WOOD BENDING

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APPARATUS FOR BENDING BOAT RIBS

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WOOD BENDING*

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Summary

Wood softened by the action of moisture and heat or by other agencies can be upset or shortened very considerably, but can be stretched or lengthened but little. Hence, since the concave and convex faces of a bent piece differ in length, it is necessary in bending to prevent stretch and to cause the entire difference in length to take place as upset, this upset being a maximum at the concave face and decreasing to zero near the convex face. This can be accomplished by supplying a metal strap with securely attached end fittings through which the compressive force, or end pressure, can be applied. The end pressure must be distributed over the ends of the stock so that localized crushing does not occur, and the rotation of the end fitting must be restrained to obviate release of the end pressure. The common arrangement of parts of wood bending apparatus does not fullfill these requirements. The requirements can be attained, however, by utilizing the principle of the reversed lever.

The distance between end fittings cannot be made exactly the same for a number of straps and cannot be kept constant, neither can pieces of wood be cut exactly to the required length. Hence, means for adjusting the distance between end fittings is necessary. Pieces whose width is considerably less than their depth must be restrained to prevent sidewise bending and the formation of lateral crooks and buckling.

This paper, which is based on studies at the Forest Products Laboratory, deals only with the requirements of bending apparatus and manipulation, emphasizes their importance, and points out that they must be correct before the large breakage losses incurred in the bending of wood can be reduced materially.

Introduction

The bending of wood to curved shape is an art that has been practiced for many decades. Observation indicates, however, that the desirable stage of perfection has not yet been reached. This is evidenced by the fact that large breakage losses occur in nearly every bending operation.

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Such breakage causes large financial loss to manufacturers. Furthermore, the ruin, for any use except for fuel, of considerable quantities of good wood constitutes a drain on timber supplies. It is the purpose of this paper to discuss the one cause of loss that can be most readily corrected. The investigations needed to accomplish further improvement are also enumerated.

The production of bent wood parts may be divided into the following steps:

1. Selection of stock.
2. Seasoning the stock (except when it is used in the thoroughly green condition).
3. Preparation of bending blanks.
4. Softening the wood and rendering it pliable or bendable.
5. Bending.
6. Fixing in the bent shape.

In the woodworking industry varied practice obtains with respect to several of these steps. Some manufacturers attempt to bend the general run of stock while others insist on freedom from cross grain and other defects and in addition attempt to select material of good "bending texture." Stock may be bent in the rough condition in which it comes from the sawmill or may be planed before bending. Blanks may be made as nearly as possible to final size to avoid failure in bending or may be left considerably oversize so that material damaged in bending can be trimmed off. Some woodworkers prefer green wood, some would rather have thoroughly air-dried wood, and yet others believe best results are obtained with partially seasoned wood. Hot water soaking, steaming with exhaust steam, pressure steaming, and softening by chemicals are variously advocated.

The seasoning and softening treatments and the wood itself ordinarily receive the major blame when excessive breakage occurs. In such a case, it is usually decided that the wood was not properly seasoned or that it was steamed too much or not enough or that the timber was "dead" or that something else was wrong. But the efficiency of the bending apparatus and appliances is seldom questioned. It is known, by many, that "end pressure" is necessary. But if some sort of a strap is used, it is assumed that the end pressure requirement is fulfilled. Furthermore, it is too frequently assumed that considerable breakage is inevitable.

The writer believes that a large part of the bending breakage will be avoided if the necessity for end pressure is fully recognized and the requirements for obtaining it understood. Furthermore, it is believed that the application of correct principles to the actual bending operation will, without other modifications of bending room practice, relieve a large number of the ills of wood bending. Unless the bending manipulation is correctly carried out, however, it is impossible to determine whether or not the practice with respect to other steps is acceptable. These
conclusions are the result of several years experience at the Forest
Products Laboratory with strength tests of wood, and observations in a
large number of plants making a variety of bent wood products.

In view of the importance of end pressure, this paper is devoted
chiefly to an explanation of the inadequacy of common bending appliances
and the presentation of a method whereby properly controlled end pressure
can be obtained.

What Happens in Bending

When a piece of wood is bent without straps, the wood fibers
on the side next to the form are put in compression and those on the oppo-
site side in tension. The compression is accompanied by shortening or
upset and the tension by lengthening or stretch. The result is that the
side next the form becomes considerably shorter than the opposite side —
the difference between the lengths of the two sides depending on the
thickness of the piece and on the angle through which it is bent. The
relative or percentage difference depends on the thickness of the piece
and the radius to which it is bent and is equal to the ratio of the thick-
ness to the radius of the convex face. If the radius is very large
compared to the thickness (say about 200 or more times as great), the
upset and stretch are exactly equal and a line drawn along the center of
the thickness of the piece before bending is unchanged in length when the
bending is complete. A piece of wood bent to such a large radius, however,
will not remain bent when released.

As the radius is reduced, the shortening or upset becomes
greater in degree than the stretch, and the neutral line, or line whose
length is unchanged in bending, moves toward the tension side of the
piece. This is because wood is much stronger in tension than in com-
pression; and the thinner layer between the neutral line and the convex
face has sufficient tensile strength to hold together while the thicker
layer between the neutral line and the concave face is compressed.

As the radius is further reduced, a stage is reached wherein the
tension layer no longer has sufficient strength to hold together and will
fail by pulling apart unless it is assisted in some manner. To give such
assistance is the purpose of the metal strap or band used in making severe
bends; although it is sometimes assumed that the purpose of the strap is
to prevent splinters from "kicking out" from the body of the piece by
exerting pressure against the convex face. Splinters, however, cannot
"kick out" until they are formed by the occurrence of tension failures.
Adequate straps that are properly used not only prevent the splinters
from "kicking out" but prevent their formation; that is, such straps
prevent tension failures.
Types of Failures in Bending

In making severe bends, failure of the wood may occur either by compression or tension or by both. In case the upset, which in successful bends is evenly distributed, becomes localized, buckling or compression failure on the side next to the form may take place. Tension failure takes place when the fibers on the side away from the form are pulled apart.

If the metal straps are sufficiently strong and their end fittings are efficient in action, tension failures can be entirely prevented by restraining the piece so that little or no stretch occurs.

The statement is sometimes made that some stretch must be permitted as otherwise compression failures will certainly result. The fact is, however, that wood can be stretched only a small amount, probably less than 1 percent on the average, without tension failure. In many bends the difference in length between the convex and concave faces is 15 percent or more and it is evident that in such cases the prevention of a possible stretch of 1 percent or less would do little to obviate compression failure.

If bending is to be done without numerous tension failures, the appliances used must be such as to enable the end pressure to be kept under control and the stretch of the outer or convex side of the bend kept within narrow limits. If the strap is to be effective in limiting stretch, it must have securely attached to it adequate end fittings against which the ends of the piece can bear.

Analysis of Action of Common Types of Wood Bending Apparatus

In order to determine the kind of end fittings required to exert a push that will prevent the stretch of the convex face of the bending stock and the consequent tension failure, it will be useful to consider some of the common types of bending apparatus and to analyze their action. If bending is attempted with straps having very short end blocks as

\[ \text{2No systematic study has been made at the Forest Products Laboratory to determine how much stretch can take place without tension failure. Some measurements of heavy oak wheel rims showed that where as much as 1 percent stretch of the convex face occurred in bending, tension failure resulted. Possibly such species as hickory and rock elm, and particularly the better pieces of these species, can be stretched considerably more than this. On the other hand, the permissible stretch is in many cases probably less than 1 percent and it seems best to assume that stretch must be restrained as much as possible.} \]
illustrated in Figure 1, a, these end blocks will tip over and slip off as shown in Figure 1, b. Consequently, the strap becomes quite ineffective.

In making bends such as chair back posts in a hot press bender, straps or bending pans, such as shown in Figure 2, are used as a rule. Although the end blocks are better than those of Figure 1, they are insufficient in length to entirely prevent stretch and tension failures. In fact, with the type of end blocks or end angle irons shown in Figure 2, the ends of the stock may be observed actually to rise during the first part of the closing of the press, thereby demonstrating that the horizontal legs of the angle irons are not long enough to prevent such tipping as is shown in Figure 1, b. Furthermore, when even slight tipping takes place, the push of the end block becomes localized and causes crushing at the lower edge of the stick, which allows stretch to occur and tension failure results. Localized crushing can be obviated by pivoting the plates against which the ends of the stock bear as illustrated by the special type of par or strap in Figure 3 where the pressure is uniformly distributed over the ends of the stock. However, the push of the stick tends to rotate the end fitting and thus relieve the end pressure. The prevention of stretch requires that the end pressure be maintained. How this fundamental requirement of bending manipulation can be attained may be better understood from an analysis of the forces that come into action during the bending operation.

Figure 4 represents a stick in process of being bent. The stick of thickness or depth $h$ is partially bent, the last point of contact with the form being $O$, that is, the bending is complete to the left of $O$. The strap of thickness $t$ is securely attached to the end fitting $m$. The stick bears through plate $n$ against a pivot at the inner end of fitting $m$. Since there is to be no rotation of the end fitting, the line of action of $P'$ will be at right angles to the end of the stick. If the stick and strap are assumed to be cut along a plane through $O$, and the center of curvature of the form, the action of the portion of the strap and stick to the left of this plane can be represented by:

- $T$, the tension in the strap acting at the center of its thickness and perpendicular to the cutting plane,
- $C$, the summation of the stresses (in the stick) perpendicular to the cutting plane, and
- $P''$, the shear parallel to this plane.

Since the summation of forces perpendicular to the cutting plane must be zero,

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2 This pan was developed at the Forest Products Laboratory and is patented for the free use of the people of the United States. For a more complete description see "Some Improvements in Hot Press Bending," published in the January 1926 issue of "Wood Working Industries," and in the February 1926 issue of "Furniture Manufacturer and Artisan." This design, however, has been superseded by a further improvement described later in this article.
\[ C = T \]

Equating external and internal moments about the intersection of the line of action of \( C \) with the cutting plane,

\[ P(X + L) = Ta \]  \hspace{1cm} (1)

where \( a \) is the distance between the lines of action of \( T \) and \( C \). Moments about \( C' \), the intersection of the center line of the strap with the plane of the outer face of bearing plate \( B \), give

\[ PX = P'b \]  \hspace{1cm} (2)

where \( b \) is the distance from the line of action of \( P' \) to the center line of the strap.

\( P \) is eliminated by dividing equation (1) by equation (2) and the following equation results:

\[ X = \frac{L}{\frac{Ta}{P'b} - 1} \]  \hspace{1cm} (3)

\( P' \) must be equal to the tension in the strap at \( 0' \). The tension at this point is equal to \( T \), the tension at \( 0 \), except for the friction force between the strap and the projecting portion of the stick. The friction force depends on the coefficient of friction and on the pressure of the strap on the stick. This pressure depends on the angle \( \alpha \) through which the projecting portion of the stick is bent. Since ordinarily this angle is small the friction force is small and the tension at \( 0' \) is approximately equal to \( T \). Hence, \( P' = T \) very nearly and without great error equation (3) can be rewritten as:

\[ \frac{X}{L} = \frac{1}{\frac{a}{b} - 1} = \frac{b}{a - b} \]  \hspace{1cm} (4)

There is to be very little\(^3\) stress or deformation at the convex face of the piece and the shortening of the stick at point \( 0 \) will vary from nothing near the face next the strap to a maximum at the face next the form. This distribution of the shortening or deformation is represented by the abscissas of the small triangle shown at \( 0 \) in Figure 4. If the stress were proportional to the deformation then \( C \), the resultant of these stresses would act at a distance of two-thirds \( h \) from the inner side of the strap.

\(^3\)Since the strap is under combined bending and tensile stress, there may be some change in the length of its inner face. Disregarding the deformation of the convex face of the stick which this would imply introduces no significant error in the further discussion.
Since, however, the stick is strained beyond the elastic limit, stress is not proportional to deformation and this distance is probably slightly less than two-thirds \( h \). It is greater than one-half \( h \), however, for if it was exactly one-half \( h \) no bending would occur and if less than one-half \( h \) the bending would be in the opposite direction. Danger of crushing at the end of the stick will be least if \( P' \) is applied at the center of the height or thickness of the stick, that is, if

\[
b = \frac{h}{2} + \frac{t}{2}.
\]

Equation (4) shows that the \( \frac{X}{L} \) ratio will be least if \( a \) is given the largest value it can have which, since it was assumed that the distance from \( C \) to the inner face of the strap cannot exceed two-thirds \( h \), is

\[
\frac{2h}{3} + \frac{t}{2}.
\]

With the substitution of these values for \( a \) and \( b \) equation (4) becomes:

\[
\frac{X}{L} = \frac{3(h + t)}{h} = 3 + \frac{3t}{h} \quad (5)
\]

This shows that in order to maintain the exact balance of forces, \( X \), which is the distance from \( O' \) to the point of application of the bending force \( P \), must be at least three times as great as \( L \), which is approximately the length of the projecting portion of the stick, and that \( X \) cannot be kept constant but must decrease as \( L \) decreases. These same conclusions are reached from a more complete analysis in which the friction between strap and stick is considered. The more complete analysis also shows that \( X \) might be kept constant if the distance could be varied during the progress of the bending.

Why not keep the leverage \( X \) constant and obtain the desired results by varying the force \( P \) as the bending progresses is a question that might be asked. The answer is that with \( X \) fixed the value of \( P \) at any stage of the operation is determined by the moment required to bend the stick at the point of contact with the form. Hence, \( P \) is not subject to being varied as desired.

Yet another way of stating the necessary balance of forces is as follows:

\[\text{The bending can be continual to the end of the stick only by making } b \text{ equal to } a.\]
1. The resistance of the stick to bending at the point of contact with the form is approximately constant during the operation. Hence, $P(X + L)$, which is the moment to bend the stick, is constant and $P$ must increase as the operation proceeds and $X + L$ decreases.

2. $P'$ is the push required to prevent stretch and it also remains approximately constant and has a constant moment about $O'$. Hence, $PX$ must be kept constant.

3. The products $PX$ and $P(X + L)$ can be kept constant as $L$ decreases only by keeping $X$ in a constant ratio to $L$.

The preceding analysis shows why bending apparatus arranged as in Figure 4 is frequently inadequate since it is seldom convenient or possible to provide long enough end fittings or to shift the points of application of forces during the operation.

However, apparatus that only approximately fulfills these requirements often functions satisfactorily. For example, the pan shown in Figure 3 operates in a very satisfactory manner in a hot-press machine. Although the end fitting rotates slightly in the early part of the operation, resulting in some release of end pressure, this is usually not enough to cause tension failures. Later, rotation of the end fitting in the opposite direction results in more end pressure than is needed to prevent stretch but usually this does not appreciably increase the tendency toward compression failures. It should be remembered that in this particular instance the total angle of bending is small and only a portion of the length of the stick is bent.

The Reversed Lever

A simple method of providing for automatic regulation of end pressure is illustrated in Figure 5. Here the longer leg of the end fitting has been reversed and extends back along the bending stock. The strap is attached to the end fitting only near the end of the strap. With this arrangement the counterclockwise moment on the end fitting resulting from the end pressure $P'$ is resisted by the pressure of the reversed lever against the stock, whereas with the arrangement of Figure 4, the resisting moment had to be obtained by providing a definite lever arm for the bending force $P$. With the Figure 5 arrangement $P$ may be applied at any point beyond that to which the bending is to continue or its position may be varied as bending progresses with the limitation that it must always be to the right of the last contact of the stick with the form. Furthermore, as the lever arm of $P$ is shortened, the pressure of the stick against the form increases and if this arm is made too small the stick will be crushed radially. Since the projecting portion of the stick bends but little near the end, approximately uniform distribution of end pressure is obtained without the pivoted bearing. However, stock can seldom be cut to fit the length of the strap with the necessary degree of exactness. Consequently, some adjustment of strap length must be provided, and it is convenient to make this adjustment...
by means of screws threaded through the end fittings and the end pressure may be applied through bearing plates pivoted on the ends of these screws.

Obviously, the bending lever and end fitting in order to function properly must be sufficiently rigid that no appreciable deformation takes place in them. Sometimes the necessary rigidity can be obtained along with other useful results by making the lever of U- or channel-section so as to surround the stock on all sides except that next to the form. If the width of the stock is much less than its depth, there is a tendency toward buckling or bending sidewise. In such a case, the use of a channel-shaped lever has the advantage that the stock can be braced laterally against the flanges of the channel.

The reversed lever principle is utilized in a second type of pan designed by the writer for use in the hot-press bending of chair back posts. This pan is shown partially assembled in Figure 6, and in Figure 7 it is shown in position ready for the press to be closed. Figure 6 shows the "sidewalls" of this pan, which serve as the reversed levers and in the lateral bracing of the stock. End plates D pivot on the points of screws C which also serve for length adjustment. Figure 7 shows how the sidewalls bear against the upper form.

By the use of this pan it was found possible to bend red gum back posts 1-1/6 inches wide by 2-1/4 inches deep with practically no loss from breakage. Furthermore, due to the clamping action of the side screws during the press operation and the subsequent drying of the stock, the product was remarkably free from sidewise crooks or bends and from warp and twist.

The statement that one of the worst ills of wood bending is the lack of properly controlled end pressure is substantiated by this experience and by the testimony of a manufacturer who had requested drawings of the pan illustrated in Figures 6 and 7. This manufacturer wrote as follows:

"A duplicate of this pan was made for the bending of portable chair legs which are about 2-1/4 inches wide and about 1 inch thick, the bending being made along the edge rather than on the side. While we were using the old pans, that is, pans of the conventional type commonly used, in wood bending rooms, our breakage was extremely high, in some cases running as high as 50 percent, although it would not average that. With the new pans made with a few minor changes from the sketches we received from you the breakage has been running between 5 percent and 10 percent. The bending operation is a rather difficult one and we are very much satisfied with the results we are obtaining from these pans. ..."

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5 This pan was developed at the Forest Products Laboratory. The pan and its operation is described in more detail in "A Further Improvement in Bending Pans," February 1927 issues of "Wood Working Industries" and "Furniture Manufacturer."

6 The reversed lever principle as described in connection with Figure 5 is not fully realized in this apparatus. With outer as well as inner forms as provided in the hot-press bender, the lever cannot extend along the outer face of the portion of the stick beyond the last point of contact of the form. Hence, considerable bending may occur in this portion and a pivot is necessary to distribute the end pressure over the end of the stick.
The principle of the reversed lever is utilized in some of the machines regularly built for bending work. This is true of the machine for the bending of heavy wheel rims shown in Figure 8. This particular machine also has means for applying considerable end pressure to the stock before bending is begun and for releasing the end pressure automatically as bending progresses.

Sometimes the end fitting is extended back along the stick for a short distance. Such an example is illustrated in Figure 9. The reversed lever principle is fully realized, however, only when the end fitting extends back as far as the last point of contact between the stick and the form. This is not the case in Figure 9 and the lack of proper regulation of end pressure is demonstrated by the reverse curvature of the stick near its end. Figure 9 represents a condition observed in an actual bending operation.

Other Deficiencies of Apparatus and Operation

Often the apparatus used in bonding and the manipulation have deficiencies other than the lack of means for the central application of end pressure to prevent end crushing and the lack of means for keeping the forces in proper balance as discussed in connection with Figure 4. Among those are:

1. The strap and other parts of the apparatus are not strong enough.

2. Stock is cut too short for the strap and stretches, and tension failure occurs before any pressure is obtained from the end fitting. Stock is cut too long for the strap and is forced into place in it, thus tipping the end fitting and causing localized crushing at the end of the stock before bending begins. Since bending blanks can seldom be cut to fit fixed length straps with sufficient exactness, some means of adjusting the strap for the length of the stick must be provided. When a number of pieces are bent in the same pan it is obvious that the same types of failures may occur unless the pieces are exactly equalized in length.

3. If the width of the piece to be bent is less than its depth there is a tendency to bend sidewise and to form lateral crooks and buckling. Provision is not ordinarily made to restrain this tendency.

Application of the Reversed Lever Principle

Application of the idea of the reversed lever presents no difficulty when bends without reversal of curvature are made with inner forms only. When both outer and inner forms are used, as is common with hot-press machines, the problem of clearance for the lever when the machine is closed must be met. In fact, in such a case the idea of the reversed lever can be only partially realized since a rigid part, such as the web of a channel section, cannot be interposed between the stick and the outer concave form. (The idea of the reversed lever is only partially realized in the design of
the pan shown in Figures 6 and 7.) Further complications arise in making bends having a reversal of curvature, such as a tennis racquet or snowshoe frame, or when parts of a bend are in successively different places as in certain chair parts.

Opportunity exists for the exercise of ingenuity in designing machines and appliances that will permit the application of correct principles in making bends that involve these complications. It should be accepted as an axiom that no bending apparatus and manipulation that permits tension failures to occur is adequate.

Importance of Other Steps

Although this paper has been devoted to a discussion of apparatus and manipulation, the importance of the other steps involved in the production of bent wood parts is not to be overlooked. Research is needed to determine:

1. What species not hitherto used for the purpose can be bent successfully and how to select bending stock of each species.
2. What method and degree of seasoning puts wood in the bent condition for the succeeding steps.
4. How the softening can best be done; whether by hot water or steam, and at what pressure; or whether by chemical treatment.
5. What procedure is best in drying the bent part and fixing it to the desired shape.
6. What allowance needs be made for change of shape subsequent to bending.
7. The interrelations of these several factors and their effect on the strength properties and the permanency of shape of the resulting product.
Fig. 1.—Sketch of a bending strap having ineffective short end blocks. (a), Before pressure is applied. (b), After pressure is applied. Note how the end blocks tip over and slide off.

Fig. 4.—Sketch of a stick in process of being bent.

Fig. 5.—A simple method of providing for automatic regulation of end pressure.

Fig. 9.—Apparatus with longer leg of end fitting extending back along the piece being bent but too short to fulfill the reversed lever idea. Note reverse curvature of projecting portion of piece.
Fig. 2.–Type of pan or strap ordinarily used in hot-press bending. Note the short length of the horizontal leg of the angle irons.

Fig. 3.–An improved type of pan, showing clamping arrangements and laminated side bars.
Fig. 6.--Latest model bending pan partially assembled to show features of construction.

Fig. 7.--Latest model bending pan with charge in place ready for closing of press.
Fig. 8.--Rim bending machine.
APPENDIX

APPARATUS FOR BENDING BOAT RIBS

The purpose of this appendix is to present a detailed description of apparatus recently developed at the Forest Products Laboratory for use in bending boat ribs and similar parts. It is believed that such a description may be helpful in assisting boat builders and others to design apparatus based on the same principles and adapted to specific needs.

The apparatus, illustrated in Figures 9 to 12, embodies the principle of the reversed lever as discussed on pages 9 and 10 of "Wood Bending." Its efficiency has been demonstrated by bending oak pieces 2-3/8 inches square around an inner form of 23-inch radius and through an angle of 180° with 100 percent success.

Referring to Figure 10, a is the stick being bent, c is a wooden form of 23-inch radius. The strapping arrangement has principal parts: d, the strap; b, two pieces of steel I-beam; e, end abutments; and g, end screws. d is brazed near its ends to parts b and parts e are brazed to parts b. End screws g are threaded through parts e and their points bear against steel plates f which in turn bear against the ends of the stick a. i represents clamping devices consisting of a piece of steel with a round shank to fit into holes bored in the bending table, above which is a rectangular section with a screw threaded through it.

The bending operation starts from the position shown in Figure 9 with end screws g tightened and with one of the clamping devices set tightly against the strap at the center of the length of the stick. It progresses by pulling the cable h bringing the stick around the form. It is desirable to follow the bending closely with clamping against the form otherwise the portion of the piece already in contact with the form may buckle away from it. End screws g may be backed off gradually as bending progresses. These screws need to be centered carefully on the end of the stick, particularly on its vertical dimension (as seen in the pictures). Otherwise buckling of the stick in a vertical plane is likely to occur. (Such buckling did occur in the stick shown -- Figure 10 -- because of imperfect centering of the screws at the right-hand end.) In some of the experiments, it was found that, by inserting between the ends of the stick and plate f wood blocks with their grain perpendicular to the grain of the stick manipulation of the end screws during the bending was unnecessary because crushing of the block gave the necessary relief from end pressure. Blocks can be used for this purpose only once.

The sticks bent in this apparatus were 3 feet long and about 2-3/8 inches square. They had been dried to a moisture content of about 35 percent and previous to bending were soaked in boiling water for 1 to 1-1/2 hours. To prevent end-checking during drying they had been end-coated with the hardened gloss oil preparation described in Forest Products Laboratory R966.
Technical Note 186. The coating also served to restrain penetration of water into the ends of the stock during the soaking and proved helpful in preventing end-checking during the drying subsequent to bending.

Dimensions of some of the parts of the apparatus shown in Figures 9 to 12 are as follows: I-beam, b, 5 inches high by 3 inches flange width; strap, d, 1/8 inch by 3 inches. This is an ordinary mild steel strap and it appears to have stretched some during use. Spring steel is probably preferable for such use. End screws g, 5/8 inch in diameter -- larger size would have been better; parts i, 1-inch diameter shank with 5/8-inch diameter screw; cable h, 1/4-inch diameter.

When the piece to be bent has a radial dimension or depth that exceeds the width of its cross-section the bending is more difficult, and special care and measures are needed to guard against lateral buckling. When the part to be formed has a depth exceeding its width the bending may be done on pieces of double or triple width which can later be resawed. When this is not feasible it may be advantageous to use for part b a channel section with its open side toward the form. With such an arrangement the piece, or a group of pieces, to be bent can be braced or wedged against the flanges of the channel for reinforcement against buckling.

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