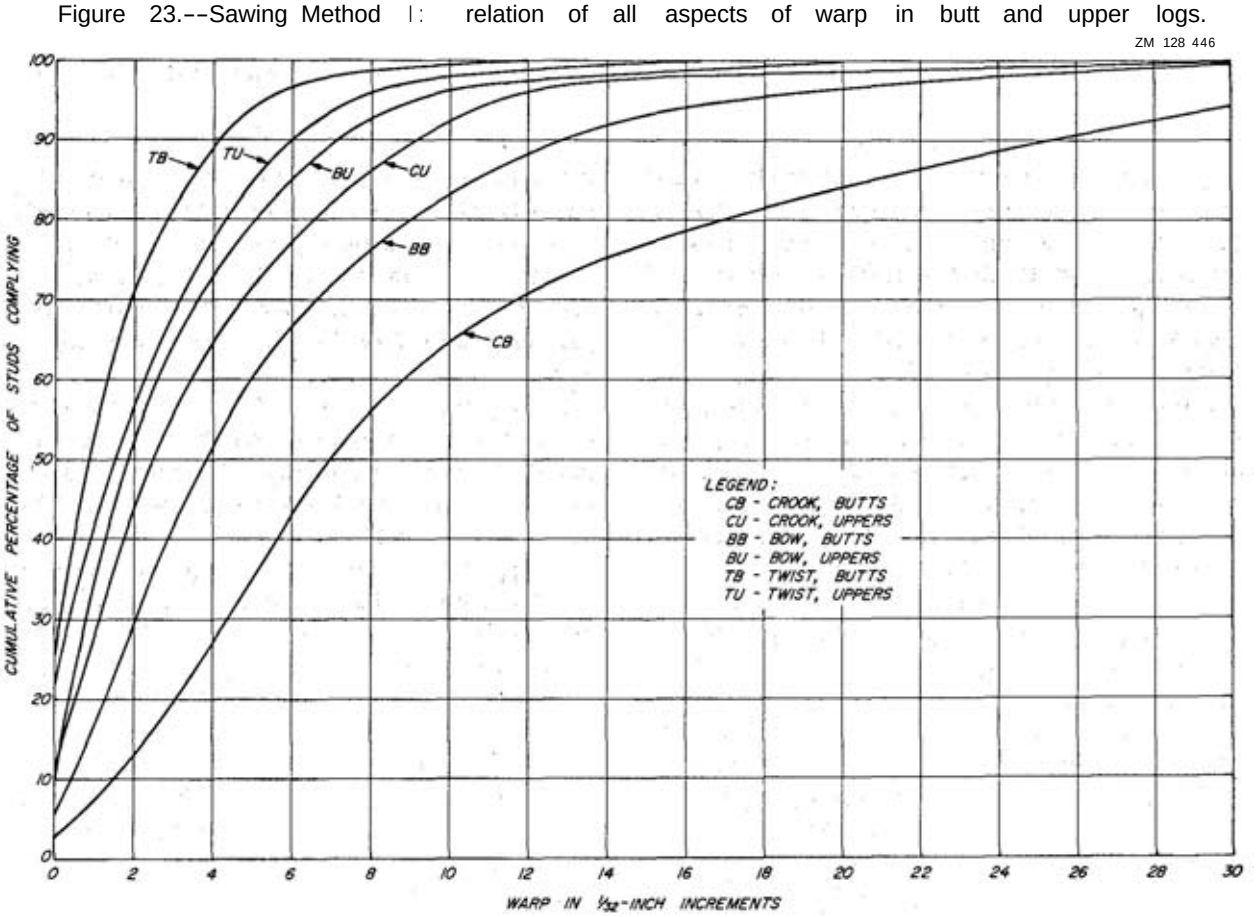
Method III shows little preference between crook in upper logs and twist in butt logs for lowest measured warp. These are followed by bow in upper logs, twist in upper logs, crook in butt logs, and highest warp occurs for bow in butt logs (fig. 25).

Logs sawn by Method IV showed least measured warp for twist in butt logs, followed by crook in upper logs. Next are twist and bow in upper logs, followed by crook in butt logs and highest in warp is bow from butt logs (fig. 26).

5. Effect of Position of Stud in Log in Relation to Each Warp Aspect

An analysis of the effect of the position of the stud in the log relative to its distance from the geometric center was made for all sawing methods, log diameters, and log positions. In any given combination, warp data were combined for studs in positions on opposite sides of, but similar distance from the center.

Figure 23.--Sawing Method I: relation of all aspects of warp in butt and upper logs.



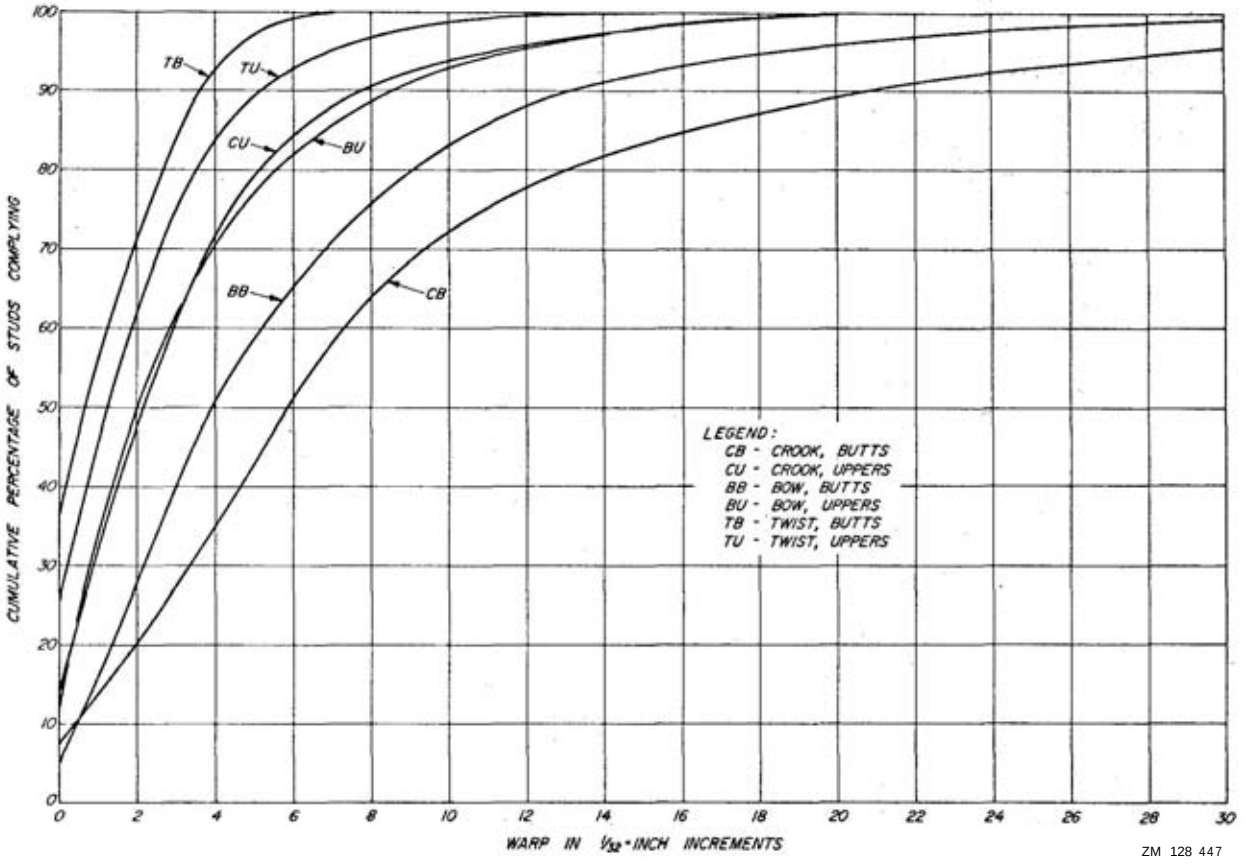


Figure 24.--Sawing Method II: relation of all aspects of warp in butt and upper logs.

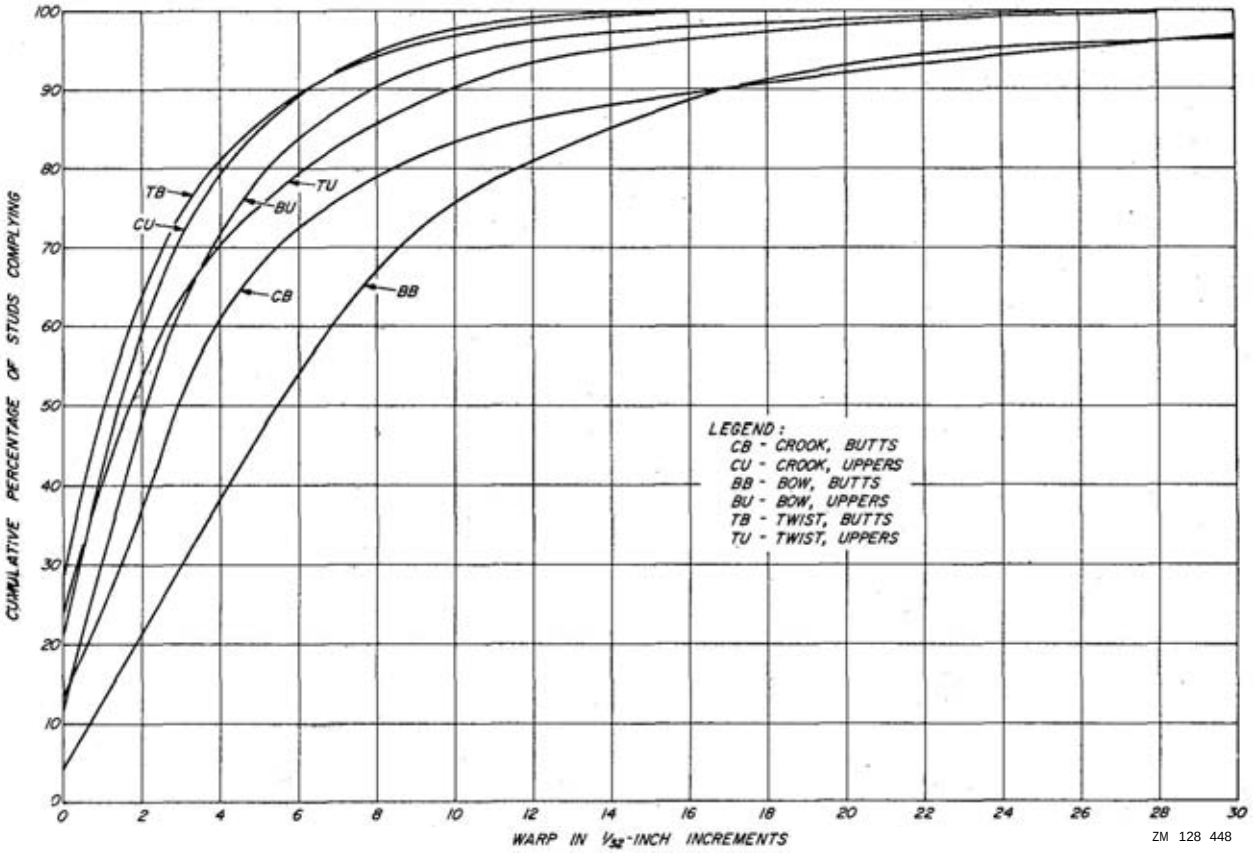


Figure 25.--Sawing Method III: relation of all aspects of warp in butt and upper logs.

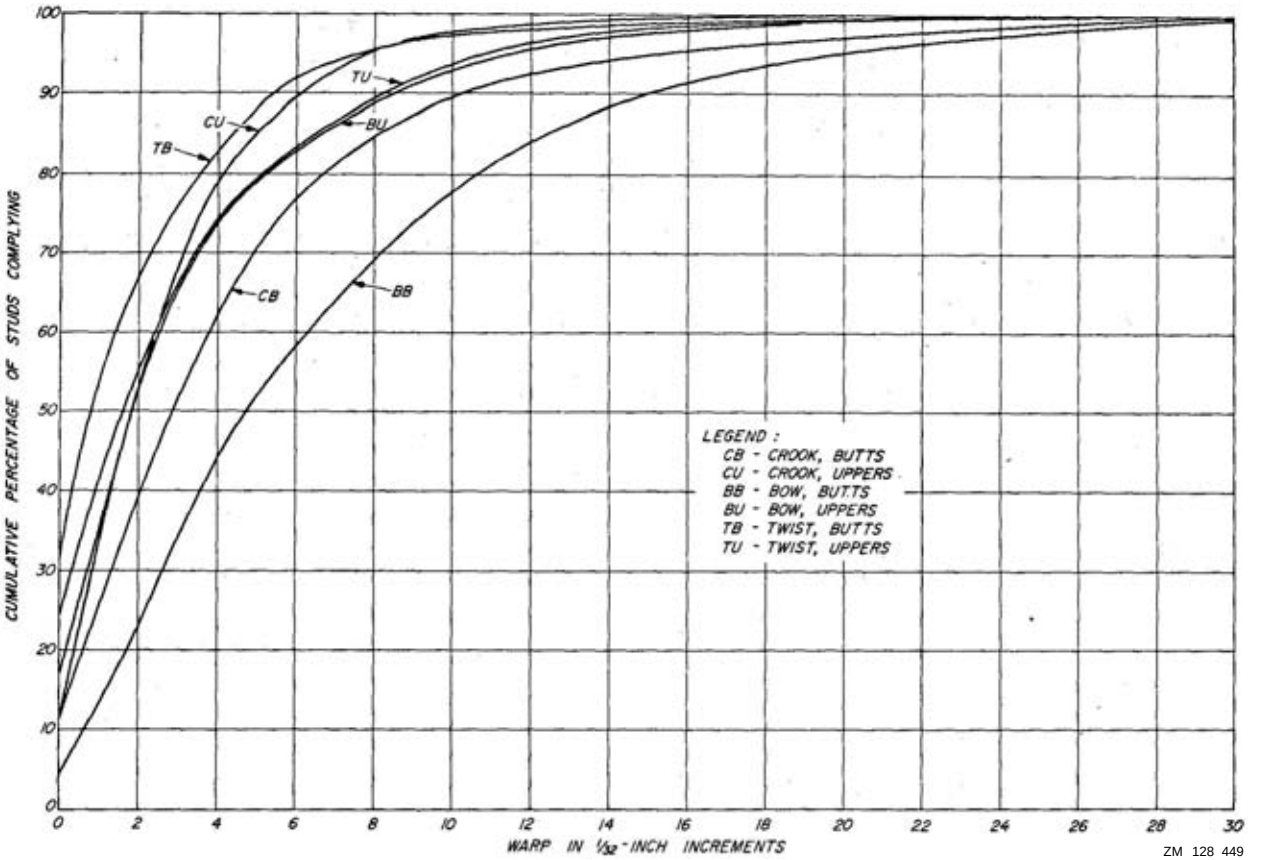


Figure 26.--Sawing Method IV: relation of all aspects of warp in butt and upper logs.

The results are presented in the following figures:

Figure 27. Crook in butt logs.
Figure 28. Crook in upper logs.
Figure 29. Bow in butt logs.
Figure 30. Bow in upper logs.
Figure 31. Twist in butt logs.
Figure 32. Twist in upper logs.
Figure 33. All warp in butt logs.
Figure 34. All warp in upper logs.

The figure shown in each rectangle representing a particular stud position is the yield in percentage of studs that meet the limitations for a particular warp aspect according to the SPIB "Stud" grade, Statistical significance between stud positions within a given log size-sawing method category is indicated by X^2P. The significance of a difference between sawing methods is indicated by X^2M.

In the 6-inch diameter class no differences are shown as only two studs are possible and they are the same relative distance from the center.

In the 10-inch class sawn by Methods I and II it was possible to develop six studs from the upper half of the diameter class (10.0 to 10.5 inches) while the lower half (9.6 to 10.0 inches) yielded only four studs. For those 10-inch logs yielding only four studs, no differences in yields are shown because all are equidistant from the center, just as in the 6-inch class.

Generally speaking, crook and bow in butt logs decreased significantly with increased distance from the center. This same relationship exists for twist in upper logs and to a somewhat lesser degree for crook and bow in upper logs.

Specifically the decrease in crook with increased distance from the center was significant for all sawing methods and diameters of butt logs. In upper logs the same relationship was found but it proved significant only in the 12-inch class.

Bow decreased significantly with increasing distance from the center in butt logs in the 8-, 10-, and 12-inch classes sawn by Methods III and IV, and in the 12-inch diameter sawn by Methods I and 11. In upper logs, this relationship

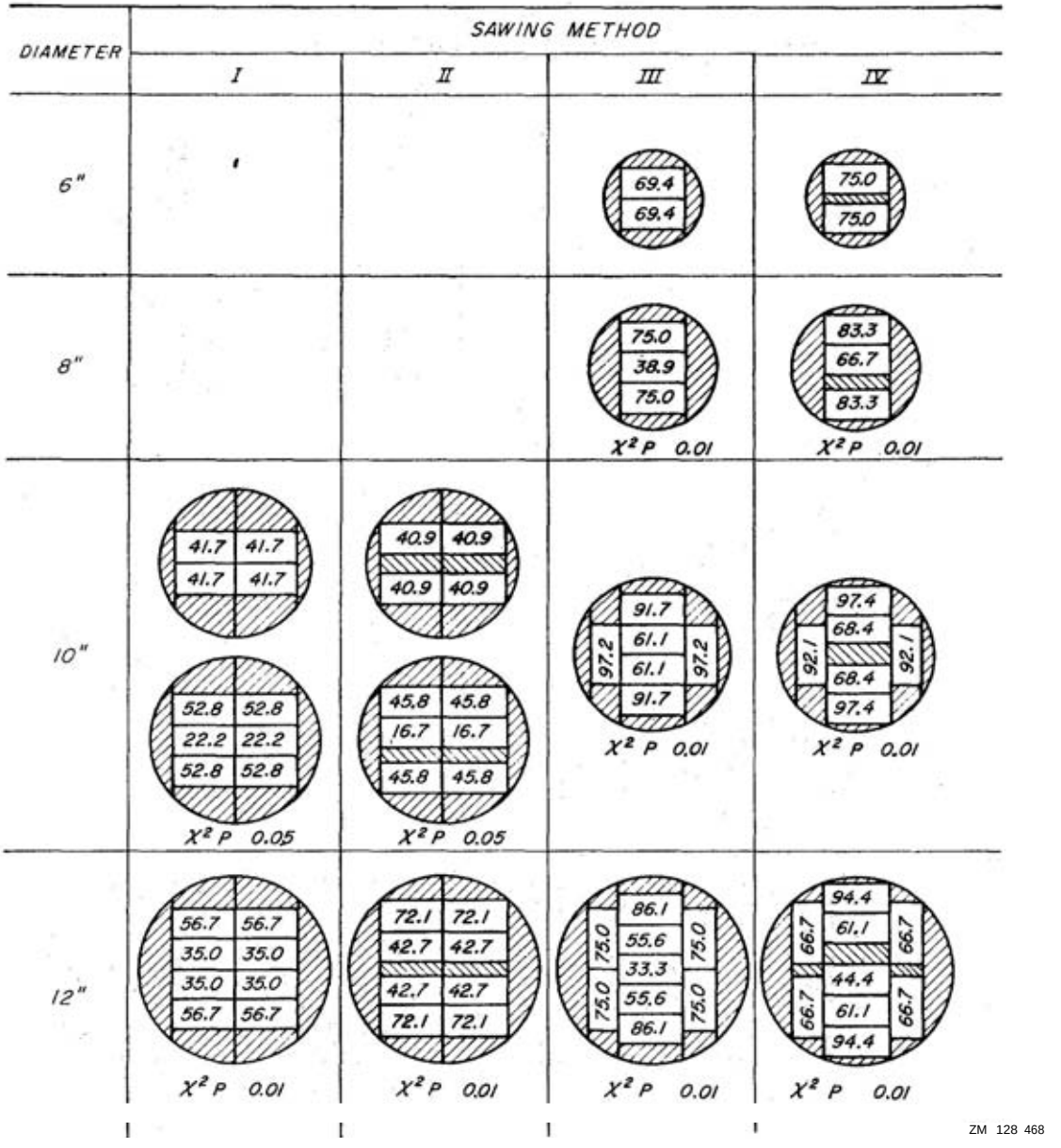


Figure 27.--Crook in butt logs: effect of stud position. Values are percentages of studs meeting crook limitations for SPIB "Stud" grade. Statistical significance for differences due to position is indicated by X^2P.

12-inch classes sawn by Methods I and 11.

The relationship of the degree of twist to the distance from the center of the log in butt logs is confusing, For the 10-inch class sawn by Methods III and IV, an increasing tendency to twist with increasing distance from the center is noted, although not quite significant at the 0.05 level. For the 12-inch class sawn by both Methods III and IV, twist tended to decrease with increased distance from the center but was not significant. There is probably no actual relationship between distance from the center and degree of twist for the butt logs.

Decreased twist with increasing distance from the center was significant in all diameters of upper logs sawn by Methods III and IV but of no significance when sawn by Methods I and II.

When all aspects of warp are considered together, decreasing warp with increasing distance from the center in butt logs is Significant in all diameters sawn by all methods. For upper logs the same relationship is significant

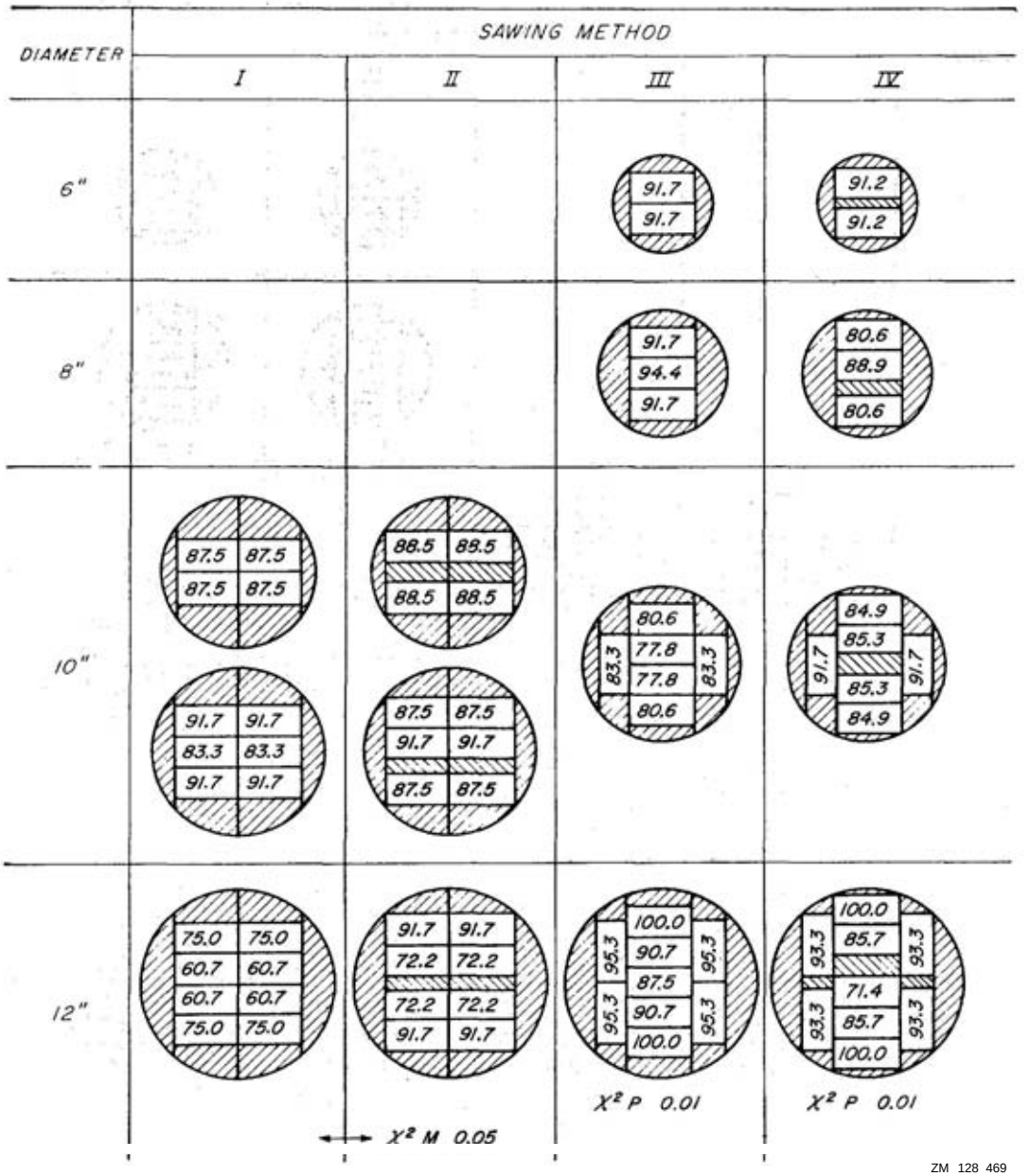


Figure 28.--Crook in upper logs: effect of stud position. Values are percentages of studs meeting crook limitations for SPIB "Stud" grade. Statistical significance for differences due to position is indicated by X^2P, between similar methods by X^2M.

for all diameters sawn by Methods III and IV. This relationship is also noted for the 12-inch upper logs sawn by Methods I and II. No relationship is noted for the 10-inch diameter upper logs sawn by Methods I and II.

Analyses of variance of mean crook, bow, and twist for the various stud positions in the 8- and 12-inch classes sawn by Methods III and IV gave the following information:

(1) For crook, stud positions differed significantly at the 0.05 level for 8-inch logs and at the 0.01 level for the 12-inch logs. The interaction of stud position and log position is significant at the 0.01 level for both diameters.

(2) When bow is the criterion, stud positions differ significantly (0.01 level) for both diameters, and the interaction of stud and log position is significant at the 0.01 level.

(3) Stud positions also differ significantly (0.01 level) for both diameters when considered in terms of twist. The interaction of stud and log positions is again significant at the 0.01 level.

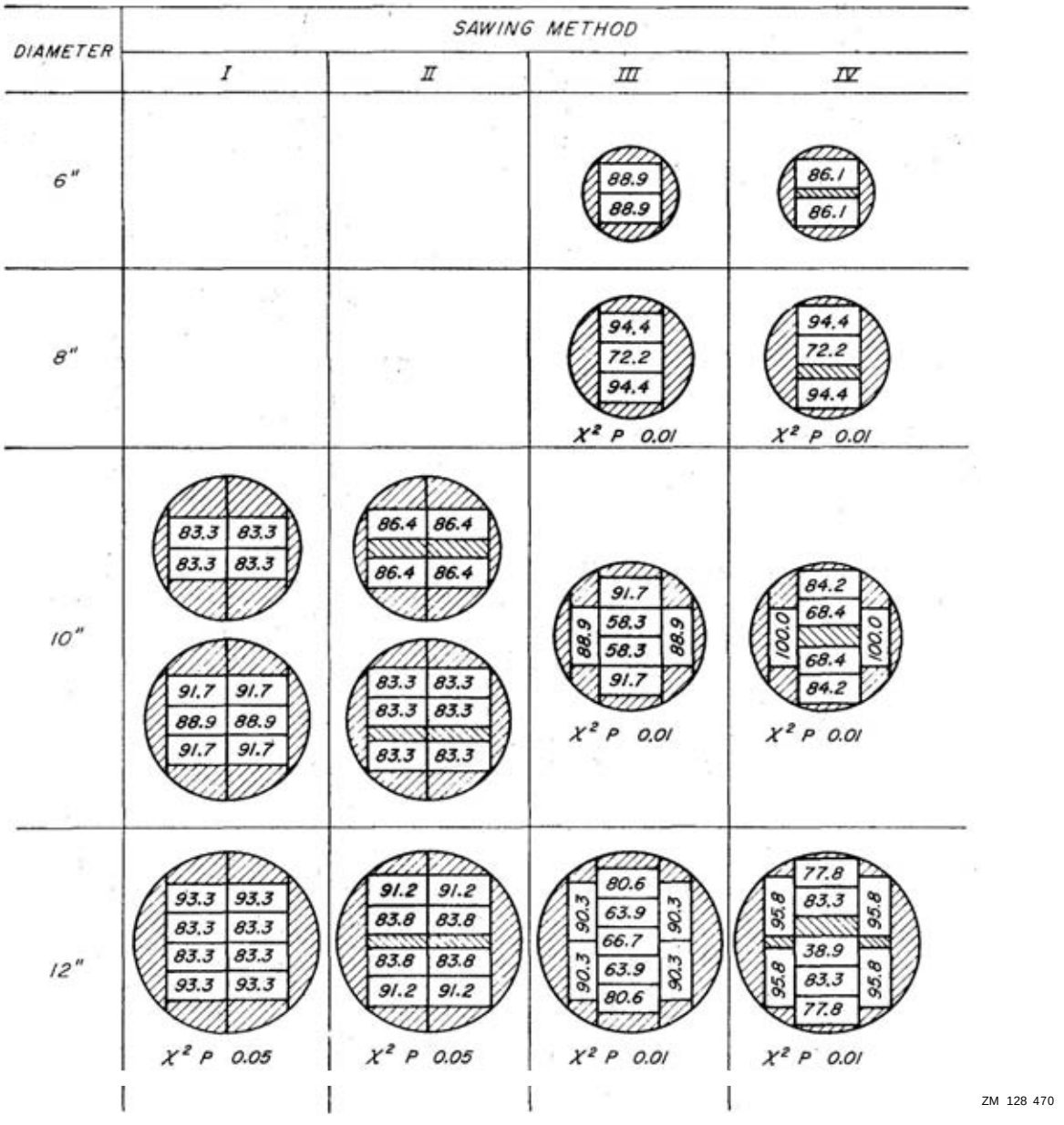


Figure 29.--Bow in butt logs: effect of stud position. Values are percentages of studs meeting bow limitations for SPIB "Stud" grades.

6. Effect of Log Diameter on Warp

The effect of log diameter on warp was evaluated two ways: the first based on yields in SPIB grades of "Stud" and No. 1 Dimension, and the second on analysis of variance based on mean warp.

Table 3 shows the effect of diameter in butt and upper logs in percentages of studs meeting the limits of warp imposed by the SPIB grades of "Stud" or No. 1 Dimension. Recovery percentages are shown separately for the three forms of warp and for all combined. Sawing Methods I and II have been combined, as have Methods III and IV, as there seems to be no reason why difference due to diameter would be further affected by the difference between Methods I and II and between Methods III and IV.

For upper logs, diameter appears to have a definite influence on yields of studs in both the SPIB grades of "Stud" and No. 1 Dimension when sawn by Methods III and IV. Table 3 shows (for

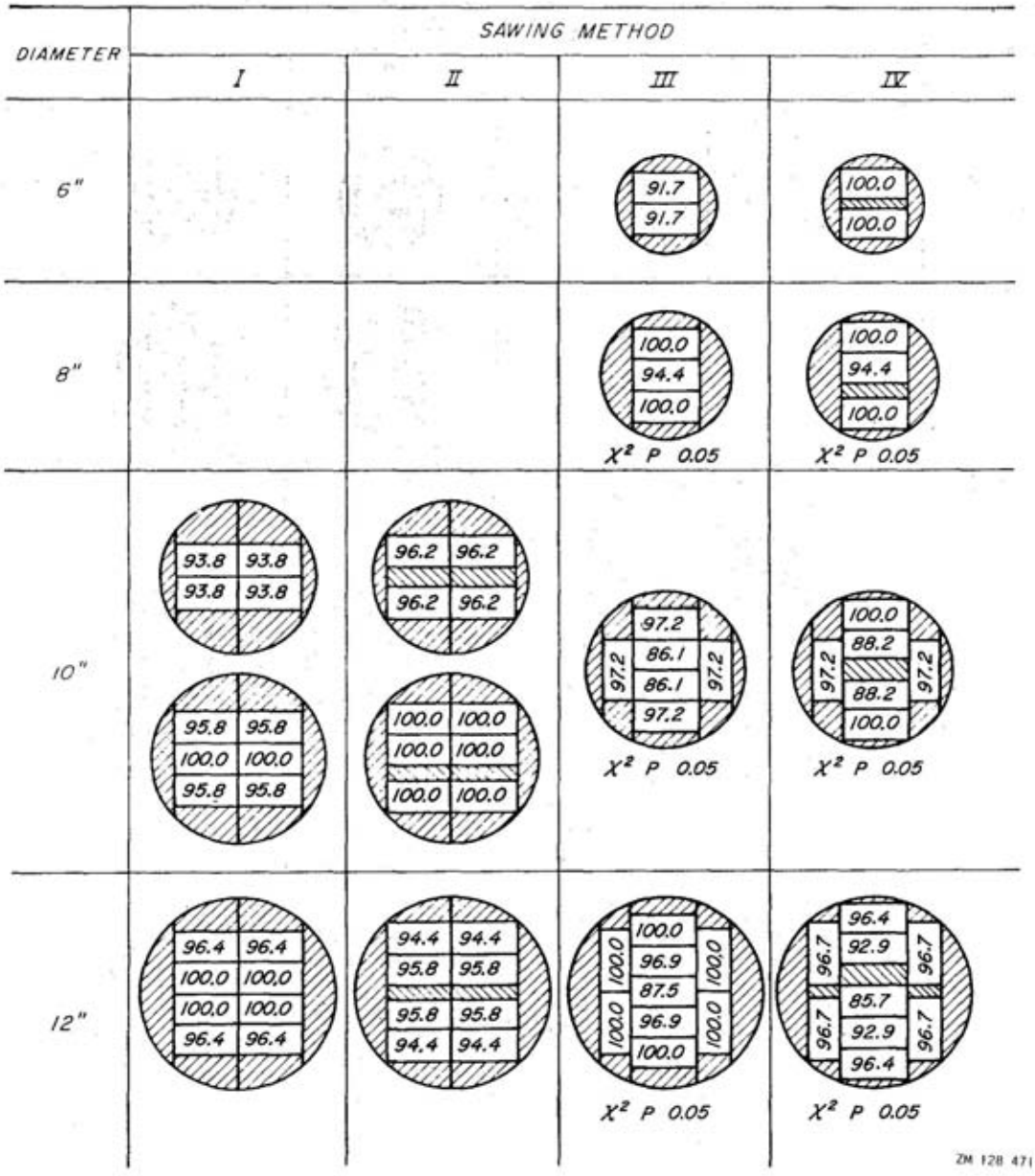


Figure 30.--Bow in upper logs: effect of stud position. Values are percentages of studs meeting bow limitations for SPIB "Stud" grade.

all warp in "Stud" grade) yields of 62.9, 70.4, 73.4, and 84.4 percent for 6-, 8-, 10-, and 12-inch upper logs, respectively. Investigations of the yield for the individual types of warp indicate that crook and bow are not consistently related to diameter but twist is. Because twist is the most important degrading factor in upper logs, of course it is reflected in the total "all warp" yields. Similar relationships are indicated when No. 1 Dimension warp specifications are applied.

For butt logs there appears to be a weak trend toward increased bow with increased diameter when the logs are sawn by Methods III and IV. Yields in "Stud" grade for bow (table 3) are 87.5, 87.5, 82.0, and 81.0 percent for 6-, 8-, 10-, and 12-inch logs, respectively. With butt logs, bow is not the most important form of warp and the all warp yields do not reflect a relationship to diameter. Similar relationships are indicated for the yields in No. 1 Dimension grade.

Analysis of variance of logs sawed by Methods

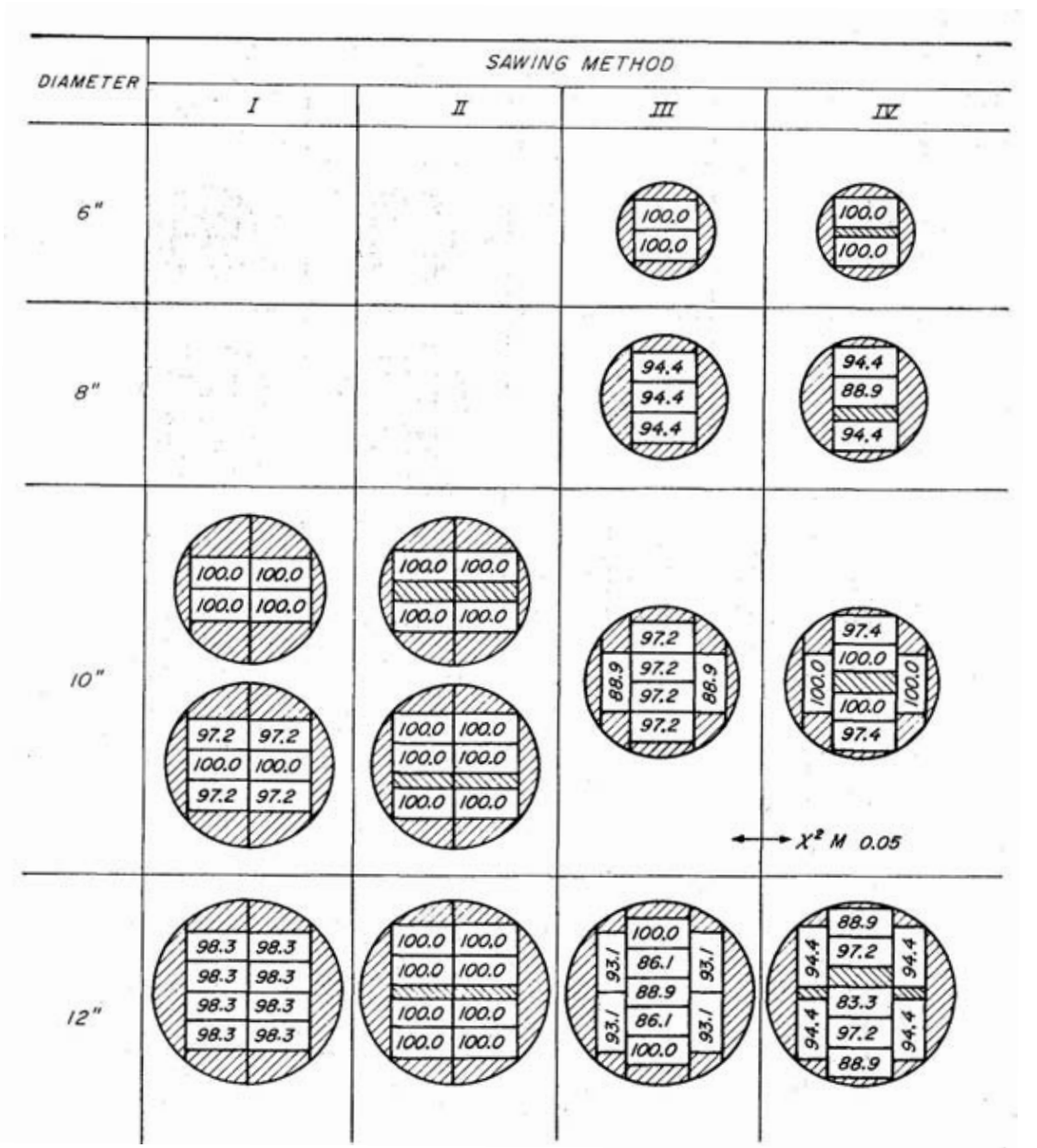


Figure 31.--Twist in butt logs: effect of stud position. Values are percentages of studs meeting twist limitations for SPIB "Stud" grade.

III and IV showed that the 8- and 12-inch classes differed significantly (0.01 level) in mean twist. For mean twist, the interaction between log position (butt or upper) and diameter was also significant at the 0.01 level.

Similar analysis showed that diameters also differed significantly (0.05 level) in average bow. The interaction of log position and diameter was not significant at the 0.05 level but did approach it.

7. Effect of Compression Wood and Cross Sectional Eccentricity on Warp

Compression wood has long been recognized as a prime cause of warp, especially crook and bow, in softwood lumber. Logs containing visible compression wood are usually more eccentric than other logs, and the compression wood is almost always found in the cross sectional quadrant bisected by the longest radius. In other

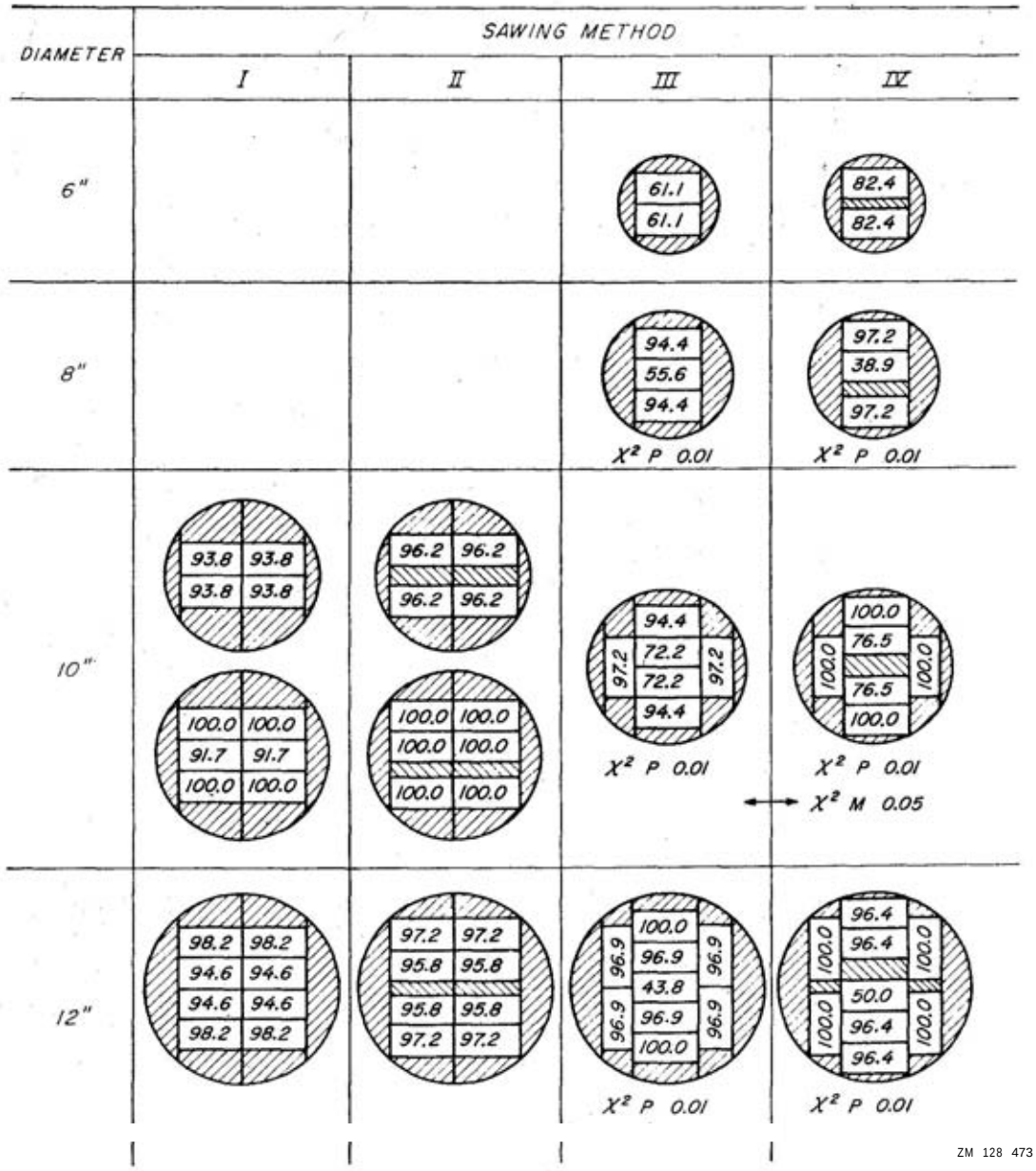


Figure 32.--Twist in upper logs: effect of stud position. Values are percentages of studs meeting twist limitations for SPIB "Stud" grade.

words, the eccentricity coincides with the compression wood.

There is a question, apparently uninvestigated, whether radial eccentricity independent of compression wood has any effect on warp of sawn lumber. The application of all the sawing methods to each of two eccentricity positions (figs. 3 and 4) within an equal number of logs in each variable combination class was undertaken to yield information on this question.

Table 4 shows in summary form the percentages of studs meeting the warp limitations of SPIB "Stud" grade. Yields are shown for compression wood and normal wood logs sawn with radial eccentricity positioned vertically as shown in figure 4 or horizontally as shown in figure 3. Yields in all categories are given for Sawing Methods I-II, Methods III-IV, and all methods combined. Part of the same data is presented in figure 35.

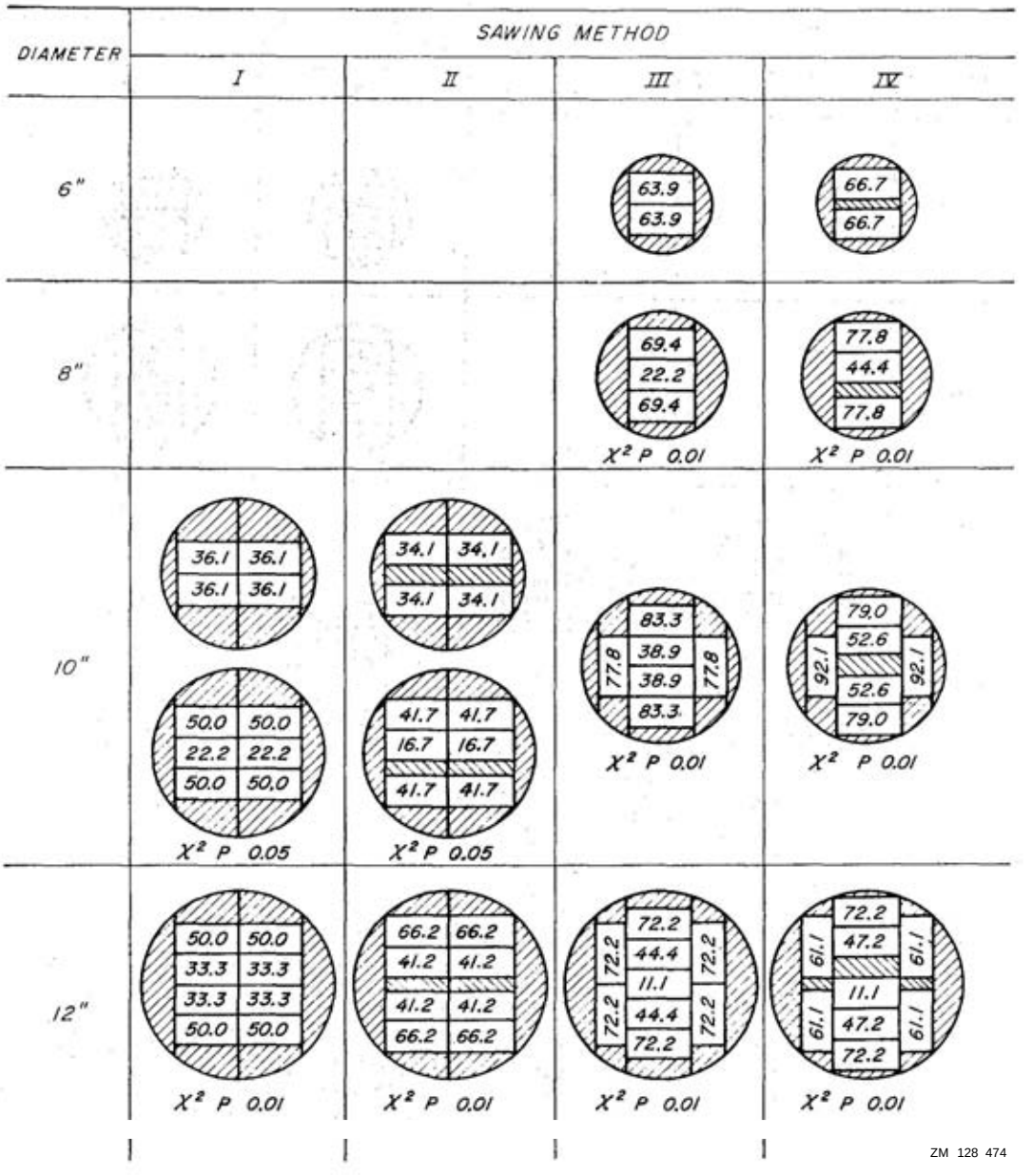


Figure 33.--All warp in butt logs: effect of stud position. Values are percentages of studs meeting all warp limitations for SPIB "Stud" grade.

Generally speaking, logs with compression wood yielded studs with greater tendency to warp than for normal wood. The difference was slightly greater in butt logs than in uppers. The findings and level of statistical significance are summarized, with percentage figures based on studs meeting SPIB "Stud" grade warp limitations:

Butt Logs--

Sawing Methods I-II

Crook - Compression wood logs inferior by 10.9 percent; significant at 0.05 level.

Bow - Compression wood logs inferior by 4.3 percent; not significant.

Twist - Apparently not affected by presence of compression wood.

All warp - Compression wood logs inferior by 11.5 percent; significant at 0.01 level.

Sawing Methods III-IV

Crook - Compression wood logs inferior by 15.0 percent; significant at 0.01 level.

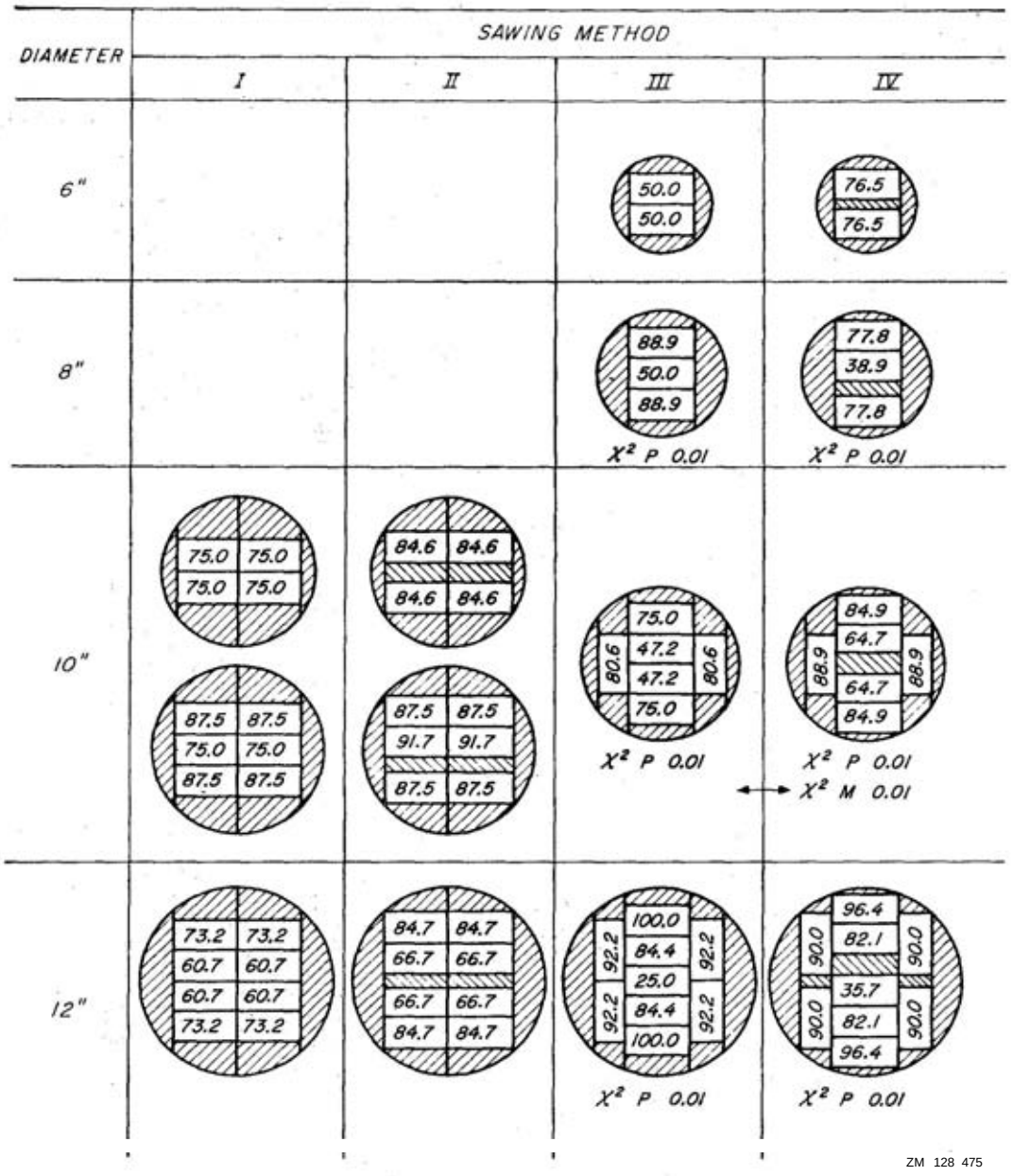


Figure 34.--All warp in upper logs: effect of stud position. Values are percentages of studs meeting all warp limitations for SPIB "Stud" grade.

Bow - Compression wood logs inferior by 4.5 percent; not significant.

Twist - Apparently not affected by presence of compression wood.

All warp - Compression wood logs inferior by 13.4 percent; significant at 0.01 level.

Upper Logs--

SawingMethods1-11

Crook - Compression wood logs inferior by 15.3 percent; significant at 0.01 level.

Bow - Compression wood logs inferior by 2.4 percent; not significant.

Twist - Apparently not affected by presence of compression wood.

All warp - Compression wood logs inferior by 16.6 percent; significant at 0.01 level.

Sawing Methods III-IV

Crook - Compression wood logs inferior by 3.0 percent; not significant.

Bow - Apparently not affected by presence of compression wood.

Twist - Apparently not affected by presence

Table 3.--Yields of studs by diameter classes in two SPIB grades

Warp aspect	Sawing method	Diameter of--							
		Butt logs (inches)				Upper logs (inches)			
		6	8	10	12	6	8	10	12
		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
		STUD GRADE							
Crook	I-II	--	--	40.6	50.7	--	--	88.1	76.0
	III-IV	72.2	70.5	84.7	69.1	91.4	88.0	84.1	92.7
Bow	I-II	--	--	86.5	88.3	--	--	96.6	96.6
	III-IV	87.5	87.5	82.0	81.0	95.7	98.2	94.4	96.7
Twist	I-II	--	--	99.4	99.3	--	--	96.6	96.9
	III-IV	100.0	93.8	96.9	92.7	71.4	79.6	89.7	92.4
All Warp	I-II	--	--	36.5	47.1	--	--	82.4	72.6
	III-IV	65.3	60.7	70.7	57.1	62.9	70.4	73.4	84.4
		NO. 1 DIMENSION GRADE							
Crook	I-II	--	--	60.6	67.5	--	--	94.9	89.0
	III-IV	83.3	81.3	91.9	80.9	100.0	96.3	95.8	97.7
Bow	I-II	--	--	93.5	96.0	--	--	98.9	99.3
	III-IV	98.6	94.6	90.1	92.4	97.1	99.1	97.2	98.0
Twist	I-II	--	--	100.0	100.0	--	--	98.9	99.3
	III-IV	100.0	98.2	98.2	97.3	82.9	89.8	96.3	98.0
All Warp	I-II	--	--	59.4	66.4	--	--	92.6	88.0
	III-IV	83.3	77.7	83.3	77.3	81.4	86.1	89.7	94.0

was significant in the 8-, 10-, and 12-inchclasses sawn by Methods III and IV but not in the 10- and of compression wood.

All warp - Compression wood logs inferior by 1.3 percent; not significant.

The apparent lower severity of bow than crook in studs sawn from compression wood butt logs was not a result of less warp, but reflects in part the increased allowance for bow in the grade (crook 6/32 inch, bow 12/32 inch). The actual amount of the deflection was not greatly different between crook and bow. In upper logs, compression wood did not affect warp significantly except crook when the logs were sawn by Methods 1-11. The overriding effect of the crook is reflected in the all warp figure for this category.

In neither butt nor upper logs did compression wood appear to be correlated with the amount of twist.

The effect of altering the rotational position of the radial eccentricity between horizontal and vertical on the yields of studs meeting the requirements of the SPIB grades is also shown in tables 4 and 5. For Methods III-IV, this information is also presented in figure 36.

For butt logs sawn by Methods III-IV, positioning the radial eccentricity horizontally results in increased yields of studs meeting the all warp specifications of "Stud" grade of 5.9 percent in compression wood logs and 8.7 percent in normal wood logs. Although this difference is just short of statistical significance, the author feels it is a real difference as it appears consistently in the same direction in all individual analyses summed to form table 4 and figure 36.

The rotational position of radial eccentricity seems to have a definite influence on crook and bow in butt logs, both compression wood and normal wood. There is some evidence that longitudinal compression stresses related to

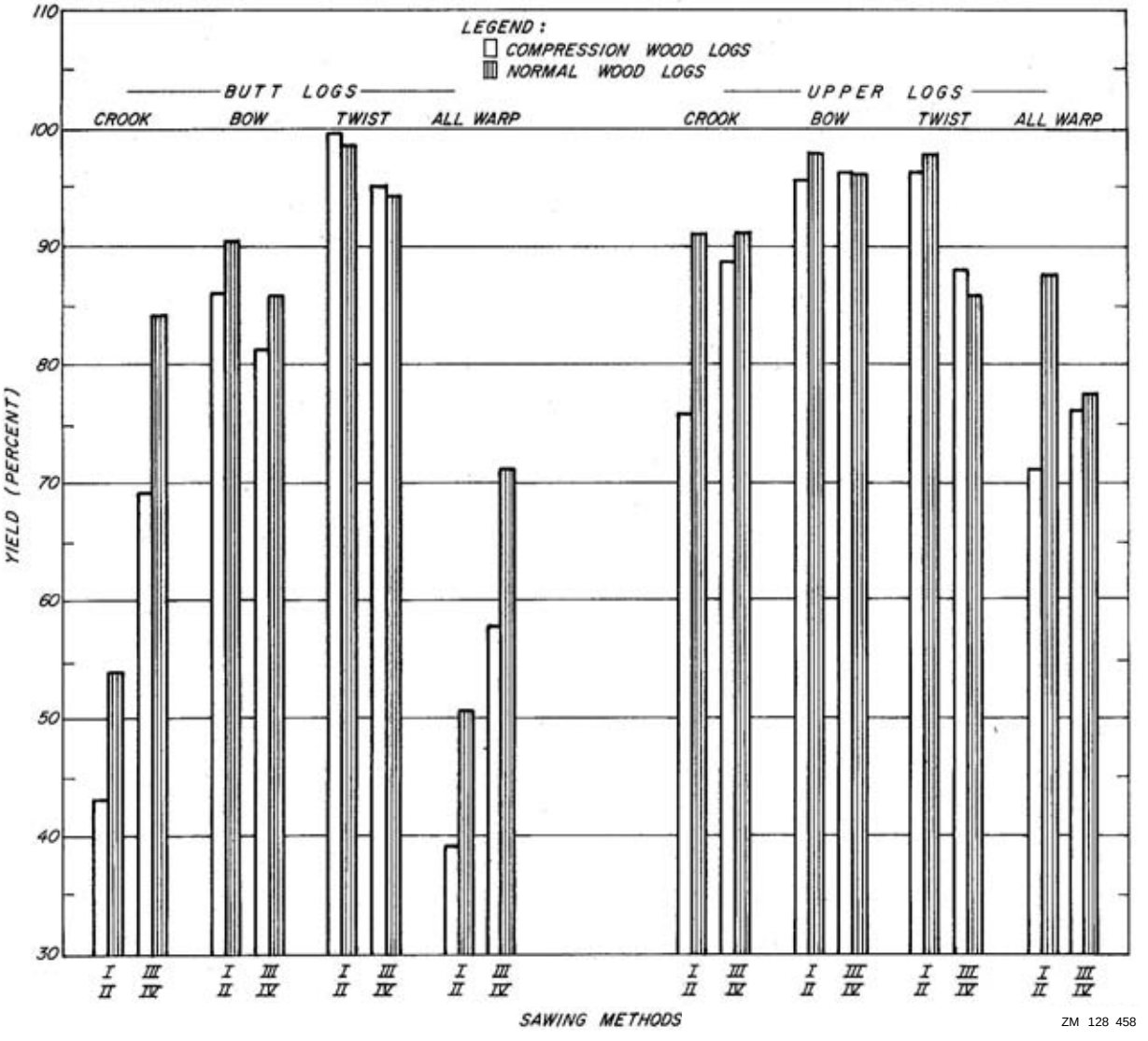


Figure 35.--The effect of compression wood on warp by sawing methods for all diameters of butt and upper logs. Yields are percentages of studs meeting warp limits of SPIB "Stud" grade.

radial eccentricity are developed during drying, and that these are opposed to the longitudinal tension stresses of drying compression wood.

Reason suggests that positioning of log eccentricity is important in distribution of compression wood in studs sawn from the 4-inch center cant by Methods III and IV. If a compression wood log is sawn with its longest radius vertical (fig. 4), compression wood should be more evenly distributed across the 4-inch dimension of studs sawn from the 4-inch center cant than if sawn with the long radius horizontal (fig. 3). With long radius horizontal, compression wood should be concentrated along the edges of one, two, or three of the studs from the center 4-inch cant.

As the longitudinal shrinkage of compression wood is much higher than normal wood, the studs from logs with long radius vertical should exhibit less crook than when the long radius is horizontal. For butt logs this was seldom the case. Perhaps the normal shrinkage of the compression wood was being restrained by a second force, or longitudinal shrinkage greater than normal was taking place in the balance of the stud.

In normal wood butt logs the effect of radial eccentricity is also least damaging if the sawing pattern is applied with the long radius horizontal.

Table 4.--Percentage of studs meeting "Stud" grade for vertical and horizontal eccentricity positioning of normal wood and compression wood logs

Warp aspect	Sawing method	Compression wood logs			Normal wood logs		
		Vertical	Horizontal	All	Vertical	Horizontal	All
			BUTT LOGS				
Crook	I-II	44.3	42.3	43.2	51.4	56.8	54.1
	III-IV	66.3	72.3	69.3	81.0	87.4	84.3
	All	58.2	60.6	59.4	69.7	76.1	73.0
Bow	I-II	85.0	87.2	86.2	96.0	85.1	90.5
	III-IV	77.5	85.1	81.4	80.2	91.3	85.9
	All	80.3	85.9	83.2	86.2	89.1	87.6
Twist	I-II	100.0	99.4	99.7	98.7	98.7	98.7
	III-IV	97.1	93.2	95.1	94.2	94.5	94.4
	All	98.2	95.6	96.8	95.9	96.0	96.0
All warp	I-II	40.0	38.5	39.2	50.0	51.4	50.7
	III-IV	55.0	60.9	58.0	66.9	75.6	71.4
	All	49.5	52.2	50.9	60.5	66.7	63.6
			UPPER LOGS				
Crook	I-II	78.4	73.2	75.8	92.9	89.5	91.1
	III-IV	88.2	88.3	88.2	92.0	90.4	91.2
	All	84.3	82.0	83.1	92.4	90.0	91.2
Bow	I-II	96.2	95.7	95.6	98.6	97.4	98.0
	III-IV	97.0	95.3	96.2	95.6	96.5	96.0
	All	96.7	95.4	96.1	96.7	96.8	96.8
Twist	I-II	96.2	96.3	96.3	98.6	97.4	98.0
	III-IV	89.4	87.0	88.2	89.4	82.5	85.9
	All	92.1	90.9	91.5	92.9	88.4	90.6
All warp	I-II	73.4	68.9	71.1	90.0	85.5	87.7
	III-IV	77.1	75.3	76.2	80.5	74.6	77.5
	All	75.6	72.7	74.1	84.2	79.0	81.5

The differences also are substantially greater than in compression wood logs, further suggesting a degree of neutralization between the warping tendencies' resulting from compression wood and those related to eccentricity.

To further cloud the issue, better grade yields were obtained from upper logs sawn by Methods III and IV if the sawing pattern was applied with the radial eccentricity vertical. Differences are slight for compression wood logs but are a substantial 5.9 percent for normal wood logs, again indicating some interaction between radial eccentricity and compression wood.

Table 5 gives similar information in terms of the warp limitations imposed by SPIB grade No. 1 Dimension.

8. Effect of Log Position on Warp

The incidence of severe crook and bow was found to be much greater in butt logs than in upper logs. On the other hand, twist was more pronounced in upper logs. This agrees with the findings of Kano, Nakagawa, Saito, and Oda (7) on Japanese larch (*Latrix leptolepis* Gordon).

Table 5.--Percentage of studs meeting No. 1 Dimension grade for vertical and horizontal eccentricity positioning of normal wood and compression wood logs

Warp aspect	Sawing method	Compression wood logs			Normal wood logs		
		Vertical	Horizontal	All	Vertical	Horizontal	All
			BUTT LOGS				
Crook	I-II	62.9	60.3	61.5	71.6	71.6	71.6
	III-IV	77.5	83.1	80.3	89.3	96.1	92.7
	All	72.1	74.3	73.2	82.6	87.1	84.9
Bow	I-II	96.4	92.3	94.3	98.7	94.6	96.6
	III-IV	88.8	94.8	91.8	94.2	96.1	95.2
	All	91.6	93.8	92.7	95.9	95.5	95.7
Twist	I-II	100.0	100.0	100.0	100.0	100.0	100.0
	III-IV	99.2	96.4	97.8	98.4	98.4	98.4
	All	99.5	97.8	98.6	99.0	99.0	99.0
All warp	I-II	62.1	58.3	60.1	70.3	71.6	71.0
	III-IV	72.5	78.2	75.4	85.1	91.3	88.3
	All	68.7	70.5	69.6	79.5	84.1	81.8
			UPPER LOGS				
Crook	I-II	88.6	87.8	88.2	98.6	97.4	98.0
	III-IV	96.2	95.7	95.9	99.1	100.0	99.6
	All	93.2	92.4	92.8	98.9	99.0	98.9
Bow	I-II	98.7	98.8	98.8	100.0	100.0	100.0
	III-IV	98.3	97.0	97.6	97.4	99.1	98.2
	All	98.5	97.7	98.1	98.4	99.5	98.9
Twist	I-II	99.4	98.8	99.1	98.6	100.0	99.3
	III-IV	94.5	95.2	94.9	97.4	91.2	94.3
	All	96.5	96.7	96.6	97.8	94.7	96.3
All warp	I-II	86.7	86.0	86.3	97.1	97.4	97.3
	III-IV	89.4	89.2	89.3	93.8	90.3	92.1
	All	88.3	87.9	88.1	95.1	93.2	94.1

Kloot and Page (10), in their work on *Pinus radiata* found that 2x4 and 2x3 scantlings sawn from 10-foot butt logs have a much greater tendency to crook and bow than those sawn from the 10-foot log immediately above. They did not, however, find any correlation between log position and twist.

The effect of log position on the percentage of studs meeting SPIB grades "Stud" and No. 1 Dimension by Methods I-II and Methods III-IV is summarized in table 6. Figure 37 shows values for "Stud" grade only. For Methods I-II the difference between upper logs and butt logs, in percent of studs meeting the crook specification of "Stud" grade, was 33.7 percent. For No. 1 Dimension the difference for upper and butt logs was 26.3 percent (table 6). When Methods III-IV are used, the figures are 14.9 percent and 12.6 percent, respectively.

When bow is considered and the logs are sawn by Methods 1-11, yields from upper logs are better than butt logs by a margin of 9.0 percent

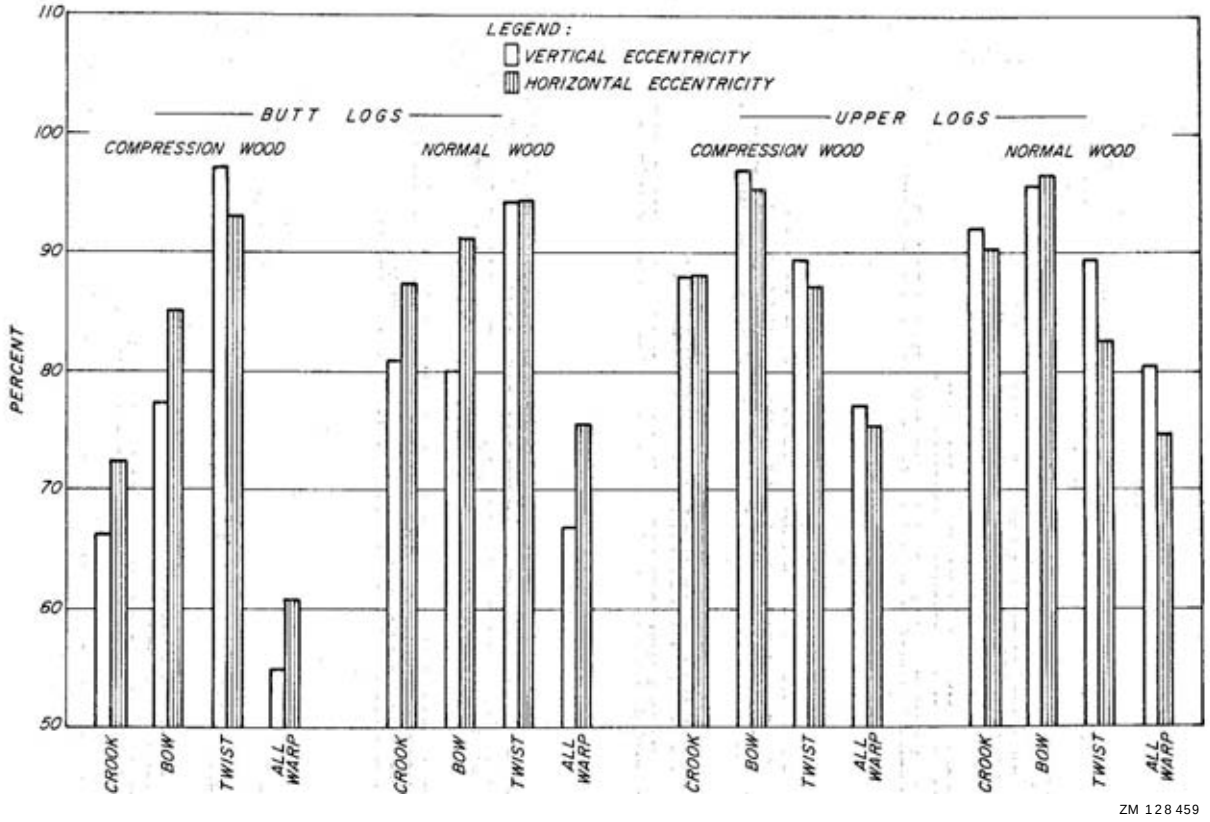


Figure 36.--The effect of vertical and horizontal positioning of log radial eccentricity on warp for compression wood and normal wood butt and upper logs sawn by Methods III and IV. Yields are percentages of studs meeting the warp limits of SPIB "Stud" grade.

in "Stud" grade and 4.1 percent in No. 1 Dimension. The figures for Methods III and IV are 12.8 percent and 4.9 percent.

The yields in terms of studs meeting twist specifications favor the butt logs. When sawn by Methods III–IV, butt logs produce 7.3 percent more studs meeting "Stud" grade and 3.3 percent meeting No. 1 Dimension. Although the same trend holds true when Methods I–II are used, the margin is slight and not significant.

When all warp specifications are applied and the logs are sawn by Methods I–II, upper logs yield 33.3 percent more studs meeting "Stud" grade specifications and 26.0 percent more meeting No. 1 Dimension limits. When Methods III–IV are used, the figures are 14.2 percent and 10.4 percent.

An analysis of variance on the mean crook and bow of studs sawn by Methods III–IV showed upper logs to be significantly better than butt logs at the 0.01 level. When twist is considered, the butt logs are significantly better at the 0.01 level. With twist, the interaction between log position and diameter is significant. A further significant (0.05 level) interaction was found between log position and Methods III–IV for crook.

9. Effect of Juvenile Core Diameter on Warp

Juvenile core wood has been shown by many investigators to possess higher longitudinal shrinkage values than normal wood. It has frequently been blamed for the excessive warp in lumber sawn in and immediately adjacent to the pith area of the log.

Hypothetically, increasing core diameters should increase warping tendencies in those pieces of lumber sawn immediately adjacent to the pith area. These pieces contain increasing amounts of juvenile core wood; in drying these exert a greater tension stress along one edge or one face of the piece and result in greater warp. The analysis of the effect of the diameter of the juvenile core on the three aspects of warp failed to support this hypothesis.

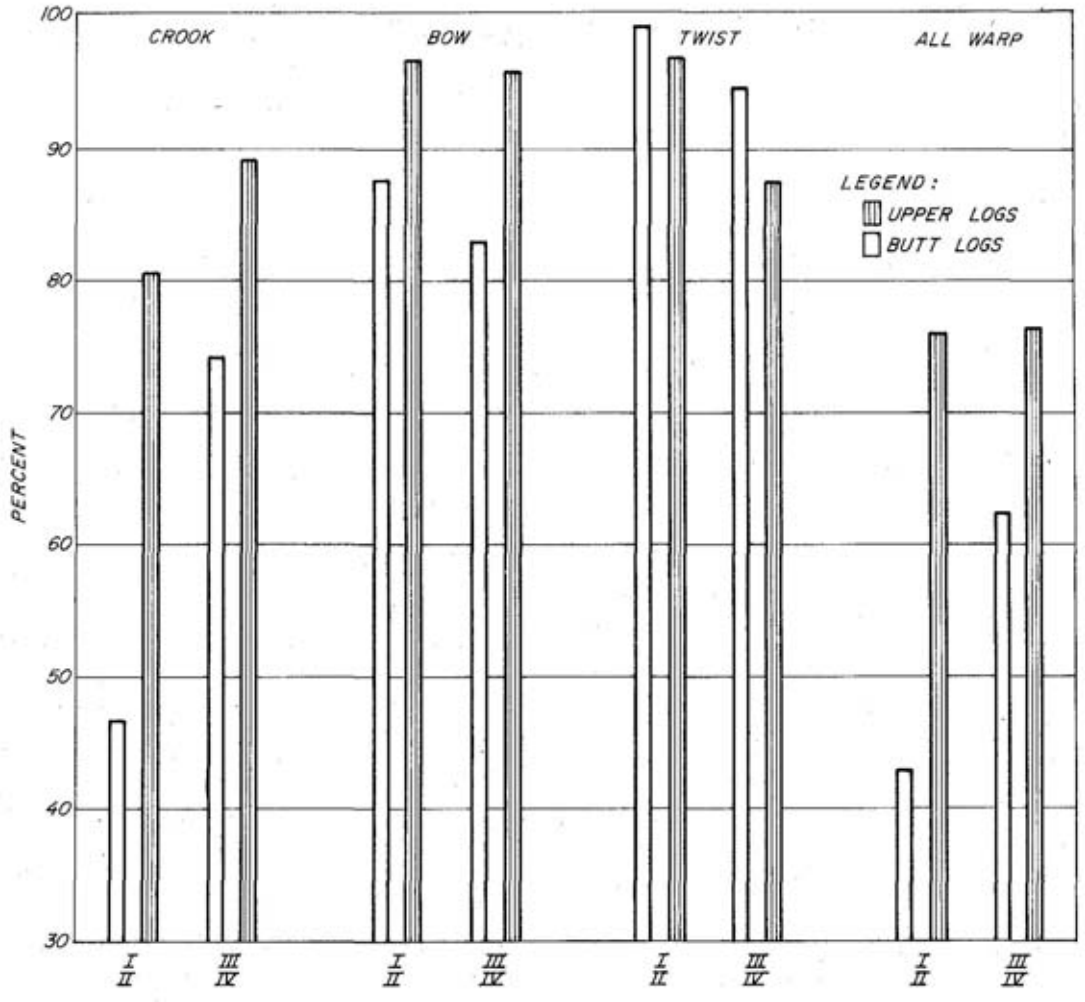


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Figure 37.--The effect of log position on warp by sawing methods for combined diameters and combined compression wood classes. Yields are percentages of studs meeting warp limits of SPIB "Stud" grade.

Table 6.--Yield of studs by log position class for Sawing Methods 1—11 and III-IV

Warp aspect	Sawing method	Stud grade		No. 1 Dimension	
		Butts	Uppers	Butts	Uppers
Crook	I-II	46.9	80.6	64.9	91.2
	III-IV	74.3	89.2	84.5	97.1
	All	64.0	85.7	77.1	94.8
Bow	I-II	87.6	96.6	95.1	99.2
	III-IV	82.9	95.7	92.9	97.8
	All	84.7	96.1	93.7	98.4
Twist	I-II	99.3	96.8	100.0	99.2
	III-IV	94.8	87.5	98.0	94.7
	All	96.5	91.2	98.7	96.5
All warp	I-II	43.0	76.3	63.7	89.7
	III-IV	62.5	76.7	79.8	90.2
	All	55.2	76.5	73.7	90.0

Analysis of the effect of juvenile core diameter was made for Methods III and IV as preliminary examination of the overall yield data for all sawing methods had indicated general and marked superiority of these two methods when all aspects of warp are considered.

Table 7 shows the results of the analysis for butt and upper logs. Juvenile core diameters have been classified by 0.5-inch intervals. The studs have been classified into inner and outer groups. The inner group comprises those studs which might be expected to contain areas of juvenile core wood, while the outer group normally would not. The inner group consists of studs 1, 2, 11, 12, and 13 and the outer group consists of the others shown in figure 6.

Table 7 shows the mean crook, bow, and twist for each of these combination classes for both butt and upper logs. No consistent relationship was evident and statistical treatment of the data also failed to indicate any.

The extremely high values shown for average crook and bow in the juvenile core 3.1- to 3.5-inch diameter class for Method III in butt logs are due entirely to the studs from a single log, number 143. This 12-inch log yielded nine studs, Four of these, when dry, were too crooked to pass through the planer and the other five had warp ranging from 1 to 2-1/2 inches. This log, whose warp was the worst in the study, contained compression wood and a rather large juvenile core, but it appeared no different than others with similar features. Two other study logs came from the same tree and their studs did not show this excessive warp.

Table 7.--Effect of juvenile core diameter on warp of inner[1] and outer studs sawn by Methods III and IV. Warp values are in increments of 1/32 inch.

Juvenile core diameter	Average crook with--				Average bow with--				Average twist with--			
	Method III		Method IV		Method III		Method IV		Method III		Method IV	
(Inches)	Inner studs	Outer studs	Inner studs	Outer studs	Inner studs	Outer studs	Inner studs	Outer studs	Inner studs	Outer studs	Inner studs	Outer studs
					BUTT LOGS							
0.0-0.5	--	--	3.8	2.4	--	--	3.5	4.4	--	--	2.8	0.8
0.6-1.0	5.5	3.5	5.2	5.7	9.3	11.9	8.8	6.6	1.4	4.0	1.3	1.7
1.1-1.5	8.9	4.3	6.8	3.8	8.9	5.4	8.6	5.2	2.8	1.5	2.5	2.0
1.6-2.0	10.2	4.5	4.2	3.1	8.6	9.7	7.5	7.0	2.5	2.5	7.2	2.0
2.1-2.5	8.5	3.5	8.3	4.3	13.8	5.8	8.5	9.9	3.2	2.6	2.6	7.1
2.6-3.0	4.3	2.3	4.5	5.2	7.1	3.4	8.7	5.2	2.2	2.5	4.1	3.2
3.1-3.5	[2]15.5	[2]11.2	3.3	--	[2]27.8	[2]9.3	7.0	0.0	3.3	3.0	2.3	0.0
3.6-4.0	5.7	3.8	6.6	4.2	10.0	5.2	7.6	3.8	5.3	2.2	1.0	.7
					UPPER LOGS							
0.0-0.5	--	--	--	--	--	--	--	--	--	--	--	--
0.6-1.0	2.9	3.3	2.6	--	3.4	2.8	1.8	--	8.1	1.0	5.6	--
1.1-1.5	2.4	3.2	2.4	2.4	4.9	3.4	3.3	2.7	7.1	1.2	5.6	2.2
1.6-2.0	3.0	2.7	4.0	2.9	4.5	2.7	4.7	3.7	5.5	2.0	4.5	1.7
2.1-2.5	2.7	2.4	3.6	2.0	4.2	3.4	3.5	3.1	3.9	2.7	6.0	1.8
2.6-3.0	5.5	2.1	3.5	3.2	4.5	2.0	5.7	4.1	2.5	1.2	4.3	1.4
3.1-3.5	2.7	1.5	--	--	2.5	3.1	--	--	5.5	1.5	--	--
3.6-4.0	3.2	2.8	--	--	5.4	3.8	--	--	4.8	3.8	--	--

[1]Inner studs are numbers 1, 2, 11, 12, and 13 as shown for Methods III and IV in figure 6. Outer studs are all others shown for these methods.
[2]Group contains studs from Log No. 143, which was badly warped.

10. Range and Distribution of Moisture Content after Kiln Drying

The SPIB specifications for kiln-dried dimension lumber indicate a maximum moisture content of 15 percent. Rules covering reinspection indicate that 95 percent of the shipment must meet the original specifications. By inference then, a maximum of 5 percent of any kiln-dried lumber shipment might exceed 15 percent moisture content and still qualify as kiln dried.

The intent of the drying phase of this study was to meet these limits with a narrow range of variation in moisture content of all studs. It was assumed that drying to an average of 12 percent with a slightly longer conditioning period would result in 95 percent of studs having a moisture content of 15 percent or less.

Figures 38 and 39 show the results actually obtained. The mean moisture content of all studs was 12.5 percent, with 87.4 percent within ±3 percent of the 12 percent target. However the mode (26 percent of the sample) occurred at a moisture content of 12 percent.

Some 91.4 percent of the studs had moisture contents of 15 percent or less, and 95.8 percent of the studs were at 16 percent or less. A few studs may actually have been below the low value, shown as 7 percent; as the moisture content figures were obtained with a resistance-type meter, this was not ascertained.

It is believed that the moisture content of the study studs was entirely satisfactory under SPIB specifications that prescribe surface moisture content, The study measurement was at 3/8 inch below the surface, which is standard practice with the type of resistance moisture meter actually used.

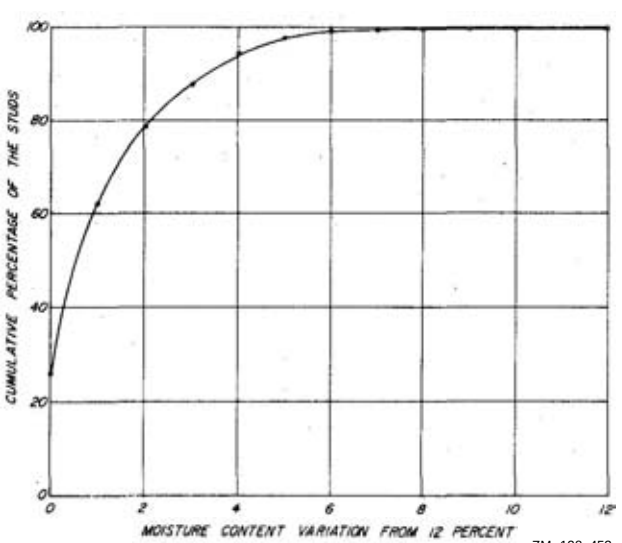

Figure 38.--Cumulative yields of studs by deviation from the target of 12 percent moisture content.

The results suggest that it is more difficult than commonly supposed to hold the moisture content in loblolly pine studs to narrow variation limits. The study studs were dried on a rather mild schedule with a longer than customary conditioning period. All drying was accomplished in the Laboratory's research kilns under closely controlled conditions in 10 charges of about 240 studs each.

11. Effect of 90-Day Restrained Storage on Warp, Length, and Moisture Content

Malcolm (11) has shown that, immediately after any lumber is kiln dried and dressed, there exists within that lumber a substantial and frequently unbalanced moisture gradient. It can be reasonably assumed that this gradient is reduced with time, through gradual adjustment of the moisture content of the entire piece to the EMC (equilibrium moisture content) established by climatic conditions. As this adjustment is taking place, additional shrinkage must also occur in the inner area where moisture content is usually higher than the EMC. Some slight swelling will also occur in the outer shell if it is drier than the EMC. This situation can be expected to set up stresses that may result in changes in warp and possibly in the length of the studs.

Most studs move from the mill to the market in packages bound with steel strapping. The strapping rather effectively restrains most of the warp in the studs from the time of packaging until the package is opened. As restraint of lumber during drying influences warp, restraint during the period of equalization of the moisture gradient within the stud to the EMC could influence changes in warp during this period. In the hope of obtaining further information on this question, 10 percent of the studs from the study were strapped in two packages and placed in 90-day storage in a dry shed.

Table 8 and figure 40 present the results of this aspect of the study. Increases in warp, length, and moisture content are shown as plus

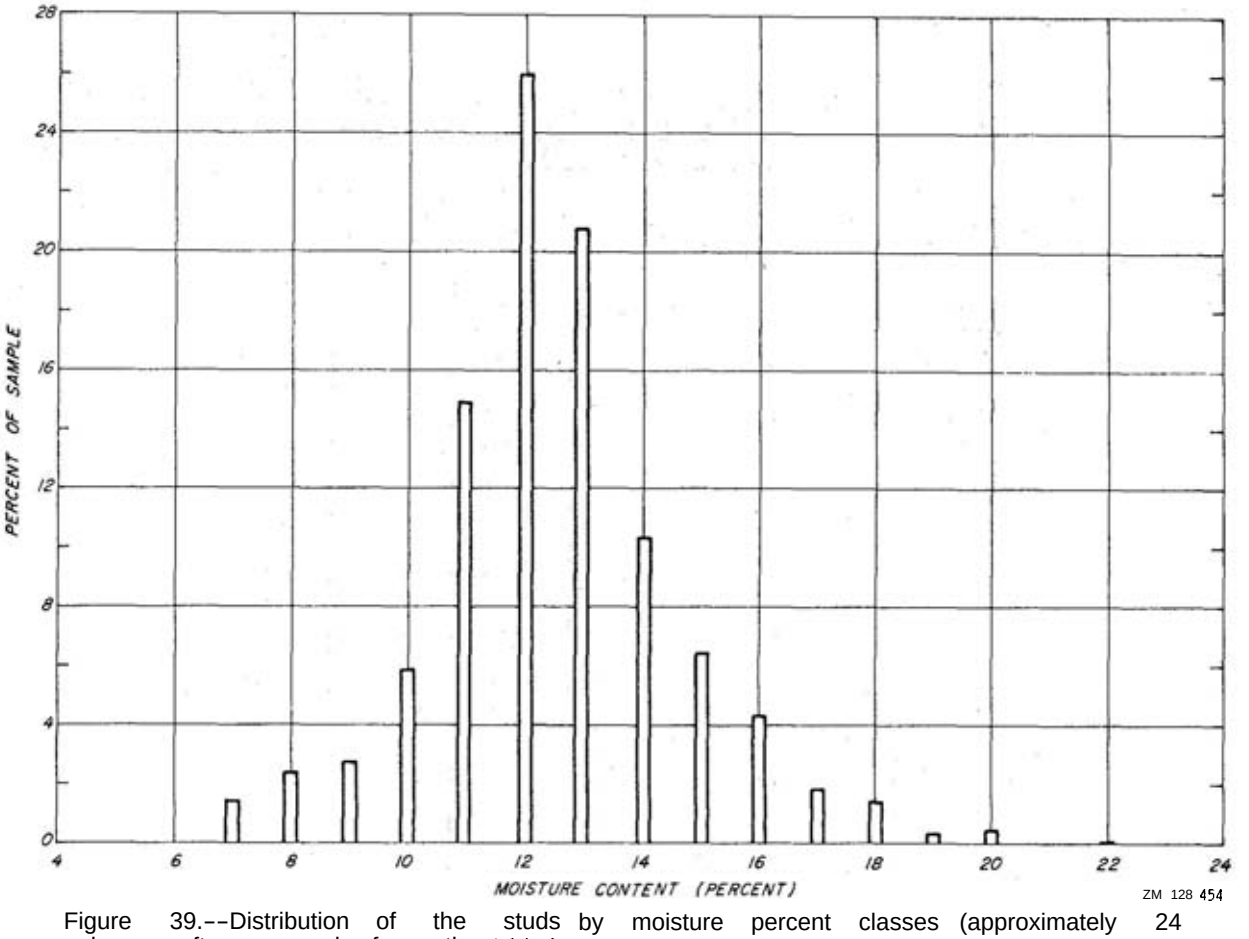

Figure 39.--Distribution of the studs by moisture percent classes (approximately 24 hours after removal from the kiln).

values and decreases as minus values.

Length measurements of any stud with bow or twist represent the length of the chord connecting the ends of the concave face. Consequently, any appreciable change in bow or crook might be expected to result in a change in the length of the stud.

Results indicate that 77.7 percent of the samples became drier, 16.7 percent remained unchanged, and 5.6 percent became wetter. Changes ranged from a +1 percent to a –7 percent in moisture content.

Length increased in 52.4 percent of the studs, remained unchanged in 24.9 percent, and decreased in 22.7 percent. Changes ranged from a +12/32 to a –39/32 inches.

Crook increased in 42.9 percent of the sample, remained unchanged in 26.2 percent, and decreased in 30.9 percent. Changes ranged from a +26/32 to a –10/32.

Bow increased in 35.9 percent of the studs, remained unchanged in 18.9 percent, and decreased in 45.2 percent. Changes ranged from +25/32 to –17/32.

Twist increased in 35.7 percent of the sample, remained unchanged in 44.2 percent, and decreased in 20.1 percent. Changes ranged from +8/32 to a –4/32.

In summary, the studs became drier and longer, crook and twist increased, and bow decreased. As a basic conflict apparently exists in this situation of decreased moisture content, increased length, and increased crook, a further analysis was made. Here the intent was to determine whether the increased warp occurred in the same studs as increased length and also whether decreased warp was in the same studs as decreased length.

Results of the second analysis indicate that, in a majority of cases, increased warp is associated with decreased length and decreased warp with increased length. There were, however, a substantial number of cases in which this was not true.

Table 8.--Changes in moisture content, length and warp of 233 randomly selected studs during 90-day strapped storage

Measurement changes[1]	Percent of sample				
	Length	Crook	Bow	Twist	Moisture content
-39	0.4				
-17			0.4		
-12	0.4				
-11			0.9		
-10		0.4	0.9		
-9			0.9		
-8	0.9	0.4	0.9		
-7			0.9		1.3
-6		0.9	1.3		3.4
-5	0.4		2.1		5.1
-4	0.4	2.1	3.4	0.4	9.5
-3	1.7	1.3	4.3	0.4	10.3
-2	3.4	5.6	11.6	2.1	20.6
-1	15.1	20.2	17.6	17.2	27.5
Sum of studs decreasing	22.7	30.9	45.2	20.1	77.7
0					
Sum of studs unchanged	24.9	26.2	18.9	44.2	16.7
+1	22.3	17.6	14.2	19.8	5.6
+2	22.8	12.2	9.0	8.7	
+3	5.2	4.7	3.8	3.0	
+4	1.3	2.1	0.9	2.1	
+5		2.1	2.1	0.4	
+6	0.4	1.3		1.3	
+7		2.1	0.9		
+8		0.4	1.3	0.4	
+9			1.3		
+10			0.4		
+11			0.4		
+12	0.4		0.4		
+15			0.4		
+21			0.4		
+25			0.4		
+26		0.4			
Sum of studs increasing	52.4	42.9	35.9	35.7	5.6
Total	100.0	100.0	100.0	100.0	100.0

[1] Figures in this column represent 1/32 inches for length, crook, bow, and twist and 1 percent increments for moisture content.

Within the 181 studs in which moisture content decreased, 86 increased in length; of these 86, 25 increased in crook; and 5 of these 25 also increased in bow. Also within this decreased moisture content group, 43 decreased in length; 5 of the 43 decreased in crook, and4 of the 5 also decreased in bow. Another group of 5 studs showed changes in length with no changes in

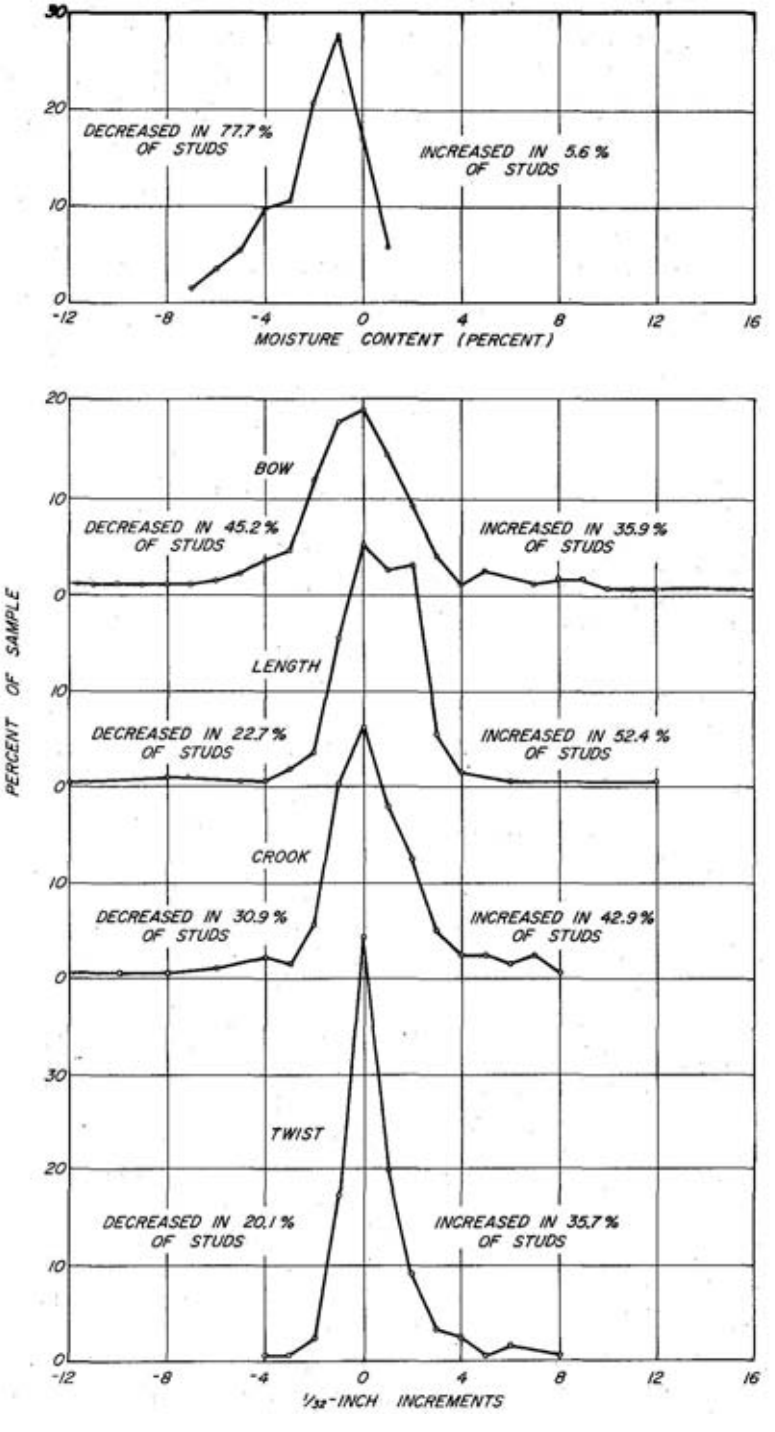

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Figure 40.--General changes in the moisture content, length, bow, crook, and twist of 233 randomly selected studs tightly strapped and stored in an open shed for 90 days.

crook or bow.

Within the 39 studs in which moisture content did not change, 28 became longer; of these 28, 6 increased in crook and 1 of the 6 also increased in bow. In this unchanged moisture content group, 4 studs shortened, of which 1 decreased in crook and in bow. Another stud showed a change in length with no change in crook or bow.

Thirteen studs increased in moisture content. Of the 8 in this group which increased in length,

2 increased in crook. Of these 2, neither showed an increase in bow, although one showed no change. On the other hand, of the 5 which decreased in length, 1 showed decreased crook and increased bow.

It must be concluded that, in an appreciable minority of studs, the adjustment in moisture content, warp, and length and their interaction continue over a rather long period of time and are not easily predictable. Similar observations of the unpredictability of the interrelation of moisture content and the various aspects of warp have been noted by Du Toit (4).

THE FPL IMPROVED METHOD

A closer examination of the data on effect of position of the stud in 12-inch logs in relation to warp gave evidence of a better sawing method than the four under study. The original analyses had already shown the superiority of Method IV when all warp specifications were considered. The analysis of stud position demonstrated that the studs developed from the 2-inch side flitches in Method III exhibited significantly less warp than the studs from similar side flitches in Method IV. Only one difference appears between the sawing technique used to develop these studs (Nos. 31, 32, 33, 34 in figure 6): In Method III the 2-inch flitches are sawn into two studs parallel to the central axis of the flitch, while in Method IV the sawing is parallel to the bark, resulting in the removal of a wedge between the two studs.

Actually, there is no reason why the system of 2-inch side flitch breakdown for sawing Method III cannot be used with the 4-inch center cant system of Method IV. This further-improved sawing method is termed the "FPL Improved Method."

Based on the differences shown in the 12-inch study logs, this improved method would result in an increase of 15.3 percent of studs from the side flitches of butt logs and 14.3 percent from the upper logs meeting the all warp specifications of "Stud" grade.

Sawing Procedures

The sawing procedures for the FPL Improved Method are defined separately for each log diameter class.

In logs of all diameters, position the long radius of the butt logs at right angles to the plane of the canting cuts. For upper logs, place the long radius parallel. In most, if not all, mills this means horizontal positioning of the long radius in butt logs and vertical positioning in upper logs.

6-inch logs.--Saw a 4-inch cant so that the cant is parallel with the geometric center of the log by splitting the taper between the slabbed faces. Saw the 4-inch cant parallel and adjacent to one of its bark edges to remove one 2x4. Saw the second 2x4 parallel to the other bark edge. The excess wood and the taper will remain in the form of a wedge from the center of the cant.

8-inch logs.--Produce a 4-inch cant exactly as in the 6-inch logs. It may be possible to recover a 4/4 board as well as the slab from one or both of the opposed slabbing faces. The 4-inch cant from an 8-inch log will yield three 2x4's, two parallel to one face of the cant and one parallel to the other bark face. If the pith is off center in relation to its distance from the bark faces in the 4-inch cant, saw the two 2x4's from the side with the longest radius. In this way the wedge is most apt to come from the juvenile core area. If the pith is midway between the bark faces of the cant, the two parallel 2x4's can be cut from either edge.

10-inch logs.--Slab the log parallel to its central longitudinal axis approximately 4-1/4 inches from its geometric center. Then make a second cut parallel to the first, removing a 2-inch flitch. Repeat the process from the 180° opposing face. The result will be two 2-inch flitches and one 4-inch cant, all with bark edges. From each 2-inch flitch, rip a single 2x4 parallel to its central longitudinal axis. The taper in the width of the 2-inch flitch should end up about equally divided between the two barky edgings. Then beginning at one of the bark edges of the 4-inch cant, rip two adjacent 2x4's parallel to each other and the bark edge. Next rip the other two adjacent 2x4's from the opposite bark edge, parallel to each other and the second bark edge. The taper of the 4-inch flitch and any extra wood it may contain will remain in a central wedge.

12-inch logs.--Follow the exact procedure outlined for 10-inch logs except that, if desired, it will sometimes be possible to recover one 4/4 board between a thin slab and the outer face

of the 2-inch flitch. It will usually be possible to recover two 2x4's from each 2-inch flitch. These should be sawn parallel to the central longitudinal axis of the flitch and adjacent to each other. Usually the center 4-inch cant will yield five 2x4's. Here as in the 8-inch diameter logs, select the side of the cant that is widest from pith to bark and saw three adjacent 2x4's parallel to the bark and each other. Beginning at the other bark face, saw two adjacent 2x4's parallel to it and each other. This will leave the taper of the log and the excess wood in a wedge in or near the juvenile core area.

Other diameters.--Logs with diameters between those outlined should be sawn in the same manner, the only difference will be in possible additional boards which could be developed in conjunction with the studs. The study did not examine the sawing of logs larger than 12.5 inches in diameter, but there would seem to be no reason why this same system could not be used on logs through at least 14 inches in diameter.

Commercial Use

The commercial application of the FPL Improved Method would require either a conventional headrig (circular or band) or a Scragg headrig. In addition, a circular gang-type edger and a merry-go-round or else two circular gang-type edgers in tandem would be needed. If a Scragg headrig is used, the slabbing, flitching, and canting cuts would be made in a single pass through this machine.

The 2-inch flitches could be ripped into 2x4's in the normal method by a single pass through the circular gang edger on the side with 4-inch saw spacing.

The change from normal sawmilling procedure occurs mainly in the processing of the 4-inch cant; in all cants two series of cuts are made which are not parallel. This can be accomplished by so positioning the cant in its first pass through the gang that only the 2x4 or 2x4's on one side of the central wedge are cut. The remainder of the cant must then be returned to the gang by means of a merry-go-round setup or passed through a second gang behind the first one. In the second gang or in the second pass through the first gang, the cant is realined so the saw lines are parallel to the bark on the remaining rough edge. The central wedge is automatically produced on this second pass.

Extra investment necessary to convert to this system would be the cost of second circular gang edger, or a merry-go-round setup if a single unit is used. The second unit is recommended when the single machine is not large enough to allow space at the infeed table for two operators to work efficiently.

It is assumed an additional man will be required. In effect there will be twice as many 4-inch cants to saw for a given volume of studs as each will be handled twice.

Detailed evaluation of the economic advantages is not within the scope of this paper but some round figures illustrate its potential, Assume that the additional investment, in a mill with a capacity of 40 MBF (thousand board feet) per day, is $12,500 for a second circular gang edger, and its depreciable life is 10 years. Assume further that an additional $12,500 is required to repair and maintain it during that 10-year period. This means a daily increase in cost of equipment operation of $10. Add to this the daily cost of an operator--assume $20. For this size of mill, the total daily cost of $30 becomes $0.75 per MBF.

The added value of the studs sawn by this method will vary depending on the mix of logs coming into the plant. Using the mix that was sawn in this study, the expected value of the lumber sawn by the FPL Improved Method compared with the regular Scragg Method (Method III in this study) and the Conventional Sawmill Method (I in this study) is shown in figure 41. The yields by grades are based on application of warp limitations only. The prices by grades which were used were a composite of the wholesale prices quoted by three large southern pine mills, FOB to yard in November 1964.

These prices were:

Dimension	Price per MBF
No. 1	$96
No. 2	$87
No. 3	$65
No. 4	$40

Figure 41 indicates a margin for the FPL Improved Method over the Scragg Method of $3.54 per MBF and $10.46 over the Conventional Method. After deducting an additional charge of $0.75 per MBF for cost of manufacture by the

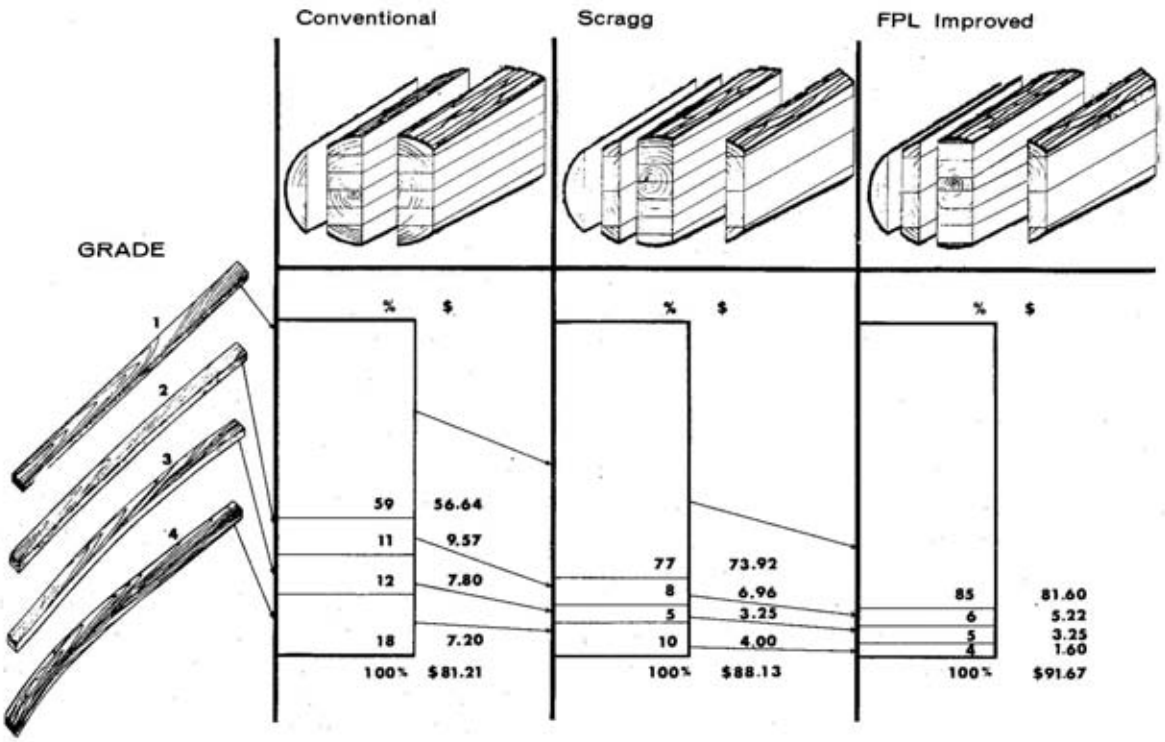

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Figure 41.--Comparison of expected grade yields based on warp only and product values for the Conventional, Scragg, and FPL Improved Method.

FPL Improved Method, the margins become $2.79 and $9.71, respectively.

Of at least equal importance is the reduction in No. 4 Dimension and the increase in No. 1 Dimension by the FPL Improved Method; this would certainly result in better acceptance by the ultimate consumer.

If both the knot and warp limitations of the SPIB grades are applied, the values of the studs for the mix of logs sawn in this study become:

Method	Price per MBF
Conventional	$80. 85
Scragg	$88. 04
FPL Improved	$91. 24

Applying the same additional manufacturing cost of $0.75 per MBF to the FPL Improved Method, the margin becomes $2.45 per MBF over the Scragg Method and $9.54 over the Conventional Method.

APPLICATION OF RESULTS

Many aspects of this research, although basic in nature, have direct application in the stud manufacturing industry as well as other lumber and wood products industries. Such application should increase volume recovery while reducing warp in the finished studs.

The position of the log in the tree has been shown to have a significant effect on warp. In a sawmill making a variety of lumber products, strong consideration should be given to using butt logs for lumber items with a greater ratio of width to thickness than that of 2x4 studs, so the inherent resistance to crook will be increased. In operations where studs are the only product it may be possible to purchase only upper logs, as butt logs generally are larger in diameter and more in demand for the production of wider dimension lumber.

Insofar as warp is concerned, the stud mill operation will profit measurably by milling only

upper logs. The benefits, in terms of the increased percentage of studs meeting "Stud" grade, would be approximately 34 percent[2] by Sawing Method I or II and 15 percent by Sawing Method III or IV. At the No. 1 Dimension grade level, the figures would be 26 percent and 13 percent, respectively.

Diameter in upper logs is significantly related to the proportion of warped studs. Larger logs yield higher percentages of studs meeting a given grade level. Upper logs of 6, 8, 10, and 12 inches yielded 63, 70, 73, and 84 percent, respectively, of the studs meeting "Stud" grade warp requirements; the figures for No. 1 Dimension are 81, 86, 90, and 94 percent, respectively. In butt logs the proportion of warped studs did not seem to change with diameter.

The possible benefits from eliminating small upper logs in the manufacture of studs is an economic question, and beyond the scope of this paper. When all logs are considered, diameter in itself is one of the less important variables involved in the control of warp. The question of whether to use small logs with lower recoveries in the higher grades because of warp must be weighed against their generally lower value for products other than lumber.

This study shows that logs containing visible compression wood yield studs averaging significantly higher in warp than logs with normal wood. Yields from normal wood butt logs sawn by Methods I and II are 12 percent better in "Stud" grade and 11 percent better in No. 1 Dimension. When sawn by Methods III and IV the differences are 13 percent in both grades. For upper logs sawn by Methods I and II the differences are 17 percent and 14 percent, respectively. When Sawing Methods III and IV are used, differences in favor of normal wood logs are less at 1 percent and 3 percent, respectively.

Based on these percentages, there would seem to be a definite economic advantage in eliminating those logs, both butts and uppers, which show appreciable compression wood on either end if Sawing Methods I or II are being used. If Methods III or IV are being used, only the elimination of butt logs need be considered. In an integrated operation, these logs could be shunted to wood fiber products or possibly to 4/4 board production where more warp can be tolerated.

The four sawing methods studied were found to possess widely different potentials in terms of the degree of warp in the studs they produced. Also, the volume recoveries (overrun) were significantly higher in two methods than in the other two,

For butt logs, in terms of studs meeting the warp requirement of "Stud" grade, Sawing Methods I, II, III, and IV yielded percentages of 39, 47, 61, and 64. At the No 1 Dimensionlevel, yields were 59, 68, 77, and 82 percent, respectively. When upper logs were sawn, the yields meeting "Stud" grade were 73, 80, 74, and 79; in No. 1 Dimension they were 88, 91, 89, and 92.

When volume recovery is considered, logs in the 10-inch diameter class yielded 21 percent more studs by Sawing Methods III and IV than by Methods I and 11. In the 12-inch diameter class the superiority of Methods III and IV was 13 percent. Logs in the 6- and 8-inch diameter class cannot be sawn by Methods I and II because they are not large enough to yield two 4-inch cants.

The proper rotational placement of the log had a consistent effect on the reduction of warp. Placing the long radius horizontal for butt logs sawn by Methods III and IV raised yields in terms of "Stud" grade warp limitation by 6 percent in compression wood logs and 9 percent in normal wood logs. Placing the long radius vertical in upper normal wood logs results in an increase in yield of 6 percent. Yields from upper compression wood logs were not found to be influenced appreciably by the position of the long radius.

Analysis of relationships of the position of the stud in the log by each diameter class and sawing method showed that a further improvement in Method IV was possible. This FPL Improved Method would add about 15 percent to the yield of studs meeting the warp limitations of "Stud" or No. 1 Dimension grades from the 2-inch side flitches.

Overall evaluation of all the results of this research indicated highest yields of studs in the upper grades and greatest reduction in the proportion of No, 4 Dimension studs will result from using the FPL Improved Method. It can be considered a "prescription" method, having been evolved from detailed analysis of all the basic data.

[2] All percentage figures in this section have been rounded to the nearest whole percent.

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APPENDIX

Table 9.--Yields from butt logs, with combined warp for SPIB dimension grades: percent of studs by sawing methods, lon diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter							
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
							No. 1 Dimension and better								
III	100.0	100.0	100.0	58.3	75.0	66.7	77.8	66.7	80.0	73.7	77.8	72.2	75.0	74.6	
IV	100.0	100.0	100.0	83.3	83.3	83.3	88.9	100.0	100.0	100.0	66.7	72.2	69.4	80.7	
							No. 2 Dimension								
III	0.0	0.0	0.0	8.4	8.3	8.3	5.5	22.2	10.0	15.8	5.5	0.0	2.8	7.2	
IV	0.0	0.0	0.0	0.0	9.0	4.7	2.8	0.0	0.0	0.0	22.2	11.1	16.7	10.5	
							No. 3 Dimension								
III	0.0	0.0	0.0	8.3	8.4	8.3	5.6	0.0	10.0	5.2	5.6	22.2	13.9	10.9	
IV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	11.1	8.3	5.3	
							No. 4 Dimension								
III	0.0	0.0	0.0	25.0	8.3	16.7	11.1	11.1	0.0	5.3	11.1	5.6	8.3	7.3	
IV	0.0	0.0	0.0	16.7	7.7	12.0	8.3	0.0	0.0	0.0	5.6	5.6	5.6	3.5	

Sawing method	10-inch Diameter							12-inch Diameter								All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch		
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined			
							No. 1 Dimension and better									
I	71.4	71.4	71.4	42.9	61.8	53.2	58.9	50.0	58.3	54.6	77.5	50.0	62.5	59.9		59.5
II	81.3	71.4	76.7	54.2	46.2	50.0	60.0	79.2	86.4	82.6	64.6	70.8	67.7	72.5		68.0
III	88.9	83.3	86.1	83.3	77.8	80.6	82.4	70.4	96.3	83.3	64.8	75.9	70.4	74.7		77.3
IV	94.4	87.5	90.5	75.0	86.1	80.6	84.2	84.0	92.6	88.5	72.2	79.0	75.9	79.8		82.1
							No. 2 Dimension									
I	21.5	0.0	10.7	25.0	8.8	16.2	14.4	5.0	16.7	11.3	5.0	8.3	6.8	8.3		10.8
II	6.2	0.0	3.3	8.3	26.9	18.0	12.5	12.5	4.5	8.7	8.3	8.4	8.3	8.5		9.9
III	5.5	16.7	11.1	5.6	11.1	8.3	9.3	18.5	3.7	11.1	0.0	9.3	4.6	6.8		7.5
IV	5.6	4.2	4.7	13.9	8.3	11.1	8.8	8.0	3.7	5.7	14.8	3.3	8.6	7.7		8.0
							No. 3 Dimension									
I	7.1	0.0	3.6	14.2	8.8	11.3	8.9	15.0	12.5	13.7	2.5	20.9	12.5	12.9		11.2
II	6.3	14.3	10.0	12.5	7.7	10.0	10.0	8.3	9.1	8.7	4.6	8.3	11.5	10.6		10.4
III	5.6	0.0	2.8	2.8	2.8	2.8	2.7	0.0	0.0	0.0	7.4	7.4	7.4	4.9		5.2
IV	0.0	8.3	4.8	11.1	2.8	6.9	6.1	4.0	3.7	3.9	5.6	6.4	6.0	5.4		5.1
							No. 4 Dimension									
I	0.0	28.6	14.3	17.9	20.6	19.3	17.8	50.0	12.5	20.4	15.0	20.8	18.2	18.9		18.5
II	6.2	14.3	10.0	25.0	19.2	22.0	17.5	0.0	0.0	0.0	12.5	12.5	12.5	8.4		11.7
III	0.0	0.0	0.0	8.3	8.3	8.3	5.6	11.1	0.0	5.6	27.8	7.4	17.6	13.6		10.0
IV	0.0	0.0	0.0	0.0	2.8	1.4	0.9	4.0	0.0	1.9	7.4	11.3	9.5	7.1		4.8

Table 10.--Yields from upper logs, with combined warp for SPIB Dimension grades: percent of studs by sawing methods, log diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter						
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined	
							No. 1 Dimension and better							
III	66.7	66.7	66.7	75.0	75.0	75.0	72.2	100.0	77.8	88.9	88.9	77.8	83.3	85.2
IV	100.0	100.0	100.0	83.3	91.7	87.5	91.2	88.9	77.8	83.3	88.9	88.9	88.9	87.0
							No. 2 Dimension							
III	33.3	16.6	25.0	25.0	8.3	16.7	19.5	0.0	0.0	0.0	5.5	11.1	8.4	5.5
IV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	5.6	11.1	5.5	8.3	7.4
							No. 3 Dimension							
III	0.0	0.0	0.0	0.0	8.4	4.1	2.7	0.0	22.2	11.1	5.6	5.5	5.5	7.5
IV	0.0	0.0	0.0	8.4	8.3	8.3	5.9	0.0	11.1	5.5	0.0	5.6	2.8	3.8
							No. 4 Dimension							
III	0.0	16.7	8.3	0.0	8.3	4.2	5.6	0.0	0.0	0.0	0.0	5.6	2.8	1.8
IV	0.0	0.0	0.0	8.3	0.0	4.2	2.9	0.0	11.1	5.6	0.0	0.0	0.0	1.8

Sawing method	10-inch diameter							12-inch diameter							All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
							No. 1 Dimension and better								
I	91.7	94.4	93.3	83.3	92.9	87.9	89.8	95.5	95.5	95.5	80.0	84.8	82.6	86.9	88.1
II	100.0	100.0	100.0	91.2	96.4	93.6	95.6	100.0	100.0	100.0	90.7	79.0	84.5	88.9	91.2
III	77.8	88.9	83.3	91.7	91.7	91.7	88.9	100.0	91.7	95.8	92.6	94.4	93.5	94.2	89.0
IV	100.0	100.0	100.0	94.3	77.8	85.9	90.6	100.0	96.2	98.0	86.3	97.8	91.7	93.8	91.5
							No. 2 Dimension								
I	8.3	5.6	6.7	13.4	3.5	8.7	7.9	0.0	0.0	0.0	17.5	8.7	12.8	8.5	8.2
II	0.0	0.0	0.0	0.0	3.6	1.6	1.0	0.0	0.0	0.0	5.6	8.1	6.9	4.9	3.6
III	11.1	5.5	8.4	8.3	8.3	8.3	8.3	0.0	8.3	4.2	5.6	3.8	4.7	4.5	7.3
IV	0.0	0.0	0.0	2.8	11.1	7.1	4.7	0.0	0.0	2.2	9.8	2.2	6.2	4.2	4.4
							No. 3 Dimension								
I	0.0	0.0	0.0	0.0	3.6	1.7	1.2	0.0	4.5	2.2	2.5	0.0	1.1	1.5	1.4
II	0.0	0.0	0.0	8.8	0.0	4.8	3.4	0.0	0.0	0.0	3.7	12.9	8.6	6.2	5.2
III	5.5	5.6	5.5	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.8	1.8	1.8	1.3	2.6
IV	0.0	0.0	0.0	2.9	8.3	5.6	3.8	0.0	3.8	2.0	3.9	0.0	2.1	2.0	3.2
							No. 4 Dimension								
I	0.0	0.0	0.0	3.3	0.0	1.7	1.1	4.5	0.0	2.3	0.0	6.5	3.5	3.1	2.3
II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
III	5.6	0.0	2.8	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
IV	0.0	0.0	0.0	0.0	2.8	1.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9

Table 11.--Yields from butt logs, with individual warp aspects for SPIB "Stud" grade: percent of studs by sawing methods, log diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter						
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined	
								Crook						
III	100.0	100.0	100.0	50.0	58.3	54.2	69.4	55.6	70.0	63.2	55.6	66.7	61.1	61.8
IV	83.3	83.3	83.3	75.0	67.7	70.8	75.0	91.7	88.9	90.5	66.7	77.8	72.2	79.0
								Bow						
III	66.7	100.0	83.3	91.7	91.7	91.7	88.9	88.9	90.0	89.5	83.3	88.9	86.1	87.3
IV	83.3	83.3	83.3	95.8	83.3	87.5	86.1	91.7	100.0	95.2	83.3	83.3	83.3	87.7
								Twist						
III	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	90.0	94.7	88.9	100.0	94.4	94.6
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.9	95.2	88.9	94.4	91.7	93.0
								All warp						
III	66.7	100.0	83.3	50.0	58.3	54.2	63.9	55.6	60.0	57.9	44.4	55.6	50.0	52.7
IV	83.3	66.7	75.0	75.0	50.0	62.5	66.7	83.3	77.8	81.0	55.6	66.7	61.1	68.4

Sawing method	10-inch diameter							12-inch diameter							All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
I	57.1	50.0	53.6	17.9	52.9	37.1	42.2	30.0	41.7	36.4	65.0	31.3	46.6	43.2	42.8
II	43.8	57.1	50.0	33.3	30.8	32.0	38.8	70.8	77.3	73.9	47.9	52.1	50.0	57.8	50.9
III	94.4	94.4	94.4	77.8	77.8	77.8	83.3	77.7	85.2	81.5	51.9	72.2	62.0	68.5	72.0
IV	94.4	91.7	92.9	80.6	83.3	81.9	86.0	64.0	85.2	75.0	68.5	66.1	67.2	69.6	76.5
								Bow							
I	100.0	71.4	85.7	82.1	94.1	88.7	87.8	95.0	87.5	90.9	92.5	83.3	87.5	86.6	88.3
II	100.0	100.0	100.0	75.0	76.9	76.0	85.0	91.7	81.8	87.0	85.4	91.7	88.5	88.0	86.9
III	77.8	83.3	80.6	86.1	72.2	79.2	79.6	66.7	100.0	83.3	68.5	87.0	77.8	79.6	81.7
IV	88.9	87.5	88.1	66.7	97.2	81.9	84.2	84.0	88.9	88.5	75.9	83.9	80.2	82.1	84.0
								Twist							
I	92.9	100.0	96.4	100.0	100.0	100.0	98.9	100.0	95.8	97.7	100.0	97.9	98.9	98.5	98.7
II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
III	100.0	88.9	94.4	100.0	88.9	94.4	94.4	85.2	92.5	88.9	94.4	94.4	94.4	92.6	94.2
IV	94.4	100.0	97.6	100.0	100.0	100.0	99.4	92.0	96.3	94.2	100.0	85.5	92.2	92.9	95.5
								All warp							
I	57.1	42.9	50.0	17.9	47.1	33.9	38.9	30.0	37.5	34.1	62.5	25.0	42.1	39.4	39.2
II	43.8	57.1	50.0	20.8	26.9	24.0	33.8	66.7	68.2	67.4	43.8	52.1	47.9	54.2	46.9
III	77.8	66.7	72.2	72.2	55.6	63.9	66.7	59.3	77.8	68.5	42.6	66.7	54.6	59.3	60.9
IV	83.3	83.3	83.3	58.3	80.6	69.4	74.6	48.0	74.1	61.5	53.7	50.0	51.7	54.8	64.0

Table 12.--Yields from upper logs, with individual warp aspects for SPIB "Stud" grade: percent of studs by sawing methods, log diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter							
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
III	83.3	100.0	91.7	91.7	91.7	91.7	91.7	88.9	100.0	94.4	88.9	94.4	91.7	92.6	
IV	83.3	100.0	90.0	91.7	91.7	91.7	91.2	88.9	88.9	88.9	72.2	88.9	80.6	83.3	
								Bow							
III	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.4	94.4	94.4	96.3	
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.4	94.4	94.4	96.3	
								Twist							
III	50.0	50.0	50.0	75.0	58.3	66.7	61.1	100.0	66.7	83.3	88.9	72.2	80.6	81.5	
IV	100.0	100.0	100.0	66.7	83.3	75.0	82.4	77.8	55.6	66.7	77.8	88.9	83.3	77.8	
								All warp							
III	16.7	50.0	33.3	58.3	58.3	58.3	50.0	88.9	66.7	77.8	77.8	72.2	75.0	75.9	
IV	83.3	100.0	90.0	66.7	75.0	70.8	76.5	77.8	44.4	61.1	50.0	83.3	66.7	64.8	

Sawing method	10-inch diameter							12-inch diameter							All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
I	91.7	83.3	86.7	83.3	92.9	87.9	87.5	86.4	81.8	84.1	62.5	60.9	61.6	69.2	76.6
II	91.7	100.0	96.2	88.2	82.2	85.4	88.6	100.0	95.5	97.8	81.5	69.4	75.0	81.5	84.0
III	72.2	83.3	77.8	88.9	75.0	81.9	80.6	100.0	83.3	91.7	96.3	92.6	94.4	93.6	89.3
IV	100.0	94.4	97.2	85.7	80.6	83.1	87.7	100.0	92.3	96.0	84.3	95.6	89.6	91.8	89.1
								Bow							
I	100.0	94.4	96.7	86.7	96.4	91.4	93.2	95.5	95.5	95.5	82.5	84.8	83.7	87.7	89.9
II	100.0	100.0	100.0	91.2	100.0	95.2	96.6	100.0	100.0	100.0	92.6	80.7	86.2	90.1	92.4
III	94.4	100.0	97.2	94.4	94.4	94.4	95.4	100.0	100.0	100.0	98.2	96.3	97.2	98.1	97.2
IV	100.0	100.0	100.0	100.0	88.9	94.4	96.2	100.0	100.0	100.0	92.2	100.0	95.8	97.3	97.1
								Twist							
I	91.7	94.4	93.3	96.7	96.4	96.6	95.5	100.0	100.0	100.0	95.0	95.7	95.4	96.9	96.3
II	100.0	100.0	100.0	100.0	92.9	96.8	97.7	100.0	95.5	97.8	94.4	98.4	96.5	96.9	97.2
III	88.9	77.8	83.3	94.4	86.1	90.3	87.9	87.5	95.9	91.7	94.4	88.9	91.7	91.7	85.9
IV	94.1	83.3	88.6	94.3	91.7	93.0	91.5	95.8	92.3	94.0	90.2	95.6	92.7	93.2	89.1
								All warp							
I	83.3	77.8	80.0	73.3	82.1	77.6	78.4	86.4	81.8	84.1	60.0	60.9	60.5	68.5	72.5
II	91.7	100.0	96.1	88.2	75.0	82.3	86.4	95.8	86.4	91.3	74.1	66.1	69.8	75.9	79.6
III	61.1	66.7	63.9	80.6	58.3	69.4	67.6	87.5	75.0	81.3	88.9	81.5	85.2	84.0	74.3
IV	94.1	83.3	88.6	80.0	69.4	74.7	79.3	91.7	88.5	90.0	76.5	88.9	82.3	84.9	79.1

Table 13.--Yields from butt logs, with individual warp aspects, for SPIB No. 1 Dimension: percent of studs by sawing methods, log diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter							
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
III	100.0	100.0	100.0	58.3	75.0	66.7	77.8	66.7	80.0	73.8	77.8	77.8	77.8	76.4	
IV	100.0	100.0	100.0	83.3	83.3	83.3	88.9	100.0	100.0	100.0	77.8	77.8	77.8	86.0	
								Bow							
III	100.0	100.0	100.0	100.0	91.7	95.8	97.2	100.0	90.0	94.7	94.4	94.4	94.4	94.6	
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.9	94.4	91.7	94.7	
								Twist							
III	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.4	94.0	94.4	96.5	
								All warp							
III	100.0	100.0	100.0	58.3	75.0	66.7	77.8	66.7	80.0	73.7	77.8	72.2	75.0	74.6	
IV	100.0	100.0	100.0	83.3	83.3	83.3	88.9	100.0	100.0	100.0	66.7	72.2	69.4	80.7	

Sawing method	10-inch diameter							12-inch diameter							All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
I	71.4	71.4	71.4	42.9	67.7	56.5	61.1	50.0	58.3	54.6	77.5	52.1	63.6	60.6	60.8
II	81.3	71.4	76.7	54.2	46.2	50.0	60.0	83.3	86.4	84.8	66.7	70.1	68.8	73.9	68.9
III	100.0	100.0	100.0	88.9	86.1	87.5	91.7	77.8	96.3	87.0	64.8	79.6	72.2	77.2	81.4
IV	100.0	95.8	97.6	88.9	88.9	88.9	92.1	84.0	96.3	90.4	77.8	85.5	81.9	84.5	87.5
								Bow							
I	100.0	85.7	92.9	100.0	94.1	96.8	95.6	100.0	95.8	97.7	100.0	89.6	94.3	95.5	95.5
II	100.0	100.0	100.0	87.5	84.6	86.0	91.3	95.8	95.5	95.7	95.8	97.9	96.9	96.5	94.6
III	88.9	94.4	91.7	91.7	96.1	88.9	89.8	85.2	100.0	92.6	83.3	94.4	88.9	90.1	91.4
IV	100.0	91.7	95.2	83.3	97.2	90.3	92.1	96.0	96.3	96.2	88.9	98.4	94.0	94.6	94.4
								Twist							
I	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
III	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
IV	100.0	88.9	94.4	100.0	97.2	98.6	97.2	96.3	100.0	98.2	98.2	98.2	98.2	98.2	98.3
								All warp							
I	71.4	71.4	71.4	42.9	61.8	53.2	58.9	50.0	58.3	54.6	77.5	50.0	62.5	59.9	59.5
II	81.3	71.4	76.7	54.2	46.2	50.0	60.0	79.2	86.4	82.6	64.6	70.8	67.7	72.5	68.0
III	88.9	83.3	86.1	83.3	77.8	80.6	82.4	70.4	96.3	83.3	64.8	75.9	70.4	74.7	77.3
IV	94.4	87.5	90.5	75.0	86.1	80.6	84.2	84.0	92.6	88.5	72.2	79.0	75.9	79.8	82.1

Table 14.--Yields from upper logs, with individual warp aspects, for SPIB No. I Dimension: percent of studs by sawing methods, log diameters, compression wood classes, and eccentricity positions

Sawing method	6-inch diameter							8-inch diameter							
	Normal wood			Compression wood			All 6-inch	Normal wood			Compression wood			All 8-inch	
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		
								Crook							
III	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.4	94.4	94.4	96.3	
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	94.4	94.4	94.4	96.3	
								Bow							
III	83.3	100.0	91.7	100.0	91.7	95.8	94.4	100.0	100.0	100.0	100.0	94.4	97.2	98.2	
IV	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
								Twist							
III	83.3	66.7	75.0	75.0	75.0	75.0	75.0	100.0	77.8	88.9	94.4	83.3	88.9	88.9	
IV	100.0	100.0	100.0	83.3	91.7	87.5	91.2	88.9	77.8	83.3	94.4	94.4	94.4	90.7	
								All warp							
III	66.7	66.7	66.7	75.0	75.0	75.0	72.2	100.0	77.8	88.9	88.9	77.8	83.3	85.2	
IV	100.0	100.0	100.0	83.3	91.7	87.5	91.2	88.9	77.8	83.3	88.9	88.9	88.9	87.0	

Sawing method	10-inch diameter							12-inch diameter								All diameters
	Normal wood			Compression wood			All 10-inch	Normal wood			Compression wood			All 12-inch		
	Vertical	Horizontal	Combined	Vertical	Horizontal	Combined		Vertical	Horizontal	Combined	Vertical	Horizontal	Combined			
								Crook								
I	100.0	94.4	96.7	86.7	96.4	91.4	93.2	95.5	95.5	95.5	82.5	84.8	83.7	87.7		89.9
II	100.0	100.0	100.0	91.2	100.0	95.2	96.6	100.0	100.0	100.0	92.6	80.7	86.2	90.1		92.4
III	94.4	100.0	97.2	94.4	94.4	94.4	95.4	100.0	100.0	100.0	98.2	96.3	97.2	98.1		97.2
IV	100.0	100.0	100.0	100.0	88.9	94.4	96.2	100.0	100.0	100.0	92.2	100.0	95.8	97.3		97.1
								Bow								
I	100.0	100.0	100.0	96.7	100.0	98.3	98.9	100.0	100.0	100.0	97.5	100.0	98.8	99.2		99.1
II	100.0	100.0	100.0	100.0	96.4	98.4	98.9	100.0	100.0	100.0	100.0	98.4	99.1	99.4		99.2
III	100.0	100.0	100.0	100.0	100.0	100.0	98.2	100.0	95.8	97.9	98.2	98.2	98.2	98.1		97.7
IV	88.9	100.0	94.4	100.0	88.9	94.4	96.2	100.0	100.0	100.0	94.2	100.0	96.9	98.0		97.9
								Twist								
I	91.7	100.0	96.7	100.0	96.4	98.3	97.7	100.0	100.0	100.0	100.0	97.8	98.8	99.2		98.6
II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.2	100.0	99.1	99.4		99.6
III	94.4	88.9	91.7	97.2	97.2	97.2	95.4	100.0	95.8	97.9	96.3	100.0	98.2	98.1		93.5
IV	100.0	100.0	100.0	94.3	97.2	95.8	97.2	100.0	96.2	98.0	98.0	97.8	97.9	98.0		95.9
								All warp								
I	91.7	94.4	93.3	83.3	92.9	87.9	89.8	95.5	95.5	95.5	80.0	84.8	82.6	86.9		88.1
II	100.0	100.0	100.0	91.2	96.4	93.6	95.6	100.0	100.0	100.0	90.7	79.0	84.5	88.9		91.2
III	77.8	88.9	83.3	91.7	91.7	91.7	88.9	100.0	91.7	95.8	92.6	94.4	93.5	94.2		89.0
IV	100.0	100.0	100.0	94.3	77.8	85.9	90.6	100.0	96.2	98.0	86.3	97.8	91.7	93.8		91.5

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