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The Bending of Wood With Steam

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THE BENDING OF WOOD WITH STEAM

by

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CHAPTER I

INTRODUCTION

During the past several years, and especially while working toward my M.F.A. degree in furniture design at Virginia Commonwealth University, my work has assumed a more distinct curvilinear quality. In order to achieve a curved element in designs, I have dealt with several methods of approaching the problem.

The first, and probably the most frequently used method, is to carve or saw the curved portion out of solid wood. This method proves to be not only wasteful, but it usually produces a weaker element than could be produced another way.

The second method is the much newer technique of lamination. This is the process of taking a number of thinly cut strips of wood, applying glue between the layers, and placing them between curved forms to create a finished curved shape. This procedure gives not only great strength, but great stability as well. The major disadvantage of lamination is the costliness of the process in terms of both money and time.

The third method of bending wood, and the concern of this thesis, creates curves in solid wood through the use of steam. Briefly, in the process of plasticizing wood, the wood is saturated with wet steam at atmospheric pressure for a period of time. Then, while the wood is warm, wet, and receptive to change, it is shaped to a predetermined curve by bending it around a curved form, until it cools and dries. I hopefully anticipated that the steam method would overcome many of the disadvantages found in the other two methods, specifically those of prohibitive cost and the loss of strength. Also, to my knowledge, the steam bending process had never been previously attempted in the wood studio at Virginia Commonwealth University.

However, the process itself is not new. Steam bending has been used for centuries, especially in the fields of ship building and in carriage/wagon construction.[1] In the nineteenth century, Thonet used steam bending to great advantage in developing a number of "Bent Wood" chairs.[2]

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[1] U.S. Department of Agriculture, U.S. Agriculture Department Handbook 125 (Washington, D.C.: Government Printing Office, 1957), p. 1.

[2] Hugh Honour, Cabinet Makers and Furniture Designers (London: Spring Books, 1972), p. 235.

Based on experimentation with the steam bending of wood to curved shapes, this thesis describes my involvement with three basic aspects of the process. First is the procurement, assimilation, and construction of the equipment and apparatus necessary for the steam bending of wood. Secondly, the determination of certain qualities of particular woods in reference to steam bending is made. This includes: woods easily bent; woods not easily bent; the time required to plasticize stock; and the time required to set curves. Also noted are some of the physical limitations involved in bending stock with steam in the craftsman's studio. Thirdly, steam bent wood is related to furniture design in terms of the craftsman's approach to the design and to the problems inherent in this process.

CHAPTER II

PROCURING AND ASSEMBLING THE STEAM APPARATUS

Steam Generator

Essential to this process is a source of steam. This could have been done in one of two ways: by using the school's existing steam system; or, by purchasing a generator. The latter method was chosen to achieve maximum portability. The use of the school's steam system was not feasible because it is a high pressure type, and wood must be steamed at atmospheric pressure in order to obtain successful bends. Also, the cost of bringing in a steam line to the studio area seemed impractical.

Basically, two types of portable steam generators are available. One type is a kerosene burner, such as Model #K5, Warner Kero Lectric Wall Paper Remover, Warner Manufacturing Company, Minneapolis, Minnesota. The second type is a totally electric type, such as the Electromatic Model #11A, All Electric Wall Paper Steamer, American Lincoln Corporation, Toledo, Ohio.

The electric type was chosen because of its availability and its safety factors. The all electric steam generator emits no harmful fuel vapors, and it is much less of a fire hazard in the wood studio. This device has a built-in safety feature which automatically shuts off the machine when the water level gets too low for safe maintenance.

The steam generator is simply filled with tap water, and plugged into a convenience outlet of 110 volts AC. Steam is produced within fifteen to twenty minutes. The only unsatisfactory thing about this generator is that its reservoir of water lasts for only three hours. This proves to be somewhat inconvenient, as one must disconnect the unit in order to refill the tank with water.

The original 12' x 1/4" (inside diameter) rubber steam hose with 1/4" brass pipe fittings was used to transfer the steam from the generator to the steam chamber. (See Illustration 3, p. 11.)

Steam Chamber

The next piece of equipment needed was a chamber or retort to house the wood stock while the steam plasticizes it. The original plan was to build a metal or a plastic container. This proved to be much too expensive, considering the lack of local availability of the appropriate materials. The cost of stainless steel, for example, was prohibitive.

Ceramic material was also considered, but the weight of a chamber built of such material would have denied the desired portability of the unit.

Therefore, the decision was made to build the steam chamber of plywood. The material used was U.S. Plywood Permaply, a special exterior grade fir plywood, with a water and chemical resistant fiber overlay. To fully utilize a 4' x 8' sheet of this material, a chamber 8' long was built, with interior dimensions of 9" x 12 1/2". The plywood was painted with three coats of epoxy paint. The box was assembled, using Weldwood plastic resin glue and brass boat-building nails.

It was clear that there was a need for a manifold system to insure an equal distribution of steam throughout the chamber. This system was made from polyethylene pipe, 1 1/2" in diameter. Some brass fittings were used. For the most part, however, galvanized steel fittings were used in making the connections. The plating on the steel fittings began to deteriorate and flake off. It would have been preferable to use all brass or copper fittings, if possible. After using the unit with steam, it became apparent that in a chamber this small, a manifold system might have been eliminated. Running the steam directly into a centrally located point could have proved to be equally as efficient as the manifold system. (See Illustration 1, p. 8.)

In the rear of the chamber, a condensation valve was provided. This was used to regulate the amount of water residue on the floor of the chamber. It is recommended that the steam be as moist as possible, in order to efficiently plasticize the wood.[1] The condensation valve insured that the interior of the box would not become excessively dry.

The point where the rubber hose joins the manifold system was designated the "top" of the chamber. This placed the manifold in an attitude of directing the steam down onto the material being plasticized. It was believed that this would give more efficient results. In retrospect, I believe it might be equally as efficient to allow the steam to rise naturally from below the level of the stock.

Next, the rear end of the chamber (which is made of 3/4" plywood) was semi-permanently caulked and screwed in place. This allowed the accommodation of longer stock when needed. For example, if it is necessary to curve the center portion of a 20' board,

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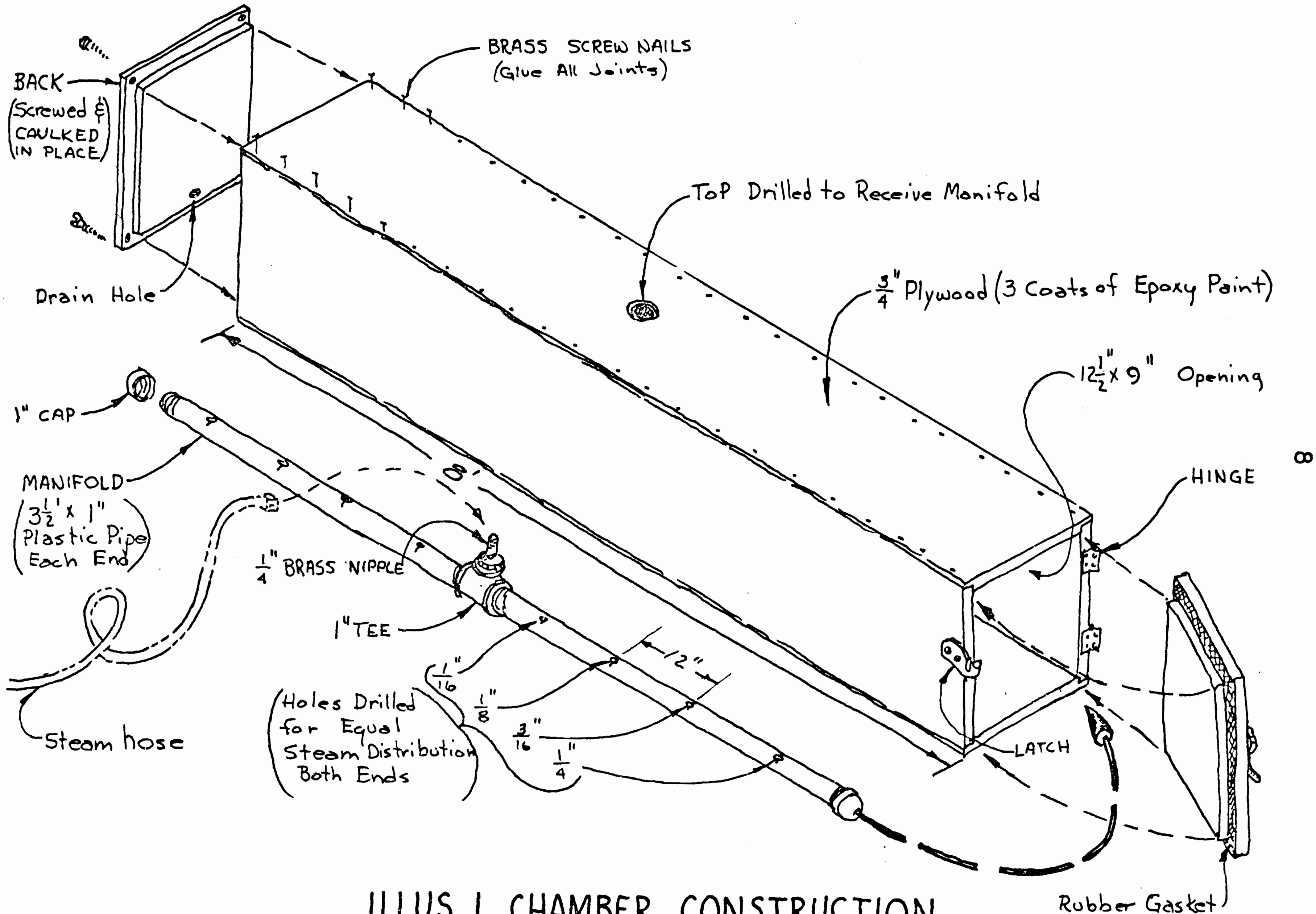
[1] U.S. Agriculture Handbook 125, p. 10.



ILLUS. 1. CHAMBER CONSTRUCTION

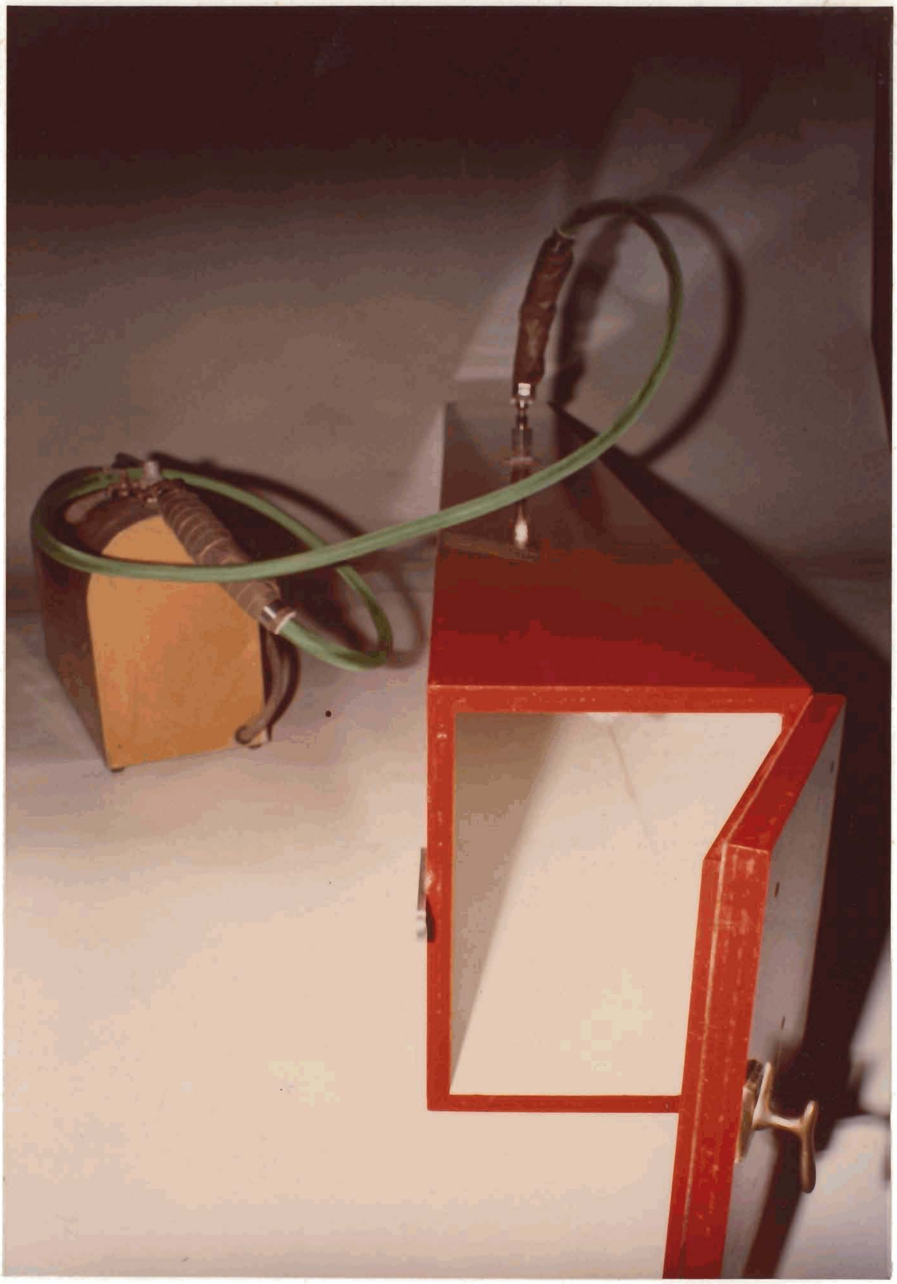
then with the back of the chamber removed and the front door open, the longer stock can be accommodated. Plastic seals can be placed around the retort openings to prevent any appreciable loss of steam.

To complete the unit, a plywood door (which also received three coats of epoxy paint) was hinged in place, and a latch mechanism was added to insure as tight a seal as possible. The chamber was installed in a slightly "down-hill" position. This angle allowed for the natural gravitational flow of the condensation away from the door. (See Illustration 1, p. 8; Illustration 2, p. 10; and Illustration 3, p. 11.)

Miscellaneous Materials

The following is a list of some of the additional materials and supplies used in the steam bending experiments performed:

2	One ton cable ratchet hoists
24'	5/16" steel cable with hooks
12'	1/4" x 1 1/2" x 1 1/2" angle iron
8'	1 1/2" x 3" x 1/4" channel iron
5'	2" x 5" x 1/4" channel iron
25'	Various sized steel strapping
30'	1 1/2" steel pipe
100	Various lengths 1/2" bolts
6	1/2" I bolts
6	5/8" U bolts
2	3/4" x 4' x 8' sheets of plywood sheathing



Illus. 2. Steam Chamber

Illus. 3. Steam Generator

As optional equipment for determining the moisture content of wood, a Delmhorst Moisture Detector #RC-1, Delmhorst Instrument Company, Boonton, New Jersey, was purchased. This instrument, though expensive, is helpful in determining when a bent piece of wood has stabilized by quite accurately determining its moisture content.

CHAPTER III

STEAM BENDING OF SELECTED WOODS

Stock Selection

It was anticipated that primarily white oak would be used in the steam bending experiments. One hundred twenty board feet of two inch thick white oak, kiln dried to a 6 per cent moisture content, was purchased. This later proved to be an unwise selection, because of the surface checking that occurred during the drying process.

When selecting the material to be used in steam bending, hardwood rather than softwood was chosen, because hardwood is more successfully bent. It is also true that certain hardwoods (such as oak, ash, or walnut) are more successfully bent than other hardwoods (such as rosewood, teak, or basswood). The moisture content recommended for air dried stock is 15 to 20 per cent.[1] The wood should be straight grained, free of knots, surface checks, decay, shake, or pith. Also, stock to be bent should be cut so that

[1]U.S. Department of Agriculture, U.S. Agriculture Department Handbook 72 (Washington, D. C.: Government Printing Office, 1955), pp. 299-300.

the end grain runs either parallel or perpendicular to the plane of the bend. (See Illustration 4, p. 15.) It is also recommended that the stock be wider than it is thick.[1] Making bends of square stock can cause some twisting problems. Also, all the bending stock was purchased rough, with four sides surfaced prior to bending.

Because of the time element involved, bends were made in one plane only. It is possible to make bends in two or more planes, but the mechanism required to accomplish this becomes increasingly complicated with each additional plane.

Free Hand Bends

First, white oak was bent free hand (without the use of end blocks), to a simple radius. (See Illustration 5, p. 16.) The stock was sawed and planed to 1/4", 3/8", 1/2", and 3/4" thicknesses. The material was placed in the steam chamber for a period of time. The chambering time is usually considered to be thirty minutes per inch of thickness of the stock (with 20 per cent moisture content).[2] From the experiments, it was found that sixty minutes

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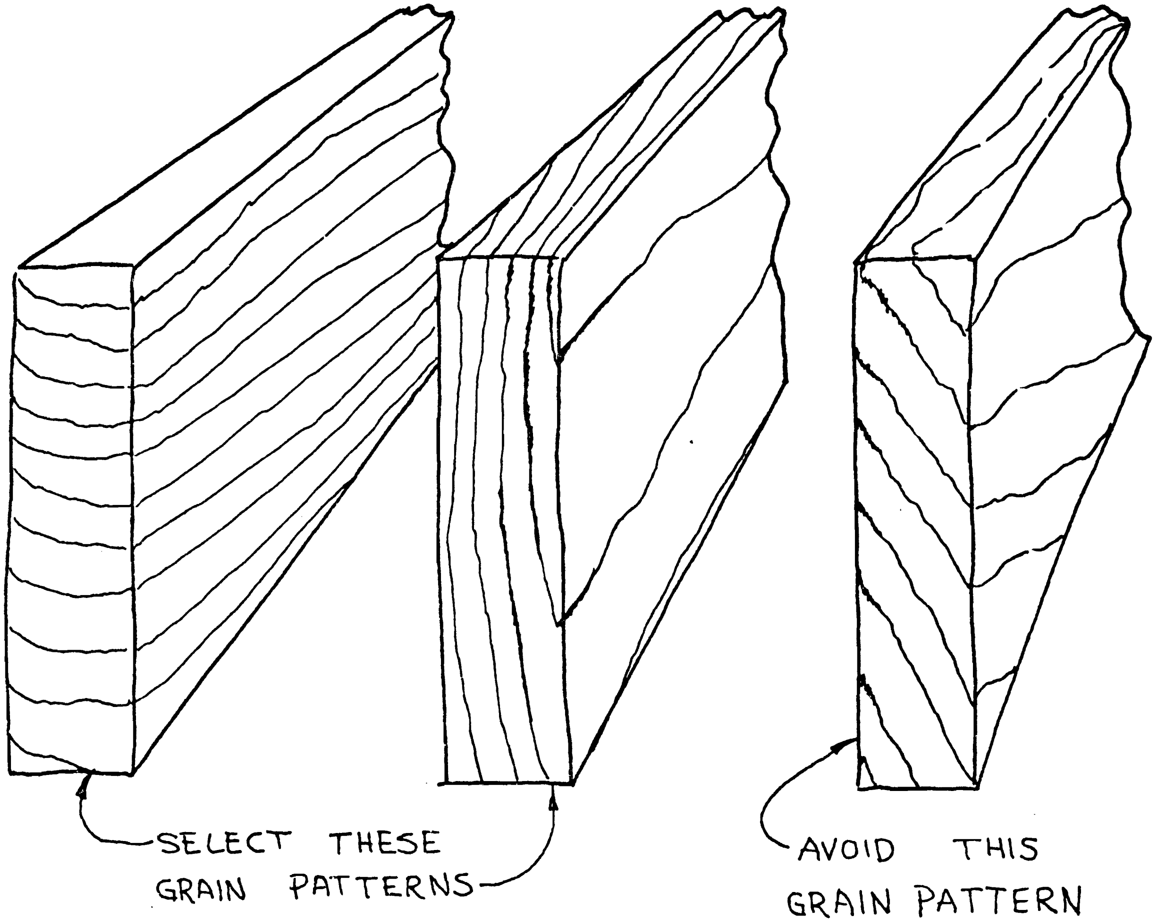
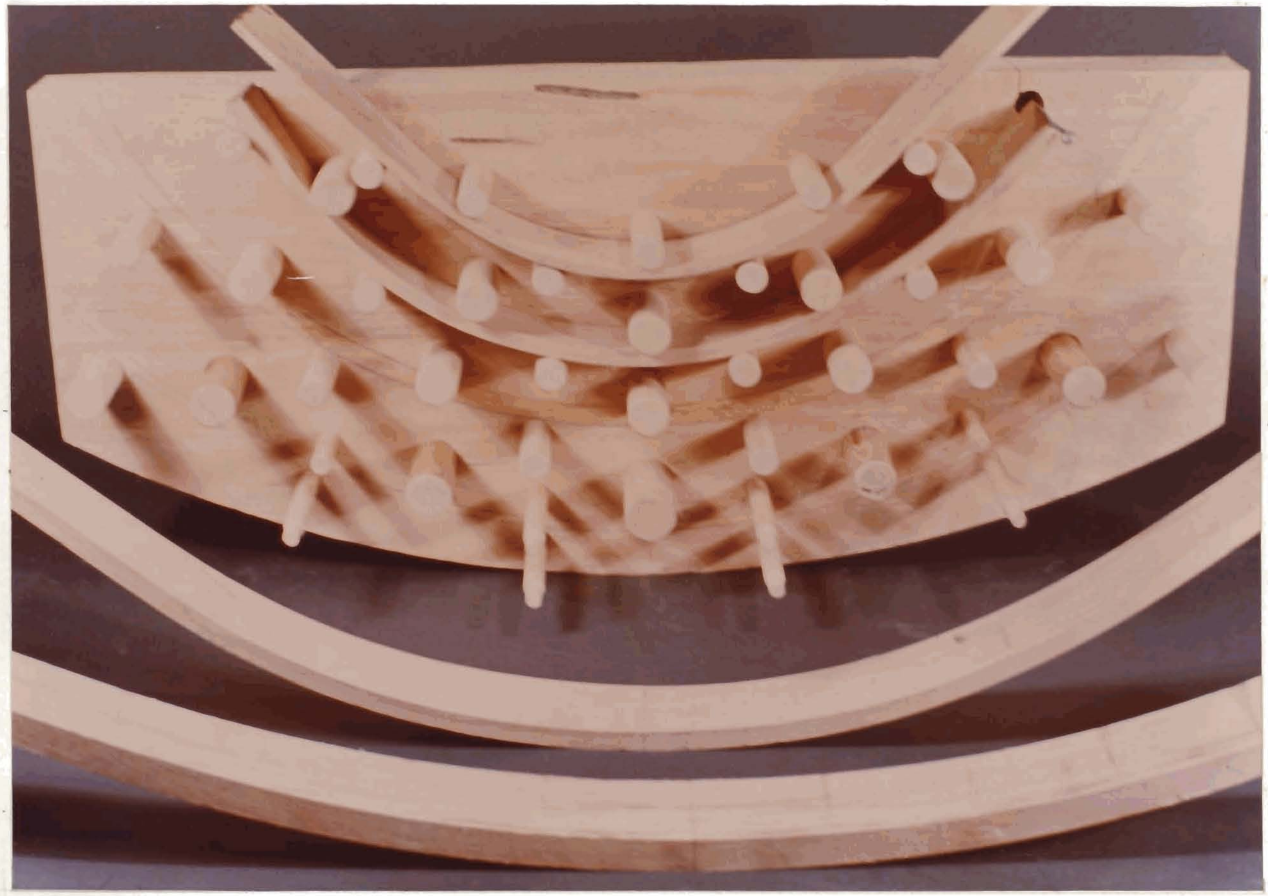
[1] U.S. Agriculture Handbook 125, p. 8.

[2] U.S. Agriculture Handbook 72, p. 300.



ILLUS. 4. GRAIN PATTERNS



Illus. 5. Free Hand Bends

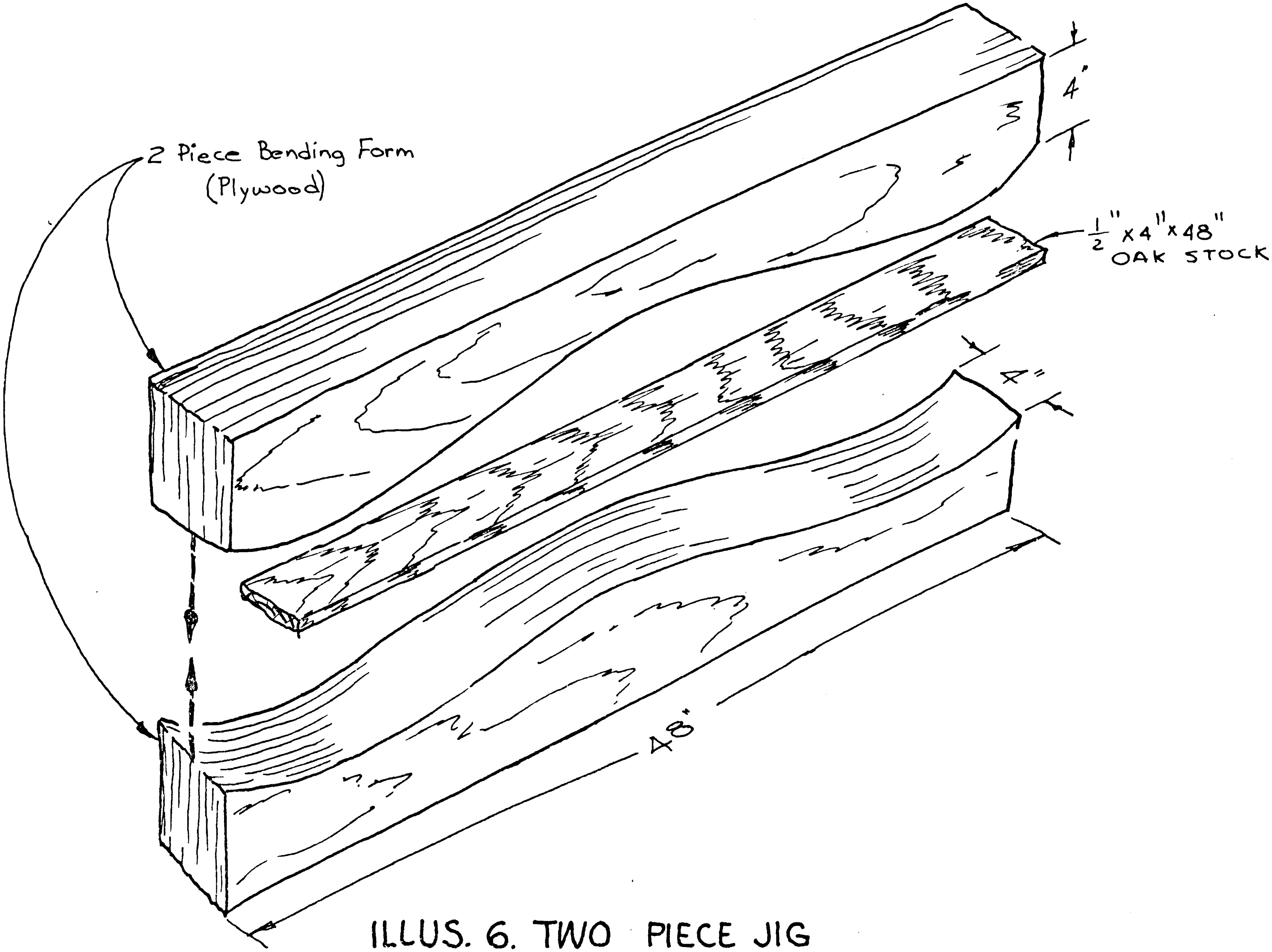
(or even slightly longer) per inch of thickness for kiln dried wood was preferable. Of course, there is a possibility of "over-steaming" the wood, but this never happened, even when steaming some 1 1/2" white oak for as long as three hours.

The free hand method of bending is acceptable for making gentle curves. These are curves wherein the difference between the inside and the outside linear measurements (along the curves) is no greater than three per cent. Exceeding this tolerance may result in tensile failure, where the fibers stretch apart on the outside of the curve.

The first bends ranged in the area of 3.2% and 4.75% linear tolerance difference. Some of the greater tolerances were not successful.

A simple reverse bend was made by using a two piece jig to accommodate a 1/2" x 4" x 48" piece of stock. (See Illustration 6, p. 18.) The bend was made by clamping the steamed material between the two forms, but the spring back factor seemed more evident with this particular bend. The oak stock checked considerably during the drying process.

Surface checking, from the beginning of the process of bending white oak, became quite noticeable



ILLUS. 6. TWO PIECE JIG

as the wood began to dry back to a normal state of 6% to 9% moisture content from the content of 18% to 25% moisture during the steaming process.

Several ways of eliminating the checking problem were tried while the wood was drying. First, the ends of the stock were coated with lacquer, prior to steaming. This failed to retard the checking problem. Next, the bent wood was sealed in plastic, immediately after the bend was made. This procedure seemed only to postpone the checking action, since the wood did not dry properly, because it was sealed off from the flow of air.

In subsequent discussions with other craftsmen who had experimented with steam bending, it was learned that one way to prevent checking might be to coat the wood surface with paste wax, immediately after making the bend. Another possible way is to use air dried oak stock of 20% moisture content.[1] Neither of these alternatives were tested, because I then switched the bending experiments to other wood species that gave little, if any, checking problems.

It is important to have the stock long enough to obtain sufficient leverage to make a bend. This is especially important when using thicker stock, such as 3/4" x 3" wide.

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[1]Bill Keyser, discussion held during weekend workshop on the steam bending of wood, Peters Valley Crafts Colony, Layton, New Jersey, April 1975.

More Acute Bending

The key to success in making curves of a small radius lies in the fact that wood can be more easily compressed than it can be stretched, before failure occurs. A device can be fashioned that will hold the stock in a compressed state during the bending process. This prevents the wood fibers on the outside of the curve from elongating no more than one to two per cent of their length. Any greater stretching will result in tensile failure. The recommended method of making severe bends is to use end blocks mounted on a steel strap.[1] (See Illustration 7, p. 21.)

The first attempt at bending with end blocks was not totally successful. The form, strap, and pulling devices are illustrated in Illustration 8, p. 22. The metal strap was made of 22 gauge stainless steel. It was much too light-weight for the 1" x 4" piece of white oak. The metal stretched and deformed during the bend. This resulted in the stock breaking through tensile failure. The end blocks also tore away from the strap because it was not adequately attached.

The second strap built was made from 1/16" x 3" wide mild steel, and this heavier metal allowed for some successful bends. (See Illustration 9, p. 23.)

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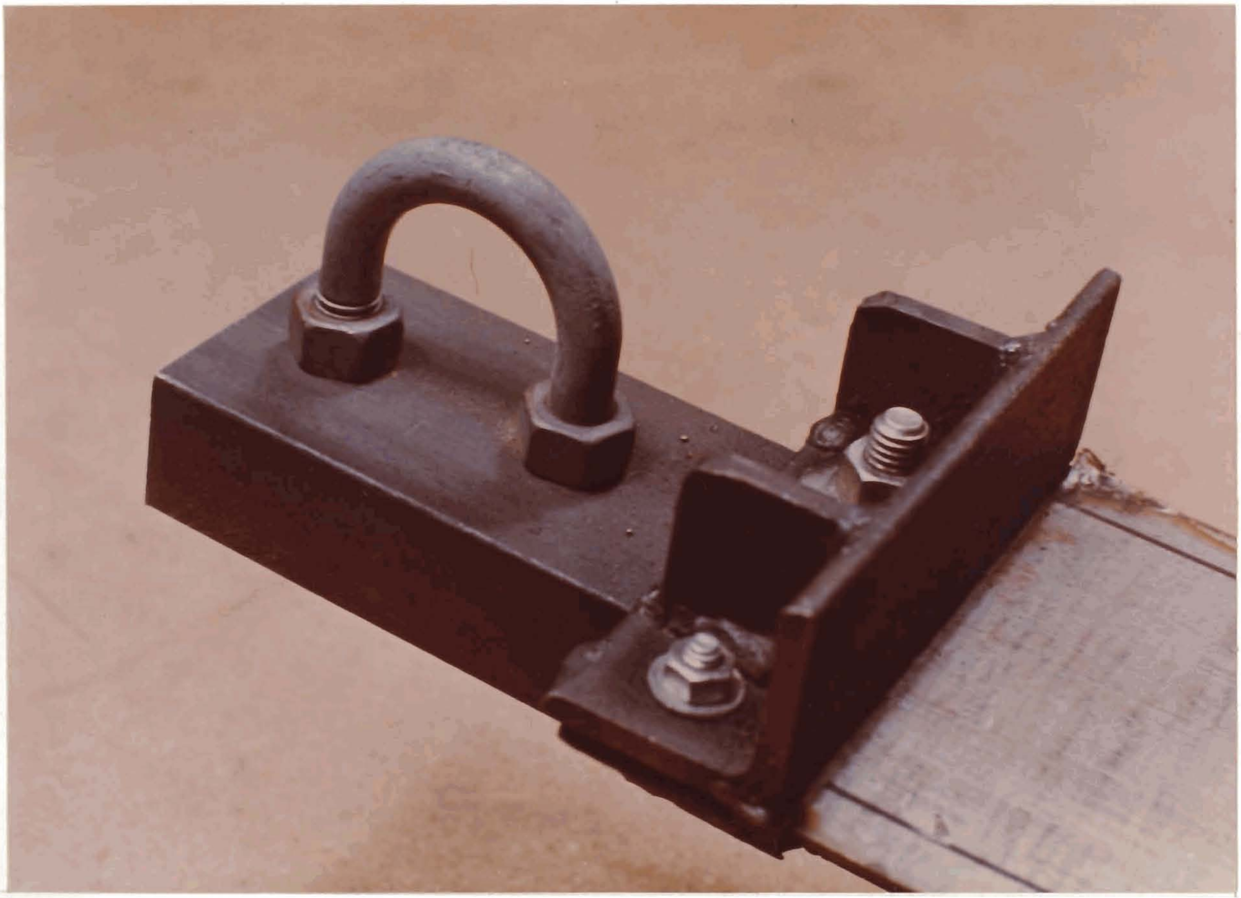
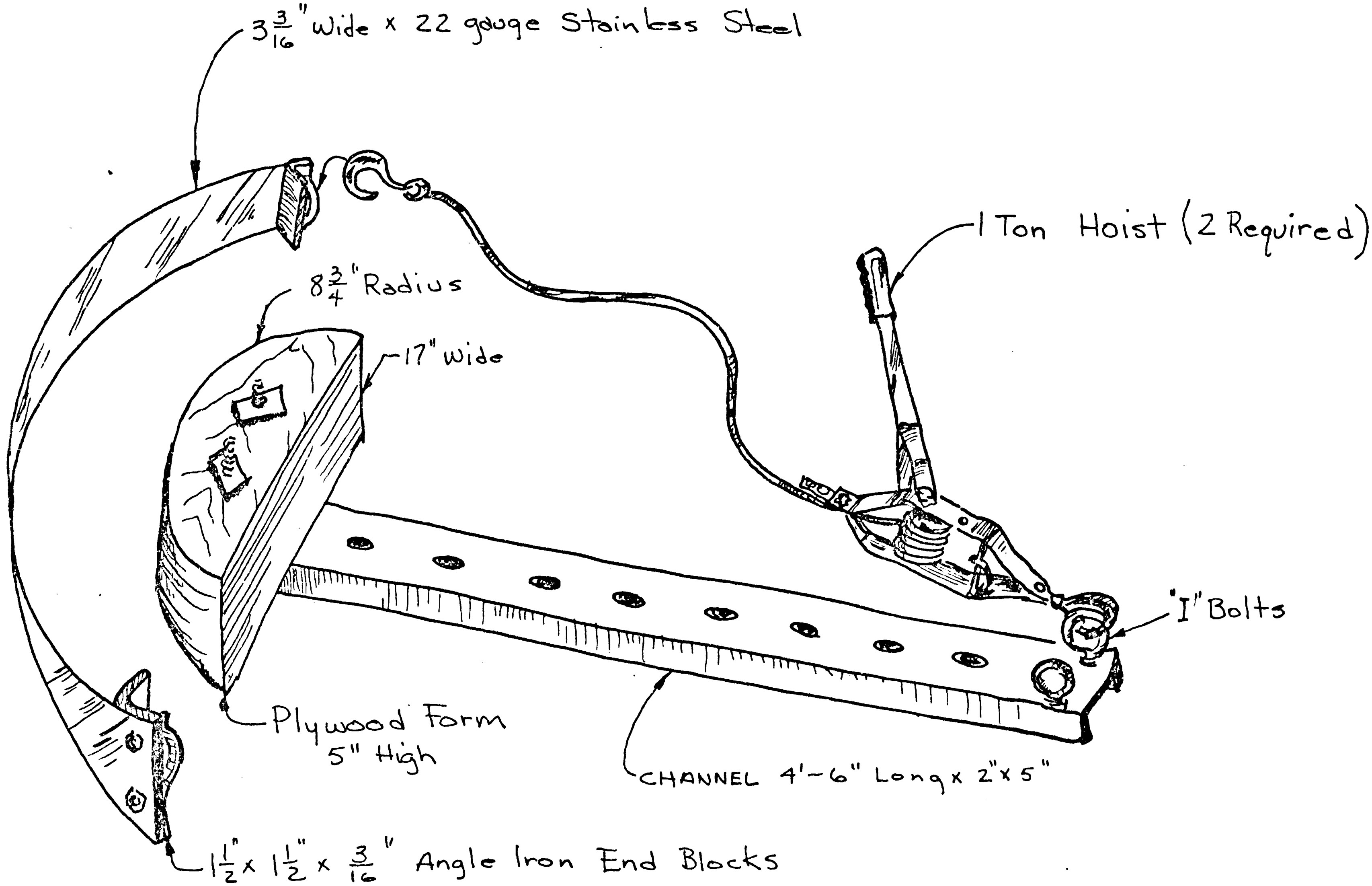
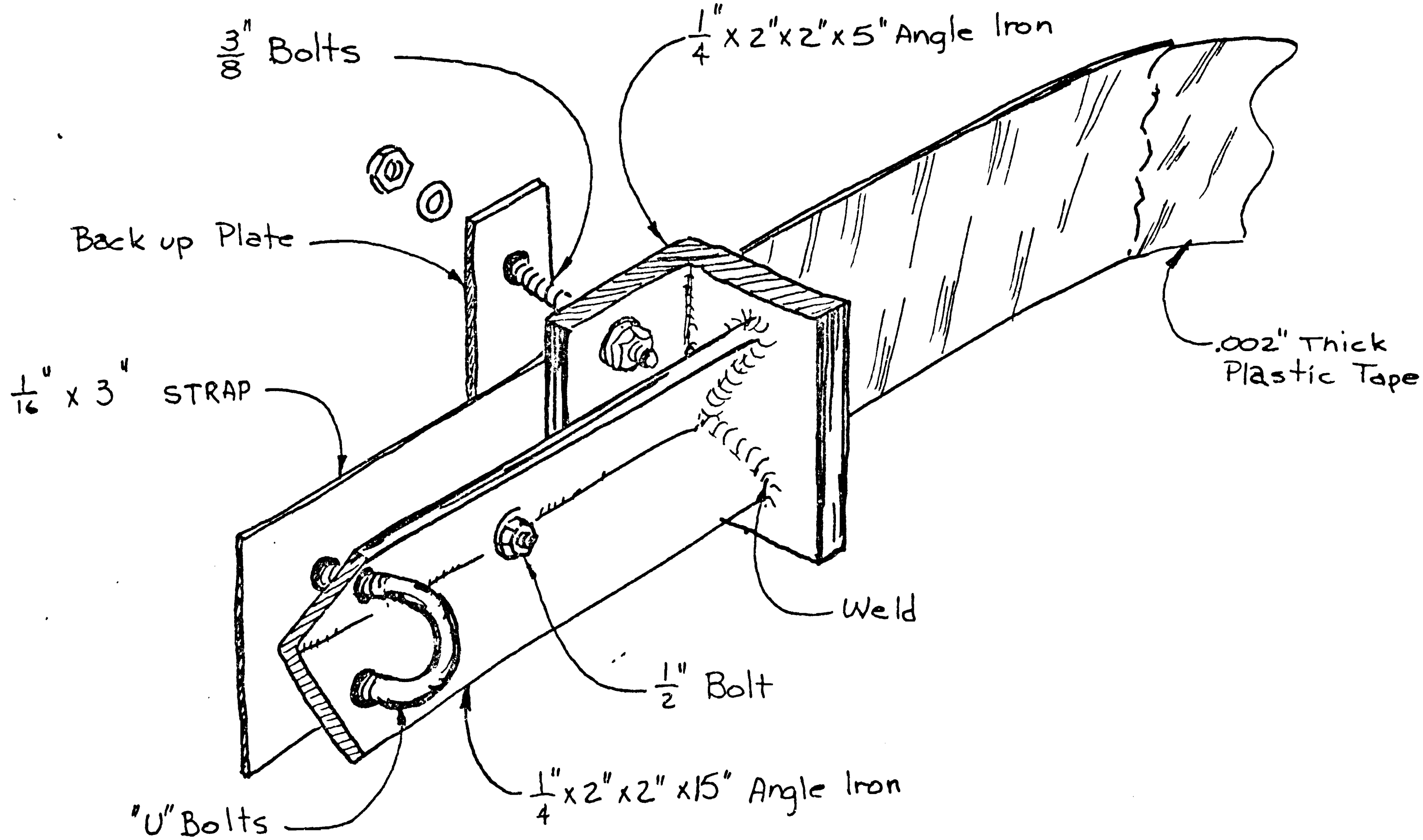
[1] *U.S. Agriculture Handbook 125*, p. 13.)



Illus. 7. End Block Attached to Strap



ILLUS. 8. FORM, STRAP, AND PULLING DEVICES



ILLUS. 9. SECOND STRAP

Pieces of white oak 1" x 3" x 40" were pulled around the 8 3/4" radius form. Staining, created by the reaction of tanic acid and iron, was eliminated by lining the portion of the metal strap that comes into contact with the wet wood. The liner was made from .002" thick plastic adhesive tape (polyethylene terephthalate). As confidence with this particular strap was gained, heavier bends were made until a 1 3/4" x 1 3/4" piece of white oak caused the steel strap to twist and deform. This rendered the strap useless for further bending.

The third strap, made of 14 gauge x 6" x 32" mild steel, was designed to prevent the stock from moving away from the form. This problem had been partially avoided up to this point by using hand clamps. Now, to prevent the stock from moving away from the form, reverse levers were employed. (See Illustration 10, p. 25.) As first designed, this strap was not very successful. The amount of leverage required for making a bend of this particular size was underestimated. Subsequently, this strap was re-designed, by simply re-positioning the reversing lever arms, and thus creating more leverage (but eliminating the principle of reverse levers).[1] (See Illustration 11, p. 26.)

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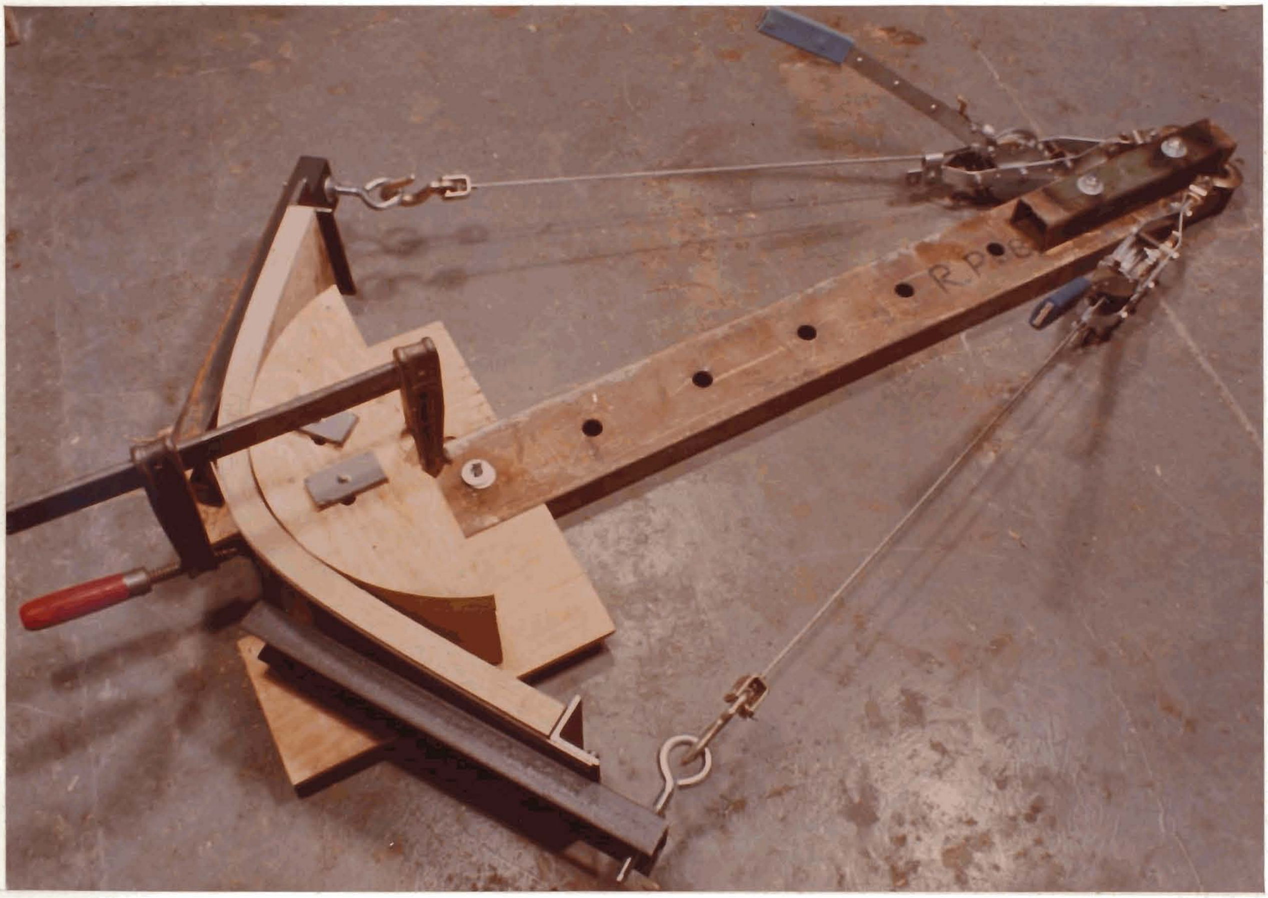
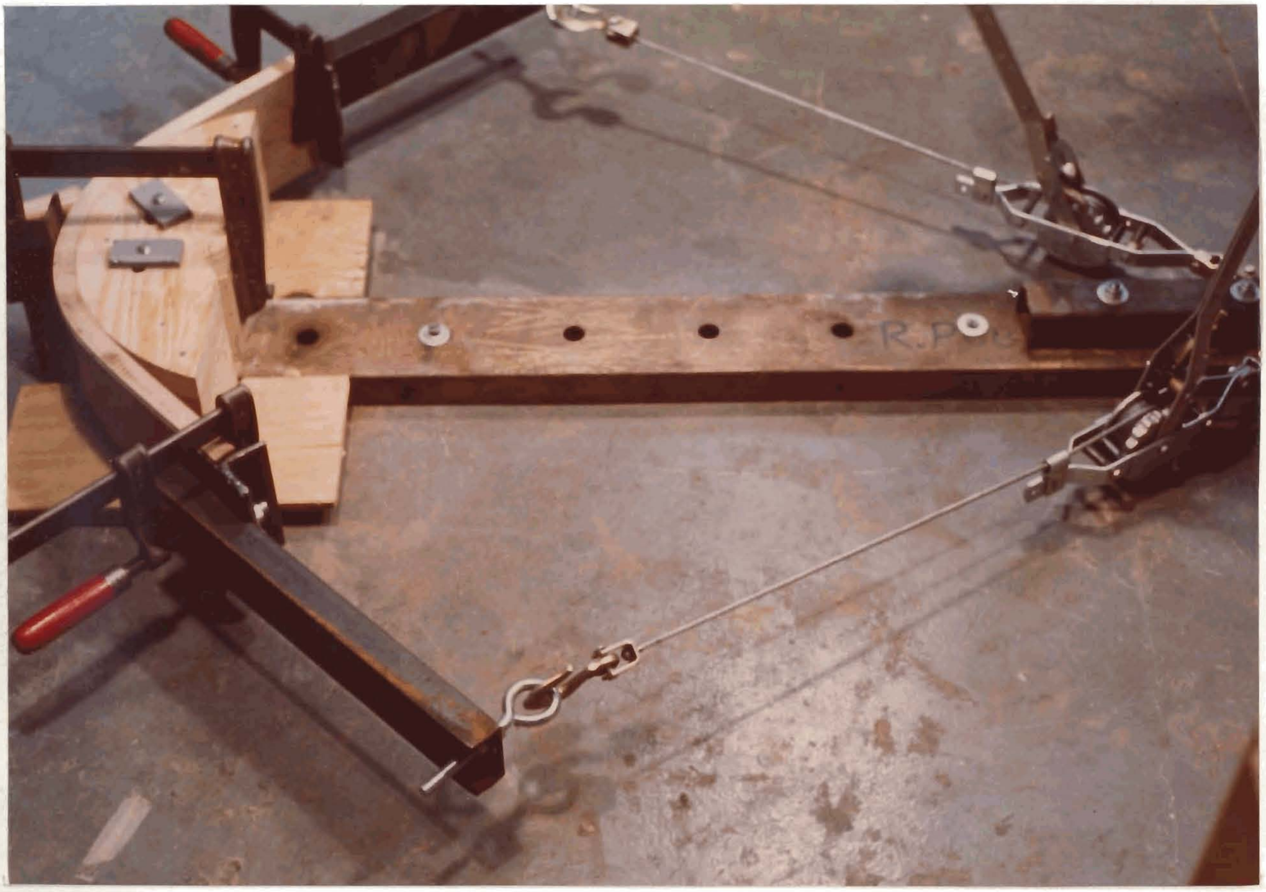
[1]Detailed explanation of this equipment and its use is given in U.S. Agriculture Handbook 125 (Washington, D. C.: Government Printing Office, 1957), pp. 2-3.



Illus. 10. Reverse Levers



Illus. 11. Modified Lever Arms

Although some backbending did occur, a number of successful bends were made with this strap. Backbending is the phenomenon that occurs at the ends of the stock, wherein the wood reverses the direction of the bend, and tries to pull away from the strap. (See Illustration 12, p. 28.) Adjustable end blocks are used in industry to prevent this.[1] An easily fabricated solution for adjustable end blocks was never resolved. It was observed that fitting the stock somewhat loosely between the end blocks (prior to bending) resulted in less backbending than occurred with a snug or tight fit. It is necessary to be aware that the metal strap may stretch lengthwise. Each piece of wood must be cut to fit the newly stretched strap size.

The fourth strap, 1/8" x 2" x 53", was made of mild steel. (See Illustration 13, p. 29.) This strap, incorporating the use of reverse levers, in conjunction with form #3, was used to make 90 degree bends on a 2 3/4" radius. The reverse lever bends were successful, but the problem of the metal strap stretching and deforming was still evident. This can be solved by using spring steel instead of mild steel. The drawbacks of

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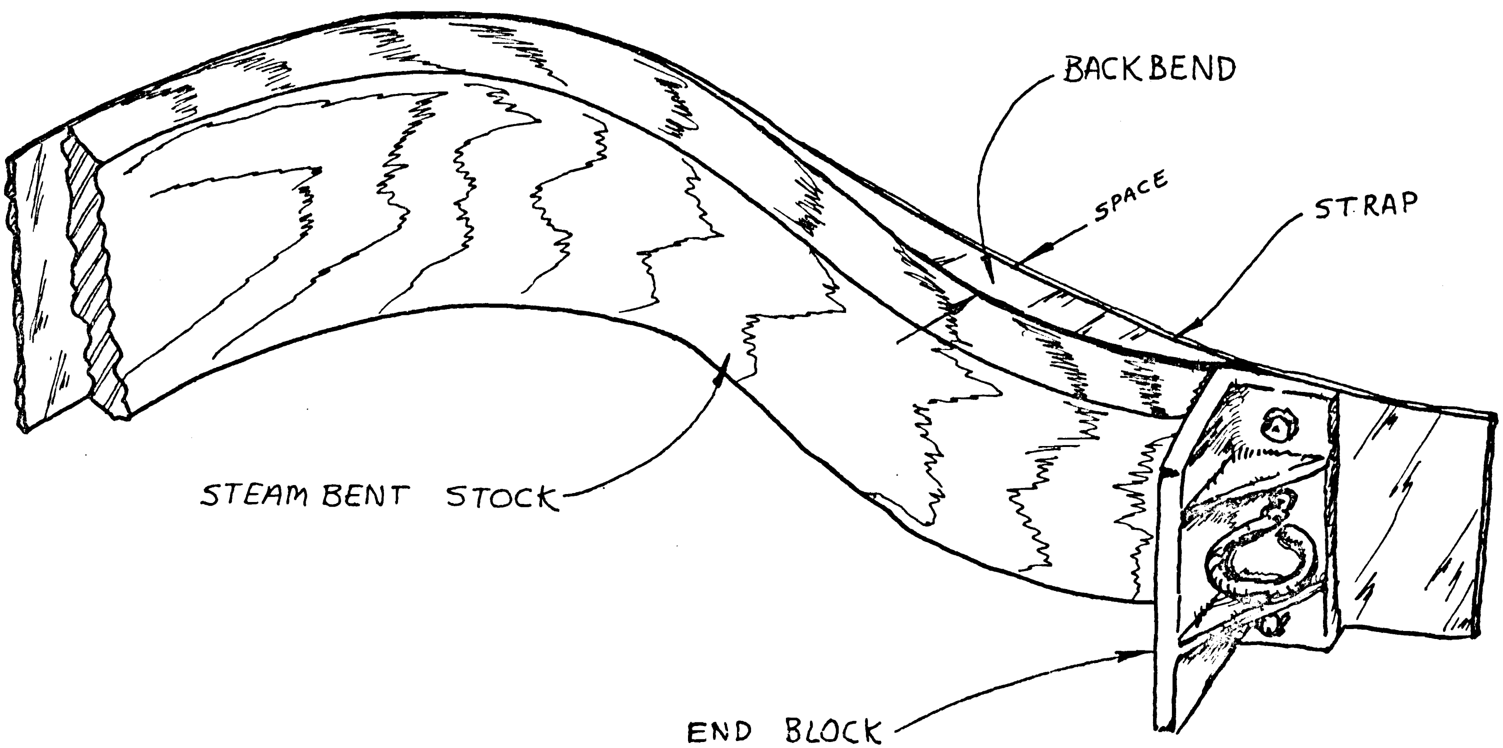
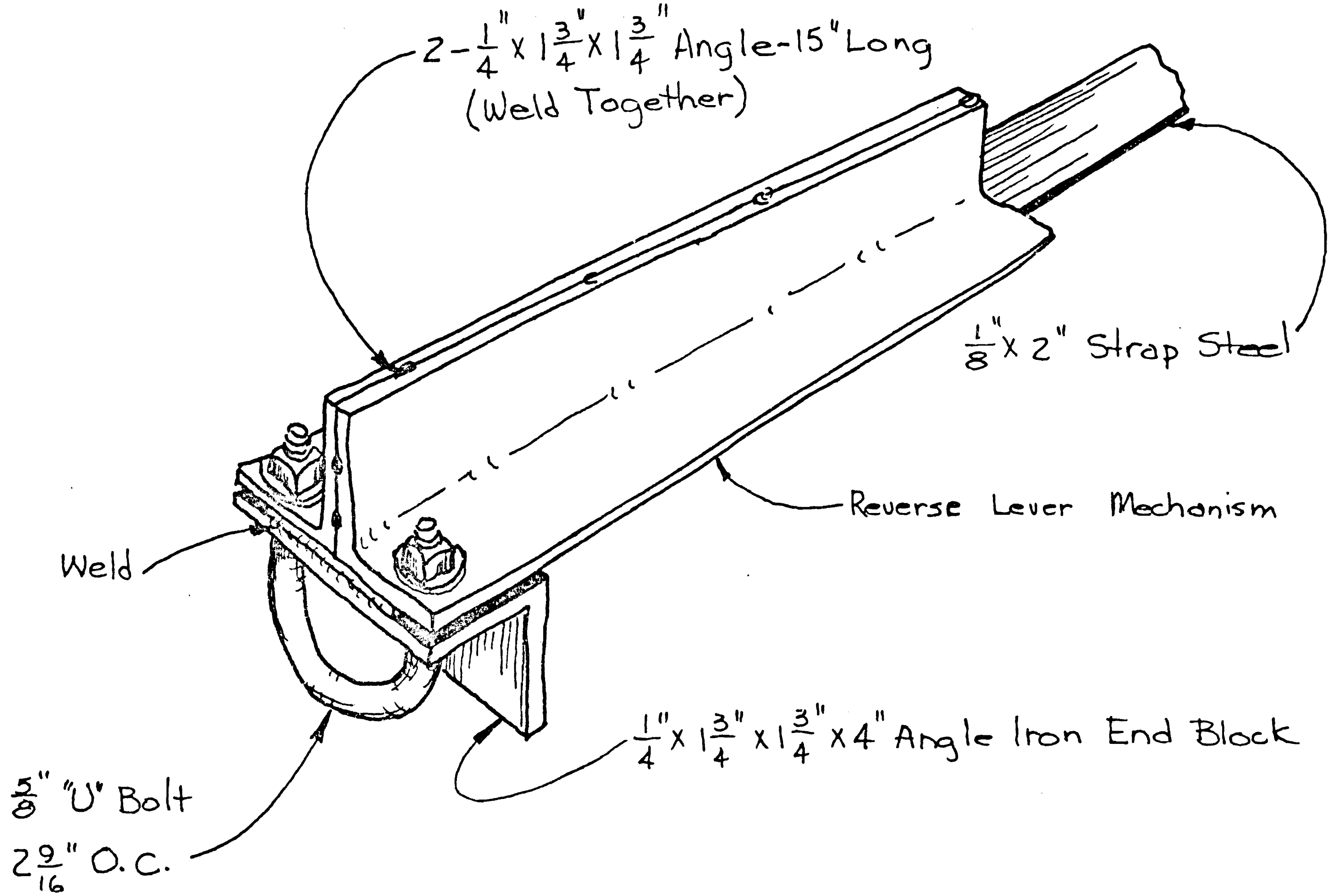
[1] U.S. Agriculture Handbook 125, pp. 2-3.



ILLUS. 12. BACKBENDING

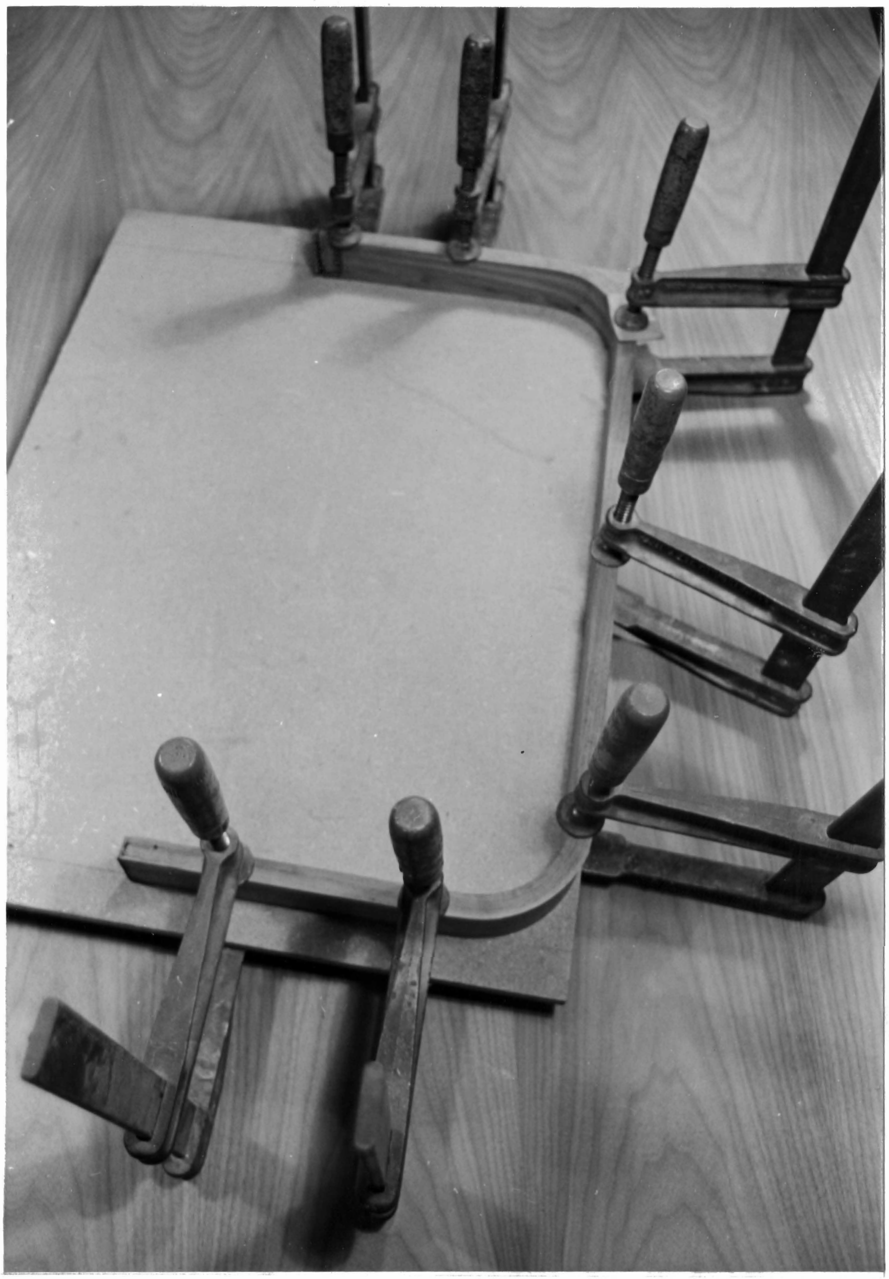


ILLUS. 13. FOURTH STRAP

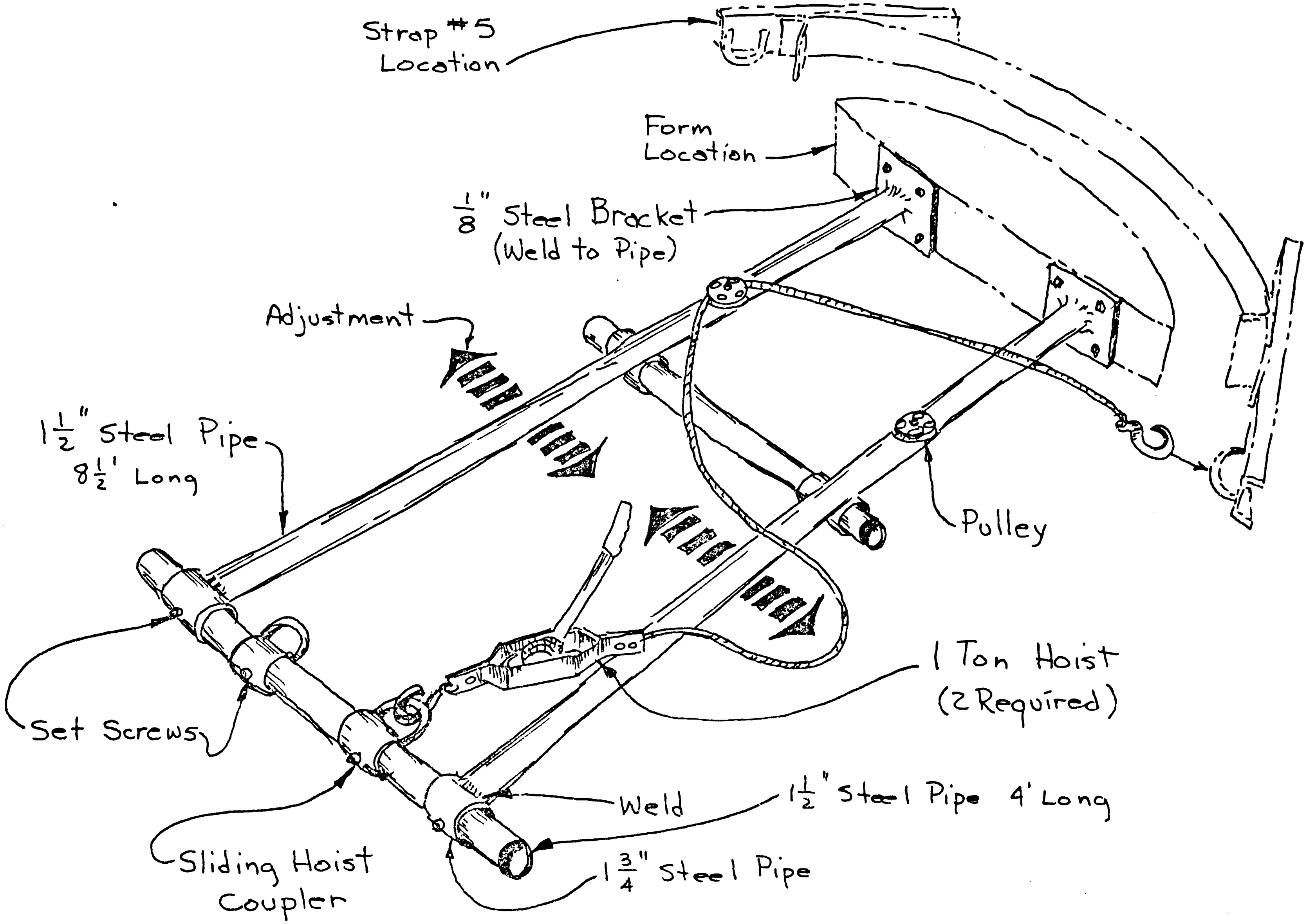
spring steel are its lack of availability in small quantities, its cost, and the difficulty of machining it in a small shop.

The 90 degree bent forms were to be used in making the frame for a mirror in a designed piece. Therefore, it was essential that these bends be within certain specific tolerances. To accomplish this, the wood was overbent approximately 12 degrees (past 90 degrees), and then the stock was fixed. As shown in the photograph, the bent stock was clamped to Novaply. (See Illustration 14, p. 31.) Clamped in this manner, the wood would dry and remain in this particular shape.

The fifth and final strap, made of 14 gauge x 6" x 56" mild steel, was also designed and built with reverse levers. It, in conjunction with the newly built adjustable form holding rack and forms, was used to make bends necessary for a finished piece of work. (See Illustration 15, p. 32.) After minor adjustments, this total apparatus was successful. See Illustration 16, p. 33, for an example of a successful bend.



Illus. 14. Fixing the Stock



ILLUS. 15. FORM HOLDING DEVICE

Illus. 16. Bent Pieces of Wood

CHART OF SELECTED STEAM BENT WOODS

WOOD	SIZE	RADIUS	COMMENT
White oak	1/4 x 3 x 24	7 1/2	Successful free hand bend; moderate curvature
White oak	3/8 x 2 x 24	10	Successful free hand bend; moderate curvature
White oak	1/2 x 2 x 24	15	Successful free hand bend; moderate curvature
White oak	3/4 x 2 x 24	20	Successful free hand bend; moderate curvature
White oak	1 x 3 x 40	8 3/4	Successful bend with use of end blocks
White oak	1/2 x 4 x 48		Gentle reverse curve; with two piece jig; excessive checking
White oak	1/2 x 4 x 48	8 3/4	Unsuccessful bend; end blocks sheared from the strap during bend
White oak	1 3/4 x 1 3/4 x 41	8 3/4	Successful bend; noticeable twisting
Ash	1 x 6 x 32	8 3/4	Successful bend, with noticeable backbending
Ash	1 x 4 3/4 x 56	7	Unsuccessful bend; backbending resulted in tensile failure
Ash	1 x 6 x 32	8 3/4	Successful bend; slight end checking on the uncoated ends

CHART OF SELECTED STEAM BENT WOODS CON'D.

WOOD	SIZE	RADIUS	COMMENT
Birch	7/8 x 6 x 32	8 3/4	Successful bend; small spotty areas of compression failure
Birch	1 x 2 x 53	2 3/4	Unsuccessful bend; tensile and compression failure
Cherry	13/16 x 6 x 32	8 3/4	Very successful heavy bend
Sugar Maple	1 x 3 x 41	8 3/4	Good bend; some end checking
Walnut	13/16 x 3 x 41	8 3/4	Successful bend; little spring back
Bald Cypress	1 x 4 x 32	8 3/4	Unsuccessful bend; wood would not compress
Poplar	13/16 x 6 x 32	8 3/4	Successful bend; some rippling on inside curve
Andoroba	1 1/16 x 3 x 41	8 3/4	Unsuccessful bend; heavy compression failure
Bubinga	1 x 2 x 52	2 3/4	Unsuccessful bend; tensile and compression failure

NOTES:

(1) All sizes are in inches.
(2) Of fifty bends, these were the most significant.
(3) With little exception, the white oak developed severe checking, rendering the stock useless.
(4) Generally, the nature of softwood is such that it will not compress.
(5) All bends were completed within ten to fifteen minutes, not allowing the stock to cool off before a bend was made.

CHAPTER IV

DESIGNING STEAM BENT FURNITURE

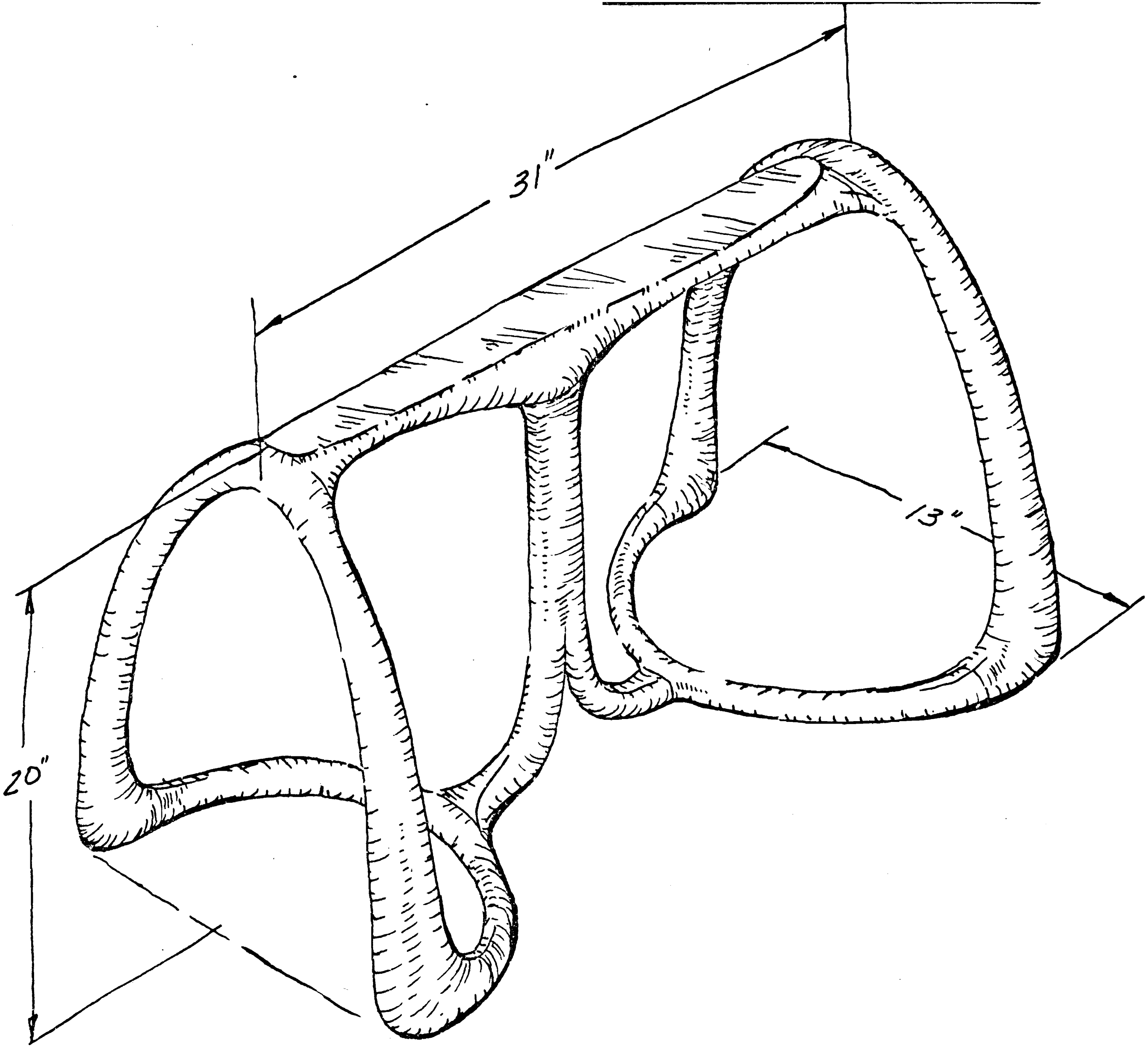
Piece #1, "Reflections," (See Illustration 17, p. 37, and Illustration 18, p. 38.) consists, in part, of a two piece steam bent walnut frame for the mirror. The two parts are joined in the center of the shorter sides with a finger joint. Rabbet joints are cut in the back to allow for the bevelled mirror to be positioned and held in place. To the front of the steam bent frame, a more conventionally made frame is attached. This frame, in turn, contains the marquetry design which comprises the door.

With the exception of the usual amount of time necessary for most pieces of designer furniture, the only problem encountered was that of keeping the mirror frame square. This problem was solved by using a plywood back, which is securely screwed into the rabbet joint of the frame. If a similar piece were to be made, both the door and the mirror frame should be cut from the <u>same</u> piece of steam bent material.

The second piece of furniture designed and worked on was a set of birch saw horses. The legs and the stretchers were to be steam bent members. (See Illustration 19, p. 39.) After several failures at holding the wood

Illus. 17. "Reflections" View I

Illus. 18. "Reflections" View II



ILLUS. 19. DESIGN FOR A SAW HORSE

within certain specific forms and size tolerances, this project was abandoned. By examining the shapes that had already been bent successfully, and regarding them as raw material, a number of sketches of several different pieces of furniture were prepared. It was ultimately decided to incorporate the bent pieces into a small table, 18" high, made of ash. The table top could have been either plate glass or a heavy, clear plastic.
The table, as shown in the photograph, is made up of five parts. (See Illustration 20, p. 41.) Four of these parts are steam bent. Only the center connecting element is not steam bent. The front and rear leg units are of staved construction, and shaped to the forms shown.

In working with these bent pieces, spring back was again a problem, but it was much less so in this case than with the other objects attempted. The spring in the cantilevered front arm was utilized to hold the top in place. The top, made of Lexan #MR4000 plastic, was placed in tension by pushing the arm down toward the floor, dropping the top in place, and then releasing the pressure. This tension holds the top in place naturally. All the through-wedged mortise and tenon joints were cut after the wood had been bent and had dried back to its normal state. This procedure is necessary for all joints cut in steam bent elements. Naturally, special jigs may be required to hold the parts in position while the joints are being cut.

Illus. 20. "Table"

The third steam bent piece built during the thesis project proved to be the least frustrating of the three completed pieces. This can be attributed to the fact that the steam bent curved parts were treated strictly as raw material. The design for "Entomon" (See Illustration 21, p. 43.) evolved by arranging and re-arranging the bent elements in many various compositions, until they assumed the final form. Spring back was overcome in this piece through the use of dowel rod pins (joining the bent elements), which restricted any movement of the mirror frames, which house Plexiglass colored mirrors.

Illus. 21. "Entomon"

CHAPTER V

CONCLUSION

This thesis project, and the experiments conducted during it, changed many assumptions initially held about the steam bending of wood. It is a far more difficult, complex, and unpredictable process than I originally perceived it to be. The amount of time required to overcome obstacles (such as the strap designs and the construction problems) was far greater than I foresaw.

From a financial standpoint, steam bending is a cheaper way of shaping wood than is lamination. This is, of course, after the initial investment in a generator, chamber, frame construction, etc., has been made. However, I still consider lamination to possess certain features which make it a superior approach to bending wood than the process of steam bending. Lamination allows for far closer tolerances which are, of course, critical in design.

To avoid the pitfalls of spring back found in steam bent elements, the craftsman must learn to make designs which allow for and/or incorporate this factor. This factor <u>cannot</u> be accurately predicted with any success.

The wood, after being bent, moves much like any other piece of wood. All wood moves with changes in the temperature and the moisture content of the air. The exception is that on a humid day, the bent wood member will tend to open up. On drier days, it will tend to close, assuming more closely the configuration of the original jig or mold form.

An approach to the design of steam bent wood objects that reduces frustration and allows for success is for the designer to begin by treating the bent wood as raw material. Instead of thinking of the wood as straight, flat lumber, the designer must think in terms of the curved shapes (either forms already bent, or to be bent). I found that my designs must contain either a way to physically restrain spring back, or, a way to let the wood move naturally within the design. Otherwise, the craftsman will find himself becoming exceedingly dissatisfied with this process.

Steam bending is an excellent manner in which to make sculptural forms in wood. It seems that only where <u>function</u> plays the dominant role do the problems of steam bending become seemingly insurmountable obstacles in the design/construction process.

My only regret regarding the work on this thesis project was the lack of time to explore additional areas of steam bending. I particularly would have liked to experiment with two plane bends. Also, I now realize many of the inhibiting problems inherent in the process itself, as well as its advantages. This knowledge alone has freed me to move on to accomplish more satisfying work in the field of designing and building furniture which incorporates steam bent wood.

SOURCES

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