NAILED AND LOCK-CORNER WOOD BOXES

December 1958

No. 2129

INFORMATION REVIEWED
AND REAFFIRMED
1965

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

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NAILED AND LOCK-CORNER WOOD BOXES

By

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Introduction

This publication presents the principles of efficient design for nailed and lock-corner wood boxes. The principles are based on extensive investigations at the Forest Products Laboratory, supplemented by studies and observations of boxes in service during peacetime and World Wars I and II.

Since the hazards that any box may encounter in service are numerous and variable, no endeavor is made to designate box construction details that are the most suitable for specific commodities or conditions of service. It remains for the box designer, on the basis of his knowledge of (1) the commodity and the expected shipping hazards, and (2) the principles of box design discussed herein, to select box construction details that will best suit his particular purpose.

Transportation Hazards

New methods of handling materials and equipment, as well as new transportation techniques, are continually being introduced to gain efficiencies in the delivery of goods. The hazards introduced -- or reduced -- by the new methods and equipment must be known and considered by the designer of boxes.

Usually the most severe shocks that a boxed commodity encounters during transportation occur at freight terminals or handling centers, rather than in transit. This is especially significant if the commodities are handled manually.

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

Combinations of transportation methods usually increase the variety and intensity of shocks because of the increased number of times the commodity is handled.

The hazards in export shipment are more numerous, more variable, and usually more severe than in domestic shipment. An export shipment may meet all the hazards of domestic transportation before being loaded into the vessel and, after reaching a foreign port, may undergo the further hazards of a long journey inland. The hazards vary from the tendency of cargo to shift on rough seas, to effects of variable climatic conditions and are, as a rule, more severe than the hazards in domestic shipment. Furthermore, goods must frequently be unloaded from vessels into lighters and, if the sea is rough, the handling of commodities from the vessel to the lighter may introduce severe hazards.

Commodities and Box Design

The purpose of any shipping box is to aid the commodity to withstand the hazards of transportation and to facilitate handling and storage. The nature of the commodity, therefore, is a fundamental consideration in designing a box.

The protection needed varies from merely holding together a number of such units as railway spikes or shovels, to elaborate protection of delicate electronic tubes. Some articles have highly polished surfaces, some have slender legs or other projecting and fragile parts, and some have large, thin plates of easily broken material. Other articles have heavy parts supported by relatively weak parts, such as the heavy mass of a gyro compass mounted on delicate bearings. Still others that are a menace to life and property, such as acids and explosives, are classified as dangerous.

It is evident, therefore, that each commodity presents its own problem, and consequently neither weight, distance traveled, nor method of shipment, when taken alone, constitutes an accurate criterion for designing a box.

Shipping hazards produce the forces and stresses of crushing, bending, shearing, diagonal distortion, twisting, puncturing, and abrading. The principles involved in aiding the commodity to withstand any of these stresses are the same regardless of the hazards that produce the stress, and frequently the same principle may be employed to prevent several different kinds of stress. For instance, diagonal distortion or twisting may result in racking of the joints in a piece of furniture, rubbing the finished surface against the container, breaking thin plates of glass, or chipping porcelain enamel from appliances. One of two principles may be employed in preventing these stresses and the consequent damage: (1) the box can be made rigid so that it resists diagonal distortion, or (2) the box can be made nonrigid and the product so packed that the box can distort considerably without touching or introducing stresses in its contents.

Commodities that are a hazard to life and property present special problems to the designer of boxes. Interstate Commerce Commission regulations govern the shipment of such dangerous commodities as explosives and chemicals so shipments of this nature must comply with those regulations.

To provide some assistance, federal box specifications define three load types for commodities; these types depend on commodity weight, their susceptibility to damage by puncture or shock, and the amount of support a commodity is able to give the box. Such requirements as member thickness and style of box may be varied to suit each load type.

Type 1 and type 2 loads include commodities that are of light to medium weight and are not easily damaged by puncture or shock. Type 1 (easy) loads completely fill and support all faces of the box. Examples of type 1 loads include sturdily boxed instruments, wood chests, and tool kits. Type 2 (average) loads need not completely fill the box. The commodities of type 2 loads must support each face of the box at several points. Canned goods, jars, and bottled goods are examples of type 2 loads. Type 3 (difficult) loads include heavy articles, articles that do not provide any support to the faces of the box, and fragile articles that require a high degree of protection from puncture, shock, or distortion. Included in this group are such items as metal castings, typewriters, and delicate scientific equipment.

By proper cushioning, blocking, or bracing it may be possible to convert a type 2 load to a type 1 load, and it may be possible to convert some type 3 loads into type 2 or type 1 loads.

Economics of Box Design

The best box for a given service is one that will deliver the commodity in a satisfactory condition at minimum total cost. Total cost includes the cost of the commodity, the cost of the box, the cost of transportation, and such indirect costs as loss of good will from delayed delivery of the commodity or its arrival in a damaged condition.

If a box is designed to deliver every unit in every package in an undamaged condition, it may be heavy, expensive, and inconsistent with minimum total cost. It may be more economical to design a box with only enough strength to protect the contents from hazards that are normally expected, and to risk encountering some minor damage during the excessive rough handling it may get occasionally.

This is not an excuse for continued use of underdesigned containers. Any increase in damage claims or complaints should be viewed with alarm. Every effort should be made to correct the situation and reduce the claims and complaints. Repeated claims of similar nature or identical damage complaints on different shipments is a good indication that the difficulty is more than just occasional abnormally rough handling.

Packing of the commodity should be considered at the time the commodity is designed. The addition of a brace or increasing the strength of machinery parts may allow reduced packing requirements, reduced total costs, and give the consumer a better product. For example, an abnormal amount of damage was being experienced in shipping a large ceiling ventilator. Attempts to reduce damage by increasing the amount of packing and strength of the box proved costly. The problem was solved by incorporating an inexpensive brace in the ventilator. The new design reduced damage during shipment as well as packing and total costs. Cooperation between the designer of the commodity and the designer of the box is necessary to gain this type of economy.

Laboratory Tests and Box Design

Tests and experiments performed in the laboratory are of utmost value in developing boxes that protect the contents, are light in weight, and low in cost.

The designer of the tests and experiments should consider the nature of the commodity and the economic factors involved. A prediction should be made of the hazards that the boxed commodity must withstand from the time it is placed in the box until it reaches the consumer, and to reproduce the resulting stresses in laboratory tests and experiments.

In lieu of laboratory methods, sample handling in a company's plant, shipping room, or warehouse often yields valuable information to assist in designing containers that are adequate and economical.

Design and Construction of Boxes

Common Styles

The styles of nailed and lock-corner wood boxes shown in figure 1 have been developed to meet most of the requirements of service and have been accepted universally. The construction of the ends is the basis of the classification.

Outstanding characteristics common to all these styles are their great resistance to crushing, puncturing, and mashing of the corners. Nailed wood boxes stack well, are easy to manufacture, and the strength of each may be readily adjusted to different service requirements by varying the sizes of members and other details of construction.

Style 1 (uncleated end) and style 6 (lock-corner and dovetail) are neat and attractive in appearance, but are suitable only for small boxes that carry relatively light loads, usually not over 50 to 100 pounds. Common failures in the style 1 box are that the one-piece ends and sides will split or that the edge joints will fail when these parts are made of more than one piece. Resistance to such failure must lie either in the strength of the joints or in the strength of the wood in tension across the grain (this value is not large and is extremely variable in any species of wood). Therefore, the strength of these boxes is comparatively low. Another fundamental weakness is the smaller withdrawal resistance of nails driven into end grain as compared with those into side grain.

The style 6 box has sides and ends joined together by a series of tenons that interlock and are held together by gluing. Tests show that many failures in lock-corner boxes occur because ends and sides split; nails may also pull from or split the edges of the ends, thus allowing the top or bottom to pull off. Failure also occurs when the tenons pull apart. Style 6 boxes usually are most efficient when the sides are of one piece and the ends are of a slightly greater thickness than the sides. Style 6 boxes usually require, for the same service, somewhat thicker sides and thinner ends than style 1 boxes. The thicker sides are required to avoid pulling the tenons apart by springing of the sides.

Each end of boxes of styles 4, 4-1/2, and 5 are reinforced with two cleats. The chief purpose of the cleats is to permit the use of two or more pieces in the ends, to prevent splitting of the box, and to permit better nailing. Some of the nails are usually driven through the sides into the cleats and some into the ends, thus increasing the strength of the nailed joint and adding rigidity to the box. The staggered nail pattern also reduces the likelihood that the nails will split the wood or shear it out at the ends of the boards.

When the character of the contents permits, the cleats can be placed inside the box, thus not increasing its displacement (style 5). In style 5 boxes the cleats may either be rectangular or triangular in cross section. If the nails are driven through the sides and cleats and are clinched, the resistance of the sides to pulling off is greatly increased. Inside cleats should be shorter than the inside depth of the box so that, if the sides and ends shrink, the cleats will not protrude above them and thus force the top and bottom away. This difficulty occurs because wood shrinks considerably more across the grain than it does parallel to the grain.

The outside cleats should be long enough to come nearly flush with the outer surface of the top and bottom in style 4 boxes, or with the sides in style 4-1/2 boxes. The cleats will thus aid in keeping in place the top and bottom in style 4 boxes and the sides in style 4-1/2 boxes; they will also take some of the thrust that comes on the nails in the top and bottom (style 4) or sides (style 4-1/2) when a box is dropped on a corner. The amount that the cleats should be cut short to allow for shrinkage depends on the moisture content of the lumber at the time the box is constructed and the storage conditions afterward. Usually an allowance of 1/8 inch at each end of the cleat is sufficient.

The horizontal cleats on the ends of style 4-1/2 boxes provide for easier manual handling of the box.

Styles 4, 4-1/2, and 5 boxes are generally designed for loads from 100 to 250 pounds.

The two horizontal cleats on the ends of a style 2, 2-1/2, or 3 box allow the nails that hold the top and bottom of the box to be staggered in the box ends and cleats. This increases the rigidity of the box faces, top and bottom, in the same manner that the rigidity of the box sides is increased by the use of vertical cleats. If the placing of nails is divided between the horizontal cleats and the ends proper, it reduces the likelihood of splitting the box ends by the nails in the top and bottom of the box. In boxes with horizontal cleats, some of the nails driven into the box ends are spaced farther from the ends of the top and bottom boards; thus, the likelihood is reduced that the nails will shear out at the ends of the top and bottom boards. The ends of the boxes of styles 2, 2-1/2, and 3 sometimes split along the inner edges of the horizontal cleats and fail by allowing the cleats, with part of the end boards, to pull away with the top or bottom. Such failures are resisted by the strength of the end board in both tension and bending across the grain, and by the reinforcing action of the vertical cleats.

Styles 2 and 2-1/2 boxes offer greater resistance to the foregoing type of failure than does the style 3 box, since more of the nails that attach the vertical cleats to the ends of the box may be placed close to the ends of these cleats. The style 2-1/2 box has an advantage over the style 2 box in that, during the nailing of the top and bottom, the notches on the vertical cleats support the horizontal cleats and take a thrust that would otherwise come on the nails joining the horizontal cleats to the ends. This thrust is sometimes severe, especially when several nails are being machine driven at the same time into a cleat made of dense wood.

Because the chief function of ends and cleats is to provide a means for fastening the box parts together, it is desirable, where maximum box strength is required, to have the ends and cleats each of a sufficient thickness to receive the nails. In order to save material, however, the ends of boxes of styles 2 and 2-1/2 are sometimes made of relatively thin material that is reinforced with heavy cleats, and the sides, top, and bottom are nailed to the cleats only. Boxes with such end construction are less rigid than boxes with thicker ends, and have less resistance to splitting at the inside edges of the horizontal cleats. The nails in the ends of the sides, top, and bottom are closer to the ends of the boards in these parts and have less resistance to shearing out. Furthermore, such nails must be closely spaced in the cleats, and consequently are more likely to split them. This construction, however, gives good service in boxes that carry relatively light loads.

In manufacturing boxes with square ends, style 3 has the advantage that all four cleats are the same length, and hence, are interchangeable. When a symmetrical end is desired, rather than the strongest possible one, these mitered cleats are preferred.

Styles 2, 2-1/2, and 3 boxes are generally designed to carry loads of approximately 250 to 600 pounds. It is generally uneconomical to use boxes of these designs to carry loads of less than 250 pounds.

Influence of Size and Form of Parts

A box designer should have a knowledge of the relation of the size and form of each box part to its static bending strength, resistance to deflection, shock-resisting capacity, and torsional rigidity. The box parts can be likened to a simple beam that is uniformly loaded and supported at its ends.

Static bending. --The static bending strength of a box part varies inversely as its length, directly as its width, and directly as the square of its thickness. For example, a box part 20 inches long will support twice as much static load as one 40 inches long; a box part 8 inches wide will support twice as much load as one 4 inches wide; and a box part 1 inch thick will support four times as much load as a box part 1/2 inch thick. In each of these situations, the assumption is that the other dimensions and the quality of the lumber remain the same.

Stiffness.--The stiffness of a box part varies inversely as the cube of the length, directly as the width, and directly as the cube of the thickness. For example, a box part 20 inches long will deflect one-eighth as much as one 40 inches long. A box part 8 inches wide will deflect one-half as much as one 4 inches wide; a box part 1 inch thick will resist deflection eight times as much as a box part 1/2 inch thick.

Shock-resisting capacity.--The ability of a box part to withstand shocks or blows without breaking varies directly as its length, width, and thickness; that is, the shock-resisting capacity of a box part increases in the same ratio as each of its dimensions. Thus, a box part 20 inches long will withstand one-half as much shock as one 40 inches long; a box part 8 inches wide will withstand twice as much shock as a box part 4 inches wide; and a box part 1 inch thick will withstand twice as much shock as a box part 1/2 inch thick.

Torsional rigidity.--Torsional rigidity of box parts varies inversely as their length, directly as the cube of their thickness, and almost directly as their width. For example, a box part 20 inches long will resist twisting twice as much as a box part 40 inches long; a box part 1 inch thick will resist twisting forces eight times as much as a part 1/2 inch thick; and a box part 8 inches wide will resist torsion twice as much as a box part 4 inches wide. Torsional stresses are seldom considered in box design but are sometimes the cause of failure.

Splitting and shearing.--The resistance of a box part to splitting at the nails, or to nails shearing from the end of a board, increases with the thickness of the board and the distance of the nails from its end.

Species of Wood

The choice of wood species should give due consideration to cost, availability, ease of working, strength, shock-resisting capacity, resistance to nail withdrawal, tendency to split in nailing, odor, weight, and resistance to decay. No single species is best for all uses. In fact, with minor modifications in design and construction, most commercially important native species of wood may be used.

A number of these native species of wood have been grouped according to properties of importance in box construction. They are presented to aid box designers to choose a suitable species for any particular situation or to satisfy their specific requirements. The species are divided into four groups and a summary of characteristics is given for each group.

The properties of importance in box construction, as used to establish the groups, were strength as a beam, resistance to nail withdrawal, shock resistance, and tendency to split when nailed. As with any such grouping, there is some variance in the properties of the different species within any one group. Further, there are species that could be called "borderline" because some of the characteristics closely resemble those of other groups. Thus, the grouping is not intended to imply that all species within a group are equal in all respects for use in containers, nor is it intended to imply that any one group of wood is better than another. The grouping does mean that a manufacturer may select any species within the same wood group and expect that boxes made therefrom will give approximately the same service.

Group I	Group II	Group III	Group IV
aspen	Douglas-fir	ash (except white ash)	beech
basswood	hemlock	soft elm	birch
buckeye	southern yellow pine	soft maple	hackberry
cedar	tamarack	sweetgum	hard maple
chestnut	western larch	sycamore	hickory
cottonwood		tupelo	oak
cypress			pecan
fir (true firs)			rock elm
magnolia			white ash
pine (except southern yellow)			
redwood			
spruce			
willow			
yellow-poplar			

A comparison of the groups shows that the woods in Group I generally have moderate strength and nail-withdrawal resistance; they do not split easily when nailed, and are light in weight, easily dried, and easily worked.

Compared to Group I, the Group II woods are stronger, heavier, harder to dry, harder to work, have more nail-withdrawal resistance, and show a pronounced contrast in the hardness of springwood and summerwood, which often causes nails to be deflected out at the sides of the piece.

Group III species, in relation to Group II, are about the same in strength and nail-withdrawal resistance, less inclined to split in nailing, heavier, and more difficult to dry or work.

Group IV species generally show the greatest strength, greatest nail-withdrawal resistance, and greatest tendency to split in nailing; they are also the heaviest, the most difficult to dry, and the most difficult to work.

Values for individual species will vary from the figures given in table 1. For example, the value for "strength in bending" for aspen is the average value (64) for both bigtooth aspen (66) and quaking aspen (62). It would be difficult and of no practical use to separate these two species for boxmaking purposes.

The numerical values given in columns 2 and 3 of table 1 are comparative numbers and can be used to make comparisons, for boxmaking purposes, of species containing like defects. These figures are not intended for making engineering calculations. Forest Products Laboratory Report No. 1169, "Standard Terms for Describing Wood," provides more detailed data.

Quality of Lumber

It is not necessary to specify lumber grades for container construction, but rather to control defects by limiting their nature and size in the board that is used in the container. By selective cutting, a carpenter or sawyer in a box plant may be able to remove enough defective material from low-grade lumber to raise the quality of the resulting box part to a suitable standard. The cost of labor to raise this lumber quality to a suitable standard, the market price of the various grades of lumber, and the quantity of suitable box parts a carpenter or sawyer is able to cut from each grade are factors that determine which grade of lumber will produce the most economical boxes. A study conducted at the Forest Products Laboratory showed that the most economical boxes were produced from the poorest grade of lumber shown in table 2. This general indication could change if labor costs increase in a greater proportion than material costs, or if new uses create a greater demand for the limited supplies of low-grade lumber.

In box construction, important defects include wane, checks, splits and shakes, decay, cross grain, and knots.

Wane.--Wane is bark or lack of wood on the edge or corners of a piece of lumber. Wane may be permitted on one edge only, and should not exceed three-fourths of the thickness or one-sixth of the width of a piece of lumber.

Checks, splits, and shakes. --Checks are longitudinal cracks in wood, generally in the radial direction or across the annual rings. They usually develop during seasoning of the wood. Checks reduce the withdrawal resistance of nails and may develop into splits. Splits are lengthwise separations of the wood, extending from one surface to an adjacent or opposite surface. Boards should be rejected when splits are 1-1/2 inches from the edge of the board and extend the entire length of the board, or when a split interferes with nailing. A shake is a longitudinal crack in wood following the annual rings. Shakes reduce the strength of the wood in shear and impair its resistance to nail withdrawal.

Decay. --Wood may become decomposed (decayed) by the action of fungi, a type of plant life that lives at the expense of wood substance. Decayed wood may be recognized as being punky, soft and spongy, stringy, ringshaked, pitted, or crumbly. The wood will often be discolored or bleached. Decayed wood should not be used for box construction. Sometimes wood that has become stained will appear decayed. Actually, the wood may be sound and suitable for boxmaking. The staining may be due to contact of wood with metal, the deposition of extractive materials near the surface of lumber in drying, or by the action of some types of fungi that can stain the wood without physically harming its structure. The presence of stains may indicate that conditions conducive to decay are present.

Cross grain. --In cross grain, the wood cells or fibers do not run parallel with the axis or sides of a board. Cross grain is one of the most serious defects to affect box material. It reduces the strength in bending and also increases the susceptibility of wood to splitting around nails. Cross grain occurs (1) around knots and burls, (2) by a growth in which the fibers assume a spiral direction with reference to the axis of the tree trunk, and (3) when lumber is sawed at an angle to the axis of the tree. It is often difficult to detect except where checks, which invariably follow the grain, are present. It is recommended that cross grain, whether on the face or edge of a piece, not exceed ratios of 1:12 for cleats and battens, 1:10 for tops, bottoms, and sides, and 1:8 for ends measured as shown in figure 2.

Knots. --Knots are the most common defects in lumber. They slightly reduce the stiffness of the board in which they occur and reduce the breaking strength of a board almost in the ratio of the width of the knot to the width of the board. Since the wood of a knot is harder, stronger, and heavier than the surrounding wood, it might be expected to add strength to a board. This would be true if it were not for the manner in which knots are formed. A knot is a portion of a branch or limb that has become incorporated in another branch or in the body of the tree. The wood fibers passing around the limb and continuing in the main body produce cross grain. Because of the difference in the strength of wood parallel to the grain and perpendicular to the grain, the weakening effects of knots result mainly from the cross grain around them. Therefore, loss of strength is considered the same if the knots are sound, decayed, loose, or missing.

By using boards that contain knots or knotholes, the breaking strength of the boards in a box part may be brought into balance with the strength of the nailed joints. With the sides, top, or bottom boards having a slenderness ratio (length divided by the thickness) of less than 60 to 1 in boxes where the knot or attendant cross grain does not prevent proper nailing, there is no reduction in strength in two instances: (1) for a knot or knothole whose diameter does not exceed one-third the width of the board, or (2) from knots or knotholes whose aggregate diameter within a length equal to the width of the board does not exceed the diameter of the largest knot allowable. But in boxes with long sides of thin material, the size of the knots must be further limited to prevent the sides from breaking across the grain, or to avoid loosening of the nails with the increased bending of the boards. The increased bending that results from knots, however, may be readily offset by a slight increase in the thickness of sides.

The width of knots in cleats or battens should not exceed one-fourth of the width of the part. For tops, bottoms, and sides, the recommended maximum allowable width of knots is 3-1/2 inches but not over three-eighths of the width of the board, and the maximum allowable width of knots for box ends is 4 inches but not over one-half of the width of a board.

The width of knots is measured between lines parallel to the edges of the board and enclosing the knot:

1. Single knots are those that are separated by a distance that is at least twice the width of the piece of lumber; knot width is measured as shown in figure 3A.

2. Knots in close proximity to each other, where the fibers of the wood are being deflected around the entire unit, are called knot clusters. The width of a knot cluster is measured as shown in figure 3B.

3. When knots are separated by a distance that is less than twice the width of a piece of lumber, they are defined as tandem knots. Their total width may be determined by either of two methods as follows: (a) Add the individual widths of all knots occurring within a length equal to twice the width of a piece of lumber as shown in figure 4A. (b) Measure the distance, at a right angle to the length of the piece of lumber, between the outside edges of the two outermost knots, as shown in figure 4B. The lesser of the two widths obtained by methods A and B shall be used when determining the suitability of a piece of lumber for box manufacture.

Moisture Content of Lumber

Wood gives off or takes on moisture from the surrounding atmosphere until a balance is achieved between the wood and the atmosphere. Designers of wood boxes need to know the effects of the moisture changes in wood and how to minimize detrimental effects that may occur. Moisture content of wood is expressed as a percentage of the ovendry weight and is usually determined by either of two methods -- the ovendry method or with a moisture meter.

In the ovendry method, a section at least 1 inch along the grain, and the full width of the board, is cut from near the midpoint between the ends of a representative sample board of the material. The section is then weighed on an accurate scale. This is the "original" weight. The section is then dried in an oven heated to 214° to 221° F. It is reweighed periodically until a constant weight is attained. This is the "ovendry" weight. The moisture content of the wood is then calculated by the following formula:

$$\text{Moisture content (in percent)} = \frac{\text{original weight minus ovendry weight}}{\text{ovendry weight}} \times 100$$

Several types of moisture meters are available. They measure electrical resistance, dielectric constant, or power loss factor, and translate this information to percent moisture content. Moisture meters are easy and fast to use and are quite accurate between 7 and 25 percent moisture content.

When timber is logged, the moisture content of the wood may be as high as 300 percent. This water may be separated into two parts, that contained as free water in the cell cavities and intercellular spaces of the wood, and that held as absorbed water in the cell walls. The absorbed water is of primary interest in the consideration of shrinkage. When all of the free water is removed but all of the absorbed water remains, wood is said to have reached the fiber saturation point. The fiber saturation point is approximately 30 percent moisture content for all species.

When the moisture content of the wood is above the fiber saturation point, wood is relatively soft, plastic, and generally lower in strength than wood at a lower moisture content. Shrinkage occurs only if moisture content drops below the fiber saturation point. The shrinkage is considered proportional to the amount of moisture lost below the 30 percent level. Thus, for each 1 percent loss in moisture content below the fiber saturation point, the wood shrinks about one-thirtieth of its total shrinkage; wood dried to 15 percent moisture content has attained about one-half of the total shrinkage possible. As the wood dries below 30 percent moisture content, it becomes harder and increases in most strength properties. Conversely, wood that has been dried to a low moisture content and then exposed to water or high relative humidities for an adequate time will absorb water and swell, will decrease in most strength properties, and will have a greater tendency to impart odor and flavor to food.

Atmospheric conditions in which wood boxes are used will usually be at an equilibrium moisture content below the fiber saturation point. Thus, the wood used in wood boxes is susceptible to changes in the moisture conditions of the atmosphere. Figure 5 shows equilibrium moisture content values for wood as they correspond to various values of relative humidity and temperature of the surrounding atmosphere.

Defects that develop in wood boxes because of moisture changes may be minimized by using wood at a moisture content corresponding to the average atmospheric conditions to which the boxes will probably be exposed in service. If a wood box made with a high moisture content is used in a dry location, the wood will shrink and nails will loosen. Knots may fall out and tight joints will open. Checking and splitting are also likely to occur. Tests show that resistance to rough handling may be reduced as much as 75 percent when boxes are assembled from green lumber and subsequently dried. The weakening effect caused by the drying of wood after the boxes have been nailed is illustrated in figure 6.

The use of lumber that is too dry is objectionable because the dry lumber splits more readily in nailing and handling than lumber with a more suitable moisture content. Boxes made of dry wood and subsequently exposed to wet conditions may be susceptible to buckling and nail pulling.

The general recommendation is that lumber be within a moisture content range of from 12 to 18 percent for boxmaking.

Thickness of Box Members

Formulas for determining the wood thickness required in sides, top, and bottom of boxes have been developed. Rules to determine the thickness for other box parts have also been devised.

The principal features of these formulas and rules have been used for a number of years. During this period they have been subjected to study and criticism by shippers and box manufacturers and have been extensively used as a guide in the design of boxes and in the preparation of specifications.

As previously discussed, it is seldom possible to determine the best design of a container other than by making successive improvements to correct weaknesses developed in service. The presentation of rules and formulas is not in contradiction of or inconsistent with this statement, but rather to afford box designs that are satisfactory for most uses and a design from which improvements may be made.

The mathematical determinations may indicate that it is most efficient to use different thicknesses for the sides, top, and bottom of a given box. For economy in production, however, boxes generally are made with sides, top, and bottom of the same thickness. The thickness selected should be the greatest of the three as determined by formula.

Formulas to determine member thickness.--The first formula for the thickness (t_1) of the sides, top, and bottom is:

$$t_1 = K \sqrt{\frac{W}{b}} \qquad (1)$$

where b equals width in inches of side, top, or bottom whose thickness is to be determined; W equals gross weight of box (weight of contents plus estimated weight of box); and K equals a factor whose value depends on the style of box, species of wood, commodity, nature of transportation, internal packing, and number of steel straps and wires used to reinforce the box.

K values of 1/8 for groups I and II woods and 1/10 for groups III and IV woods have been found to give satisfactory results for unreinforced boxes carrying average commodities in domestic shipment.

Formula (1) does not take into consideration the length of the box. The influence of length on the thickness of wood required is most important in boxes with long sides of relatively thin material (in which the bending of boards works the nails loose), and in boxes with relatively thick short sides (in which failures occur from the direct thrust of the contents on the nails). The need for thinner material in relatively short boxes and for thicker material in long boxes is taken into account in the second formula for the thickness (t_2) of sides, top, or bottom. The second formula is:

$$t_2 = \left(t_1^6 \frac{L}{60}\right)^{1/7} \qquad (2)$$

or written in logarithm form:

$$\log t_2 = \frac{1}{7}(6 \log t_1 + \log L - \log 60)$$

where $\underline{L}$ equals length of box in inches and $\underline{t_1}$ equals the thickness as determined by formula (1).

These formulas give the minimum required thickness of lumber. If any thickness found by formula is not available, the next greater available thickness should be used.

Rules to determine member thickness. --After the required thicknesses of sides, top, and bottom of boxes are determined, thicknesses (of ends, sides, tops, and bottoms) for lock-corner boxes, dimensions of other parts of nailed boxes, and modifications allowable where boxes are strapped may be determined by rules devised for the purpose. Experience has shown that the application of these rules produces a good balance of box construction. The rules, which are stated in the following paragraphs, give minimum thicknesses. The required thicknesses of box parts are often stated as the ratios of their thickness to the thickness of sides. These ratios are to be applied to the required thickness of side as determined by formula and not to the available thickness adopted for use.

Lock-Corner Boxes:

1. Tops and bottoms of lock-corner boxes should be the same thickness as required for nailed boxes.

2. Ends and sides of lock-corner boxes should not contain less than the total amount of lumber required for the ends and sides of uncleated, end-nailed boxes, and in no instance should the thickness of the ends be less than 1-1/2 times the thickness required for the sides of unstrapped nailed boxes. Sides whose ratio of length to thickness is less than 40 should be not less than the thickness required for nailed boxes; sides whose ratio of length to thickness is greater than 40 should be not less than 1-1/4 times the thickness required for nailed boxes.

Nailed Wood Boxes:

1. The ends of style 1 boxes should be twice the required thickness of the sides.

2. When the sides, top, and bottom of styles 2, 2-1/2, and 3 boxes are nailed to both the ends and the cleats, the ends and cleats each should be 1-1/4 times the thickness required for the sides.

3. When the sides, top, and bottom of styles 2 and 2-1/2 boxes are nailed only to the cleats, the ends and sides may be the same thickness, provided the

thickness of the cleats is not less than 1-1/2 times the required thickness of the sides.

4. When the sides of styles 4 and 5 boxes are nailed to both the ends and cleats, the ends and cleats each should be 1-1/2 times the required thickness of the sides. When the sides are nailed to the ends only, the cleats and sides may be the same thickness, provided the ends are at least 1-3/4 times the required thickness of the sides.

5. The ends and cleats in style 4-1/2 boxes each should be 1-1/2 times the required thickness of the top and bottom.

6. Ends and cleats may be reduced 20 percent in thickness if they are made of woods of groups III or IV rather than of woods of groups I or II.

7. The width of cleats for ordinary boxes should be at least three times the thickness. Extremely long cleats, however, should exceed this width in order to prevent breaking across the grain. Triangular or square cleats used for style 5 boxes should have at least the same cross sectional area as the requirements for ordinary rectangular cleats.

Part thickness for strapped boxes.--If nailed or lock-corner boxes of any style are adequately reinforced with straps or wires, the thicknesses of the sides, top, and bottom may be reduced 20 percent when one strap (or the equivalent wire) is used, and 36 percent when two straps are used. The use of straps or wire does not justify any reduction in thickness of the box ends or cleats. Consequently, in applying the rules for thickness of ends and cleats, the thickness of the sides that would be required for a box without straps or wires should be used as the basis for the ratio of end-to-side thickness.

Thickness of single-piece sides.--When the sides of nailed and lock-corner boxes are made of single-piece stock, they may be 12-1/2 percent less in thickness than that required by the preceding formulas and rules.

Nailing

Observations of boxes that have failed in service have shown that the most common defect in box construction is inadequate nailing. Without good nailing, a potentially good box may not have sufficient strength to resist the hazards of shipping. Only a little extra care is required in this important phase of box construction to greatly improve boxes with a minimum of cost. Whether the box is built in a box shop by machines or in a home by hand nailing, the principles of good nailing apply.

The strength of a nailed joint depends on the direct- and lateral-withdrawal resistance of the nails, the number of nails used, the adequacy of the nail pattern, and the thickness of the members being joined.

Withdrawal resistance.--The withdrawal resistance of individual nails varies with the direction of driving the nails with respect to the direction of the grain of the wood, whether the nails are clinched or unclinched, species of wood and its density, nature of the shank of the nail, changes in moisture content of the wood, the kind of nail point, size of nail, and depth of penetration.

Direction of driving.--The resistance of nails to withdrawal is greatest when the nails are driven perpendicular to the grain of the wood (side-grain nailing). When nails are driven parallel to the wood fibers (end-grain nailing), the withdrawal resistance in the softer woods may be 50 percent less than when a nail is driven perpendicular to the grain. In dense woods the effect of the driving direction on withdrawal resistance is less than in softer woods. Slant driving has some advantages over straight driving when nails are driven into the end grain of the wood, but shows little advantage under other conditions.

Clinching.--Nails should be clinched whenever possible as the withdrawal resistance of clinched nails is considerably higher than that of unclinched nails. In dry or green wood, a clinched nail provides from 45 to 170 percent more withdrawal resistance than an unclinched nail when both are withdrawn soon after driving. In green wood that seasons after a nail is driven, a clinched nail gives from 250 to 460 percent greater withdrawal resistance than an unclinched nail. This improved joint strength of the clinched over the unclinched nail does not justify the use of green lumber, because it is not possible to clinch all of the nails used in the assembly of boxes. Nails clinched across the grain have approximately 20 percent more withdrawal resistance than nails clinched along the grain.

Species.--It can be seen from columns 4, 5, and 6 of table 1 that the average nail-withdrawal resistance varies with the species of wood into which it is driven. Actually, these values tend to vary directly with the density, both of and within a species. Thus, as the density increases, the nail-withdrawal resistance tends to increase and, therefore, the heavier, denser species generally have higher resistance to nail withdrawal than the lighter, softer species. It should be remembered that the denser species also have a greater tendency to split when nailed and are more difficult to nail.

Nail shank.--The nature of the shank of a nail can cause variations in nail-withdrawal resistance. Nail shanks may be coated, roughened, or mechanically distorted to increase withdrawal resistance.

Nail coatings.--Of the various coatings applied to nails, so-called "cement" coatings are the most frequently used in the wood box industry. Cement coatings, contrary to what the name implies, do not include cement as an ingredient; they generally are a composition of resin applied to the nail to increase the resistance to withdrawal by increasing the friction between the nail and the wood. Good-quality cement coatings are even, not sticky to the touch, and cannot be rubbed off easily. Tests show that nail-withdrawal resistance of good-quality cement-coated nails may be twice as much as that of common nails when the nails are driven into the softer, less dense woods and pulled immediately. If there is a time interval of several months or more between driving and pulling, or if appreciable moisture changes occur in the wood, cement-coated nails lose much of their advantage. This is illustrated in figure 7. Also, there is little advantage in using cement-coated nails to fasten the harder, denser woods because much of the coating is rubbed off as the nail penetrates the wood.

Zinc coatings are applied to nails primarily to enhance resistance to corrosion. If properly applied, zinc coatings may also increase nail-withdrawal resistance, but such extreme irregularities as are sometimes seen on the surface of galvanized roofing nails, may have the opposite effect.

Nails with roughened surfaces.--Sandblasted or chemically etched nails give higher withdrawal resistance than coated nails. They also retain much of their superiority under varying moisture conditions. Under impact loading, however, the withdrawal resistance is little different than that of common nails. The following procedure is suggested for chemically etching nails: Prepare a 10 percent solution (by weight) of commercial monoamonium phosphate in water. Do not use a metal container for preparing or storing the solution. Keep the solution near room temperature (about 68° F.). After cleaning nails in a solvent such as acetone, immerse the clean nails in the monoamonium phosphate solution for about 7 hours, stirring occasionally. At the end of the etching period, remove the nails from the solution, rinse in water, and allow them to drain and dry. About 5 gallons of the chemical solution is sufficient to etch approximately 100 pounds of nails.

Deformed-shank nails.--The shanks of nails may be mechanically twisted, grooved, or barbed. These deformations on the shank produce different properties of nail-withdrawal resistance. The withdrawal resistance of these nails, except for some types of barbed nails, is generally somewhat greater than that of a common wire nail in wood that does not change in moisture content. Under changing moisture conditions, however, most of these special nails have greater withdrawal resistance than the common wire nails. This is especially true of nails driven into green wood that subsequently seasons. In general, the annular grooved nails sustain larger withdrawal loads, and spirally grooved nails sustain greater impact-withdrawal values than other nail forms.

Some types of these special nails are more difficult to drive than the plain shank nails, especially in the denser species of wood and in species that have a marked difference between springwood and summerwood.

Changes in moisture content. --Changes in moisture content adversely affect nail-withdrawal resistance because, when the wood dries, the fibers in contact with the shank of the nail shrink and probably recede from the shank of the nail. This adverse effect is especially significant for nails with smooth shanks. If it is necessary to make boxes of wood at a higher moisture content than is recommended, or if it is known that the wood will be subjected to alternate swelling and shrinkage, nails with spirally grooved or annular grooved shanks should be used. The withdrawal resistance of these deformed-shank nails is affected to a lesser extent by moisture changes than nails with smooth shanks.

Nail points. --The two most common types of points on nails used to fasten box members together are the diamond and blunt points. Blunt-point nails provide less nail-withdrawal resistance but cause less splitting of the wood than diamond-point nails. The blunt points crush the wood fibers, thereby reducing the friction between the nail shank and the solid wood. Crushing the fibers instead of wedging them apart reduces splitting of the wood.

Types of nailheads. --Nailheads are necessary to prevent the nail from pulling through the board when stresses are applied. Nailheads vary in shape and size. Those nails with reinforcing fillets under the head (sinker and corker nails, for example) have heads sufficiently strong to withstand the force required to withdraw the nail from most species of woods. The use of nails with thin heads (broad and flat) in some of the denser woods may result in loss of the heads when the nails are driven or when stresses are applied.

Overdriving nails. --Overdriving of nails crushes the wood fibers surrounding the nailhead. It also reduces the resistance of the nailhead to pulling through the wood, and to the nail shank shearing out at the end of the board. The effect of overdriving is illustrated in figure 8. This undesirable practice occurs most often in machine nailing of boxes. It may be caused by variations in the thickness of boards, by differences in the density of the boards, or by improper setting of the nailing machine.

Nail size and number. --One difficulty in box construction is to provide enough nails to fully develop the strength of wood. If nails are spaced too close in a row, they will split the wood; if too few nails are used, the wood between the nails and the ends of the boards may be sheared out.

The proper size and number of nails depend on the species of wood and the thickness of the parts joined. With some combinations of species and thicknesses of material, a large number of small nails are required, while other combinations require a small number of large nails. The nail shank should be long enough to prevent the nail from pulling out and also to prevent any prying action from splitting the piece into which it is driven. Nails should be large enough to be driven easily without bending and so they will not break when bent back and forth in service.

Nail patterns are used to space the nails so that a minimum of splitting will occur. The patterns should provide for enough end clearance and enough spacing between nails. The nails should be staggered in rows if at all possible.

Member thickness and joint strength.--The use of thick members does not necessarily mean that strong joints and better boxes will result. In fact, it has been shown that if the thickness of box members is increased without additional nailing, there will probably be no gain in strength (possibly even a reduction), the box will be more expensive, and the weight will be increased.

The type of joint failure depends on the relation of the thicknesses of sides, top, and bottom to the size of the box. Repeated bending of long thin sides, tops, and bottoms causes the nails to work loose, to shear out, or to split the parts that hold their points. In boxes with relatively short and thick sides, the shocks incident to rough handling are not absorbed by the springing of the boards, and failures occur because the contents of the box push on the nails. If boxes are properly nailed, the two types of failure are about equally common when the slenderness ratio, ratio of length to thickness of the boards in the sides, top, or bottom, is about 60 to 1. Failures by the repeated bending of the box boards become more prevalent as the slenderness ratio increases, and failures by direct nail withdrawal increase as this ratio decreases. In boxes whose wide faces consist of a number of narrow boards, the weaving of the box in service loosens the nails and produces the same type of failure as occurs in boxes with long sides of thin material.

For the same thickness of end, boxes with wide sides permit better nailing than boxes with narrow sides and, therefore, require less thickness of material for the same gross weight to prevent nail failures. Box sides made of wide boards, especially single-piece sides, resist weaving of the box and loosening of the nails. These single-board sides also require less thickness to resist nail shear out at the ends of the boards than do box sides of two or more pieces. Failures occur in such boxes, however, through the thrust of the contents knocking out the ends or loosening the nails.

Boxes for heavy commodities require better nailing and thicker material than those for light commodities. Lightweight commodities, however, often require relatively thick material in the box sides, tops, and bottoms in order to prevent damage to the commodity from the springing or puncturing of the boards. Since lightweight packages frequently receive more severe handling than heavier packages, thicker lumber and better nailing in comparison to the weight of the contents are required. If springing, puncturing, and breaking across the grain as well as nail failures are to be avoided, the thicknesses of the box sides, top, and bottom should be varied with the weights, nature of the contents, and the size of box.

Nailing Recommendations

These nailing recommendations are satisfactory for boxmaking for most conditions of service. The recommendations include the type, number, and size of nails to use. Nail patterns are also included.

Nail manufacturers have provided a great variety of nails that are adaptable to almost any use where fastenings are required. These nails are made from different metals and have different sizes and shapes. The nails most frequently used in the wood box industry are the common, box, sinker, corker, cooler, and some deformed-shank nails. They are shown in figure 9. Such special purpose nails as egg case, apple box, fruit box, berry box, and orange box nails are available.

Table 3 gives a comparison of the different characteristics of the nails most frequently used for nailed wood boxes.

It may be noted that both common nails and box nails may be purchased uncoated. Box nails may also be purchased coated. Cooler, corker, and sinker nails are always coated. The diameter of the shank of coated box nails (for a given penny size) is smaller than the diameter of the shank of an uncoated box nail.

Cooler and sinker nails are identical except for their heads. The head of a cooler nail is flat on the underside, while the head of a sinker nail is cone-shaped on the underside. Corker and sinker nails have the same type of head, which is strong and rarely breaks or pulls off. Cooler, common, and box nails have the same type of head. Coated nails are shorter than uncoated nails for the same penny size.

The sizes of spirally grooved and annular grooved nails are stated in length and gage of wire rather than penny size. The length and gage of wire may vary somewhat between manufacturers.

Fabrication nailing. --The fastening of the various pieces into box parts, such as fastening the cleats to the end sheathing boards, is referred to as fabrication nailing. In fabrication nailing, the nails should be driven through the thinner member, then through the thicker member, and be clinched across the grain of the wood. The clinched nails need not be coated or roughened. Common nails and uncoated box nails are those most frequently used.

The clinch should be at least 1/8 inch long for nails of fourpenny and smaller; 1/4 inch for fivepenny, sixpenny, and sevenpenny nails; and 3/8 inch for eightpenny nails. Longer nails may require a 1/2-inch clinch. These lengths are based on the difficulty of clinching the larger nails, as well as on the withdrawal resistance provided by a good clinch. Too long a clinch is undesirable because it is difficult to bury the point and end of the nail shank.

As shown in figure 10, the sheathing and cleats are nailed in two rows in a staggered pattern. Each sheathing board should be nailed to each vertical or through cleat with at least two nails.

Recommended nail spacing for fabrication of box parts of nailed wood boxes is:

Size of nails Penny	Average spacing Inches
4 or smaller	2
5	2
6	2
7	2-1/4
8	2-1/2

Assembly nailing.--The fastening of the box parts into complete boxes, such as nailing the sides, top, and bottom to the ends, is referred to as assembly nailing. Assembly nails in wood boxes ordinarily receive greater stresses during rough handling than do nails used in the fabrication of parts; therefore, proper assembly nailing is of utmost importance.

Sinker, cooler, and cement-coated box nails are those most frequently used for box assembly. Annular grooved and spirally grooved nails, however, are also used for some box-assembly applications. The nails should be long enough so the depth of penetration is at least 2 to 2-1/2 times the thickness of the part holding the nailhead.

The spacing of cooler or sinker nails, in inches, is:

Size of nail Penny	Nail point in end grain Inches	Nail point in side grain Inches
3	1	1-1/4
4	1-1/4	1-1/2
5	1-1/2	1-3/4
6	1-3/4	2
7	2	2-1/4
8	2-1/4	2-1/2
9	2-1/2	2-3/4

The nailing schedule given in table 4 is recommended for most uses. Recommended nailing patterns for most of the common styles of wood boxes are shown in figure 11.

Side nailing or nailing through the top and bottom into the edges of the sides, adds little to the strength of the box. The difficulty is that the weight of the contained commodity and the hazards encountered in service spring the box sides and produce splitting of the top and bottom at the side nails (fig. 12). Even in strapped boxes, the springing of the box sides is often sufficient to cause side nails to split the box top and bottom. After such splitting, side nails may protrude and be a danger to hands and clothing.

Number of Pieces

The number of pieces in the various parts of a box influences its strength. Boxes with several narrow boards in the sides, top, and bottom have less resistance to diagonal distortion and weaving than those with a smaller number of wider boards; consequently, more bending stress is transmitted to the ends and cleats. In such boxes the weaving action loosens the nails, splits the pieces holding the nail points, shears the nails out at the ends of the boards, or breaks the nails off between the two united pieces. Boxes with parts consisting of a number of boards therefore require better nailing and thicker lumber than boxes with parts made of a single piece. Furthermore, the use of wide stock makes pilfering from the box more difficult. Narrow boards are least objectionable in cleated box ends.

Edge Joints

The weakening effect of increasing the number of boards in a box part may be overcome by securely joining the edges of the boards together. The edges may be joined with either glue, corrugated metal fasteners, or a combination of both glue and corrugated fasteners. Some of the different types of edge joints are shown in figure 13.

Great care is necessary to make a strong glue joint. Both the wood and glue must be properly prepared to make a joint that is as strong or stronger than the wood itself.

Linderman joints.--A Linderman joint (fig. 13) that is properly prepared is the most satisfactory edge joint for boxes. Linderman joints are made on a special machine that automatically cuts the edges of two boards, which are to be joined, into a double dovetail that is tapered 1/16 inch along the length of the boards; the machine then spreads glue on and within the dovetail and finally, with a wedging action, forces the boards together. The joint is mechanically strong and tight enough to produce adequate pressure for proper glue curing. The boards must be of approximately the same length and thickness to be joined by the Linderman method.

Other joints.--The strength of butt, tongue-and-groove, and shiplap edge joints (fig. 13) depends on the efficiency of the glue and the corrugated fasteners. For best results both the glue and the corrugated fasteners should be used. The boards should be at least 1/2 inch thick and be accurately machined. After the glue is spread, the boards should be drawn together with the corrugated fasteners. The fasteners, if properly applied, will provide enough pressure for proper glue curing. If possible, they should be driven alternately from opposite faces of the boards.

A common commercial practice is to use corrugated fasteners to edge join the boards used to make ends of uncleated boxes. These fasteners are seldom used to edge join the side, top, and bottom boards, although the strength of boxes would be increased with the side, top, and bottom boards so joined.

Reinforcements

The use of battens, wire, and steel strap reinforcements adds greatly to the ability of a box to withstand rough handling.

Battens.--Properly applied, battens assist in preventing shear at the joints between the boards, and thus increase the rigidity of the box. They also increase its resistance to puncture, and render pilfering of the box contents more difficult.

It is recommended that battens of the same width and thickness as the end cleats be applied to sides, top, bottom, and ends when the unsupported span exceeds that given in table 5 for the thickness of the part involved.

When battens are applied to the ends of boxes, their grain direction should be perpendicular to the grain direction of the end boards, and the battens should be centered between the cleats. When battens are applied to the sides, top, and bottom, it is recommended that the batten be placed at right angles to the grain of the part to which it is applied, and that it be placed inside the box whenever the nature of the contents will permit.

Battens placed on the outside of the box increase the displacement of the box, are likely to be knocked off, and often interfere with stacking. When battens are placed on the outside of the box, it is recommended that two sets be used to provide 2-point support for the box when it rests on the floor or on another box. Battens placed on the outside of boxes should always be fastened with clinched nails. The battens should be applied so that those on the widest surface of the box extend over those that are placed on the narrowest surface of the box. Battens may be located at the extreme ends of the box, but generally are placed at some distance from the ends.

Metal straps and wires.--Metal straps and wires are the most common reinforcements for nailed boxes. They are lighter than wood battens, do not appreciably increase the displacement, and interfere less with sliding and stacking. These metal reinforcements are generally of three types: (1) Round wire strapping, (2) flat metal, nailed-on strapping, or (3) flat metal, nailless strapping. The overlapping ends of round wire are usually twisted together or knotted to form a seal (fig. 14). Usually, where metal straps are placed around the extreme ends of the box, they are nailed (fig. 14). Where metal straps are applied some distance from the ends, they are held in place by drawing them tight and fastening their overlapping ends with a seal or spot welding (fig. 14).

Metal straps or twisted wire of two or more strands, when properly nailed around the box at the extreme ends, retard the pulling out of the nails from the box ends; assist in preventing the nailheads from pulling through the sides, top, and bottom; and aid in preventing the nails from shearing out at the ends of side, top, and bottom boards. The additional nailing required to hold metal straps on the box increases the rigidity of the box. To attain the maximum rigidity, the strapping should be fastened with nails of the same size as those used in assembling the box. The tensile strength of flat strapping is reduced by driving nails through it; yet the reinforcement added to the box by the strapping nails offsets the reduction in tensile strength of the strapping.

Straps placed some distance from the box ends (usually a distance of approximately one sixth of the length of the box from the ends, provided this distance does not exceed 9 inches) absorb part of the shocks that would otherwise be transmitted to the sides, top, or bottom. Such shocks are distributed to the various parts of the box through pull on the straps. This action relieves the direct thrust of the box contents on the nails, and reduces splitting or breaking across the grain of the sides, top, and bottom. Straps placed at some distance from the ends are not as effective in preventing diagonal distortion as those nailed at the end of the box; therefore, they are less effective in reducing the shear on the nails in the ends of the sides, top, and bottom. Nailed straps placed away from the ends of the box are less efficient than nailless straps similarly placed because of the weakening effect of the nail holes in the straps, and because only short nails can be used except through the strap at the edges of the box or through straps applied over battens. The nails at the box edges do not add sufficient strength to compensate for the weakening of the straps caused by the holes.

Straps lengthwise of the box and perpendicular to the grain in the ends assist in absorbing shocks, and thus help to prevent the ends being knocked out. Straps lengthwise of the box and parallel to the grain of the ends add little strength to the uncleated box.

A strap placed away from the box ends loses most or all of its efficiency upon breaking, whereas a failure at any point in a strap nailed around the ends of the box causes only local weakness.

To be most effective, metal bindings, particularly the nailless variety, must be drawn tight enough to cut into the corners or edges of the box, and must be kept taut until they have served their purpose. For this reason, the binding should be applied just before the box is shipped in order to avoid, as far as possible, any loosening effect that may be caused by the drying and shrinking of the lumber.

Staples used to prevent reinforcing wire or steel strapping from falling off boxes may be both beneficial and, at other times, detrimental. The staples are beneficial when used to hold loose wire or strapping on the boxes. Although loose wires or straps are much less efficient than tight wires or straps, they are better than nothing to hold a box together and to prevent the contents from spilling when subjected to rough handling.

When metal bindings are placed on properly made boxes and are not likely to loosen in service, the use of staples appears somewhat questionable. The points of the staples may protrude through the lumber and damage the contents, and any overdriving of the staples may nick and weaken the wires or straps sufficiently to cause premature breakage. It is better to allow broken wires or straps to fall from the box. In this way, the broken ends will not cause handling hazards, and the missing wires or straps may be easily detected and replaced.

Metal bindings are effective means of reducing the weight of the box (by reducing the thickness of the sides, top, and bottom) without sacrificing serviceability. The reductions possible are given on page 17. When straps are used in order to allow a reduction of the thicknesses of the sides, top, and bottom, it is necessary that the nailing be adapted to the reduced thicknesses of lumber.

The proper number of straps and method of applying them for any particular purpose depend upon a number of factors, the most important of which are the size of the box and the weight of its contents. Boxes carrying heavy loads and boxes carrying light loads are handled quite differently in service; consequently, although the straps should be larger for the box carrying heavy loads, the size of the straps required is not necessarily in direct proportion to the weight carried in the box. The nature and value of the contents, the shape of the box, and the transportation hazards also have an important bearing on the number and size of straps needed.

Table 6 may be used as a guide for the selection of the size of steel strapping and wire to use for various weights of box contents under average shipping conditions.

Imparting Taste and Odor to Foods

Occasionally questions arise as to the tendency of wood to impart taste and odor to foods, particularly those susceptible to tainting, such as butter. This tendency is almost nonexistent when the moisture content of the wood is below 20 percent.

Although the tendency to impart taste and odor is difficult to measure, this characteristic of different wood species has been studied to a considerable extent. It is generally considered that ash has the least tendency to impart taste and odor. Closely following ash are soft maple, hackberry, sycamore, beech, yellow-poplar, soft elm, blackgum, sweetgum, and cottonwood.

On the other hand, some of the aromatic and resinous woods, such as pine, cedar, western larch, and Douglas-fir, might better be avoided if the wood is to be in direct contact with foodstuffs susceptible to tainting.

A further precaution might be to seal the food within a vaporproof barrier or film. The use of paraffin or other coating on the wood retards, but does not prevent, the transfer of taste and odor.

Corrosion of Metals in Contact with Wood

Most metals corrode when wet. Certain acids accelerate the rate of corrosion, and some of these acids are present in varying degrees in different species of wood. Under wet conditions oak, chestnut, western redcedar, and redwood appear to be more corrosive than species of low acidity, such as pine and maple. Corrosion of metals from contact with wood that is drier than 20 percent moisture content is negligible.

When the usefulness of metal parts may be diminished by corrosion, parts in contact with wood should be isolated from the wood by placing special papers, plastic films, or other barriers between the metal and wood.

Preservative Treatments

The idea that wood must be coated with a water-repellent paint or preservative to make it serviceable is incorrect. Century-old, uncoated, untreated wood exposed in a dry atmosphere has been found to be perfectly sound.

The use of coatings need not be considered for wooden boxes unless the boxes are expected to give longtime service when stored on the ground in warm, humid regions or when used for applications where they will be subjected to frequent or prolonged wetting.

Decay is caused by a form of plant life called fungi. The "seeds" of these plants, called spores, are small and can float in the air for long distances. If the spores fall on wood, and if the conditions for their growth are suitable, they germinate and grow on or into the wood and obtain their nourishment at the expense of the wood.

Like most other forms of plant life, decay fungi must have four things to live -- air, moisture, a favorable temperature, and food. If the air or moisture is removed, favorable temperature changed, or if the food is poisoned, decay stops.

As far as boxes are concerned, it is only practical to remove the moisture or poison the wood as a source of food. Water may be removed by storing boxes under cover or in a well-drained area off the ground if out-of-door exposures are necessary. A box that will be exposed to the rain should be designed to shed, not trap, the water.

Food essential for fungi growth is poisoned with such preservatives as creosote, pentachlorophenol, copper napthenate, and zinc chloride, or by using the heartwood of a species of wood that is comparatively resistant to decay. Preservative-treated lumber or lumber of decay-resistant species should be used only when it is not possible to keep the box dry in service and the box is required to have a long service life.

Pressure treatments with preservatives can prevent decay for over 30 years when the wood is exposed to conditions under which untreated, low-resistant species would decay in 1 or 2 years. Surface coatings of preservatives increase the service life as long as the coatings remain intact.

The heartwood of such woods as cypress, redwood, and the cedars has a high natural resistance to decay. The sapwood of all species of wood has a low resistance to decay. The heartwood of Douglas-fir, eastern white pine, southern yellow pine, sweetgum, western larch, and white oak has moderate decay resistance and gives good service when exposed to mild decay conditions. Species with low resistance to decay include aspen, basswood, the true firs (Douglas-fir is not a true fir), cottonwood, spruce, willow, yellow-poplar, hemlock, ash, elm, maple, sweetgum, tupelo, sycamore, beech, birch, hackberry, hickory, and red oak.

Water repellents, paints, and varnishes applied to wood retard, but do not prevent, the passage of water vapor to or from the wood. Neither do they poison the wood as a source of food for wood fungi. Thus, for practical purposes, water repellents, paints, and varnishes only enhance appearance or provide for better marking.

Table 1.--Various commercially important native species of wood and their rating in properties for nailed and lock-corner wood box construction

Species	Comparative bending strength[1]	Comparative shock resistance[1]	Nail withdrawal resistance[2]			Tendency to split when nailed	Dry weight (15 percent moisture content)	Ease of drying	Ease of working
			End	Edge (radial)	Flat (tangential)				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			Lb.	Lb.	Lb.		Lb./cu. ft.		
GROUP I									
Aspen	64	65	137	194	204	Low	27	Moderate	Moderate
Basswood	61	53	138	199	194	Low	26	Moderate	Easy
Buckeye	58	53	(3)	(3)	(3)	(3)	26	(3)	(3)
Cedar	68	69	118	192	202	(3)	25	Moderate	Easy
Chestnut	67	69	172	258	273	Low	30	Moderate	Easy
Cottonwood	60	65	132	191	196	Low	27	Moderate	Moderate
Cypress	83	76	144	266	291	(3)	33	(3)	Moderate
Fir (true firs)	72	62	87	176	200	Low	27	Easy	Moderate
Magnolia	78	81	(3)	(3)	(3)	Low	36	Difficult	Moderate
Pine (except southern yellow)	74	74	168	270	284	(3)	29	Easy	Easy
Redwood	82	66	106	221	226	(3)	29	Difficult	Moderate
Spruce	68	66	143	205	207	Low	28	Easy	Easy
Willow	61	102	(3)	(3)	(3)	Low	28	Difficult	(3)
Yellow-poplar	76	76	162	212	223	Low	30	Moderate	Easy
GROUP II									
Douglas-fir	82	75	183	273	296	Moderate	32	Easy	Difficult
Hemlock	76	70	138	245	253	Moderate	30	Moderate	Moderate
Southern yellow pine	100	102	237	330	376	Moderate	39	Easy	Difficult
Tamarack	84	83	(3)	(3)	(3)	Moderate	38	Moderate	Moderate
Western larch	97	107	180	299	319	Moderate	39	Difficult	Difficult
GROUP III									
Ash (except white)	83	112	(3)	(3)	(3)	Moderate	39	Difficult	Difficult
Soft elm	88	142	236	344	339	Low	37	Difficult	Difficult
Soft maple	80	101	280	333	338	Moderate	35	Difficult	Difficult
Sweetgum	85	106	192	292	278	Low	36	Moderate-difficult	Moderate
Sycamore	74	79	(3)	(3)	(3)	Low	36	Difficult	Moderate
Tupelo	82	78	233	376	345	Low	36	(3)	Moderate
GROUP IV									
Beech	102	134	358	495	460	High	44	Moderate	Difficult
Birch	89	152	331	473	451	High	42	Moderate	Difficult
Hackberry	76	145	(3)	(3)	(3)	Moderate	37	Moderate	Difficult
Hard maple	103	134	376	488	437	High	41	Difficult	Difficult
Hickory	134	283	(3)	(3)	(3)	High	50	Difficult	Difficult
Oak	100	130	316	418	433	Low	45	Difficult	Difficult
Pecan	109	157	(3)	(3)	(3)	High	53	(3)	(3)
Rock elm	106	190	(3)	(3)	(3)	(3)	44	Difficult	Difficult
White ash	109	136	385	455	452	Moderate	43	Moderate	Difficult

[1] In comparison to the average of all species listed.

[2] Average direct withdrawal resistance for 1 sevenpenny cement-coated nail driven to a depth of 1-1/4 inches and pulled at once.

[3] NA - complete data not available and thus no value given.

Table 2.--Comparison of cost of boxes with different grades of lumber

Tree species studied	Grade 1 lumber		Grade 2 lumber		Grade 3 lumber		Grade 4 lumber		Grade 5 lumber	
	Lumber cost	Box cost	Lumber cost	Box cost	Lumber cost	Box cost	Lumber cost	Box cost	Lumber cost	Box cost
	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Douglas-fir	112.50	2.28	108.00	2.27	90.00	2.15	52.25	1.80	....	....
Southern yellow pine	125.00	2.43	110.00	2.36	101.00	2.36	58.75	1.88	....	....
Hemlock	105.00	2.14	102.00	2.13	92.00	2.17	51.25	1.78	....	....
Ponderosa pine	140.00	2.69	127.50	2.52	108.00	2.28	90.00	2.16	60.00	2.01
White fir	110.00	2.18	110.00	2.25	102.50	2.17	85.00	2.07	57.00	2.01

Table 3.--Nails commonly used for box making[1]

Size of nail	Nail length						Nail gage[2]						Approximate number of nails per pound					
	Bright		Cement-coated				Bright		Cement-coated				Bright		Cement-coated			
	Common	Box	Corkers	Sinkers	Coolers	Box	Common	Box	Corkers	Sinkers	Coolers	Box	Common	Box	Corkers	Sinkers	Coolers	Box
	Inches	Inches	Inches	Inches	Inches	Inches	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
2d	1	1	...	...	1	...	15	15-1/2	...	...	16	...	830	1010	...	...	1094	...
3d	1-1/4	1-1/4	...	1-1/8	1-1/8	1-1/8	14	14-1/2	...	15-1/2	15-1/2	16	528	635	...	850	843	988
4d	1-1/2	1-1/2	...	1-3/8	1-3/8	1-3/8	12-1/2	14	...	14	14	15-1/2	316	473	...	495	488	710
5d	1-3/4	1-3/4	...	1-5/8	1-5/8	1-5/8	12-1/2	14	...	13-1/2	13-1/2	15	271	406	...	364	364	522
6d	2	2	1-7/8	1-7/8	1-7/8	1-7/8	11-1/2	12-1/2	12-1/2	13	13	13-1/2	168	236	232	275	275	310
7d	2-1/4	2-1/4	...	2-1/8	2-1/8	2-1/8	11-1/2	12-1/2	...	12-1/2	12-1/2	13-1/2	150	210	...	212	212	283
8d	2-1/2	2-1/2	2-3/8	2-3/8	2-3/8	2-3/8	10-1/4	11-1/2	11	11-1/2	11-1/2	12-1/2	106	145	129	142	142	131
9d	2-3/4	2-3/4	2-5/8	2-5/8	...	2-5/8	10-1/4	11-1/2	11	11-1/2	...	12-1/2	96	132	114	130	...	172
10d	3	3	2-7/8	2-7/8	2-7/8	2-7/8	9	10-1/2	10	11	11	11-1/2	69	94	84	104	104	118
12d	3-1/4	3-1/4	...	3-1/8	...	...	9	10-1/2	...	10	...	...	63	88	...	77	...	...
16d	3-1/2	3-1/2	...	3-1/4	...	...	8	10	...	9	...	...	49	71	...	61	...	...
20d	4	4	3-7/8	3-3/4	...	...	6	9	7	7	...	...	31	52	36	37	...	...

[1] Other pertinent information concerning nail sizes is given in catalogs published by nail manufacturers.

[2] American Steel & Wire Company's steel wire gage.

Table 4.--Recommended nailing schedule for assembly nailing with cooler or sinker nails[1]

Species of wood holding nails	Thickness of ends or cleats to which sides, top, and bottom are nailed, in inches								
	3/8 or less	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8
	Penny	Penny	Penny	Penny	Penny	Penny	Penny	Penny	Penny
Group I	4	5	5	6	7	7	8	8	9
Group II	4	4	5	5	6	6	7	7	8
Group III	3	4	4	5	5	6	6	7	7
Group IV	3	3	4	4	4	5	5	6	7

[1]Nails one size smaller than the size designated may be used, but should be spaced 1/2 inch closer.

Table 5.--Recommended use of battens[1]

Thickness of end, side, top, or bottom				Length of unsupported span
Groups I and II woods		Groups III and IV woods		
Exceeding	Not exceeding	Exceeding	Not exceeding	
Inches	Inches	Inch	Inch	Inches
....	3/8	....	5/16	19
3/8	1/2	5/16	7/16	23
1/2	9/16	7/16	1/2	30
9/16	5/8	1/2	9/16	34
5/8	11/16	9/16	5/8	38
11/16	3/4	5/8	11/16	42
3/4	25/32	11/16	3/4	45
25/32	13/16	3/4	25/32	47
13/16	1-1/16	25/32	7/8	50
1-1/16	....	7/8	....	64

[1]Battens should be used whenever the unsupported span of a wood box exceeds the value given for the part thickness and group of wood.

Table 6.--Guide for the selection of minimum size of flat metal bands or round wire for nailed wood boxes

Net weight of contents		Gage of wire[1]	Size of flat metal bands
Exceeding	Not exceeding		
Pounds	Pounds	Gage	Inch
0	70	16	3/8 by 0.015
70	125	15	3/8 by 0.020
125	175	14	1/2 by .020
175	250	13	5/8 by .020
250	400	12-1/2	3/4 by .020
[2]400	600	12-1/2	3/4 by .023

[1]Tensile strength of 140,000 pounds per square inch.

[2]Generally three bands or wires are used in this weight range.

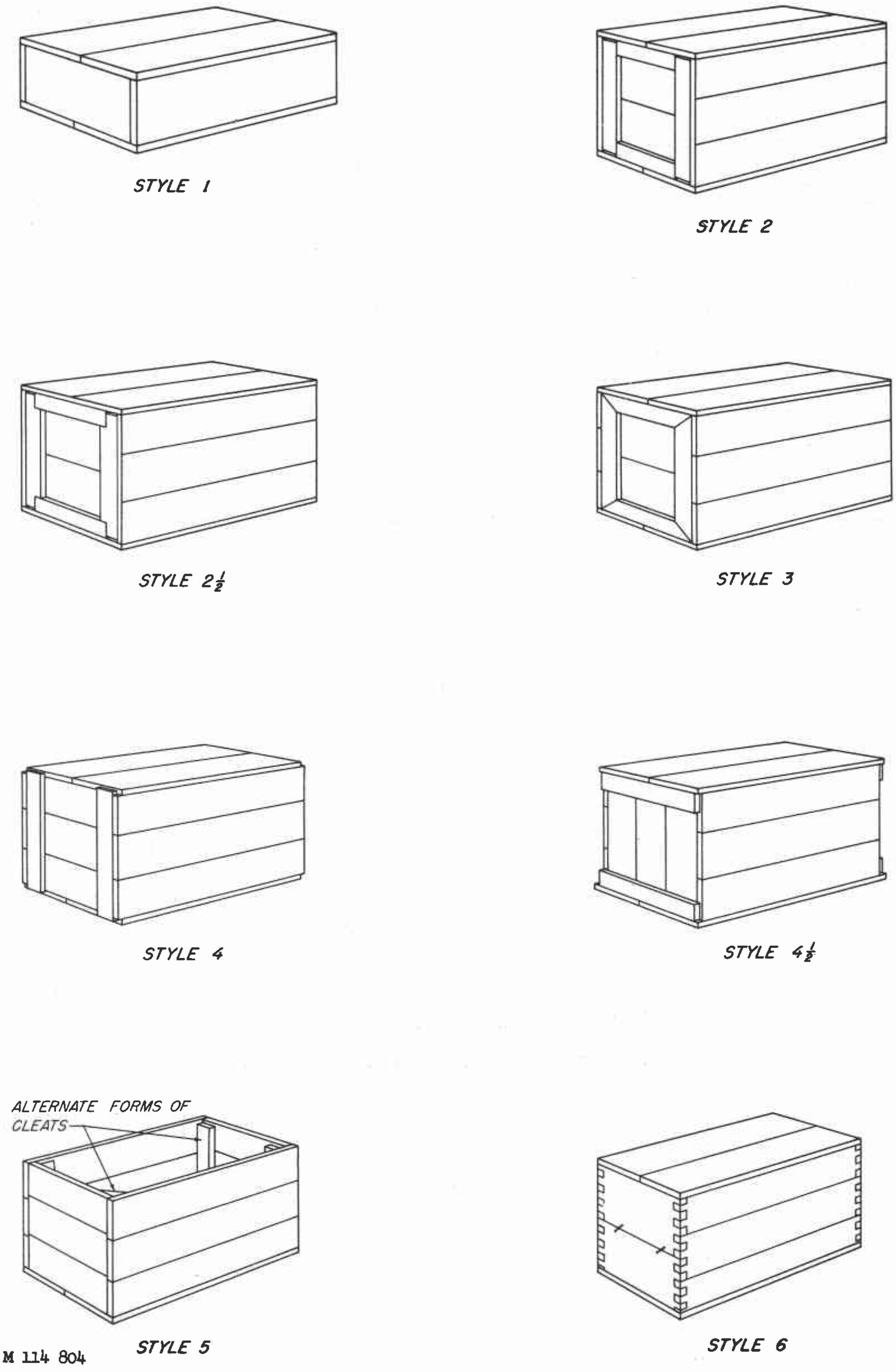

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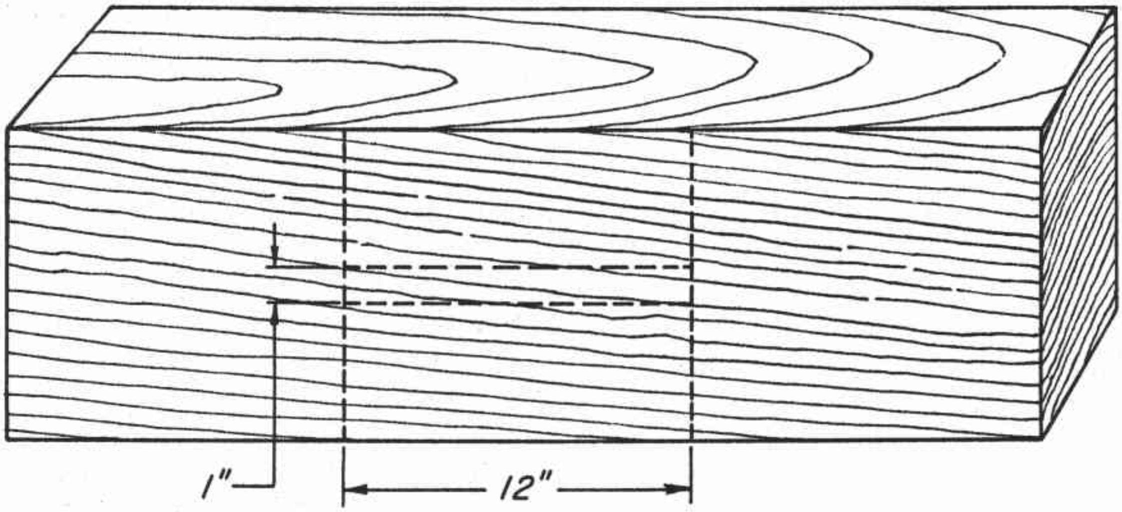
Figure 1. --Eight styles of wood boxes. Style 1 box has uncleated ends; style 2 box has full-cleated ends and butt joints; style 2-1/2 box has full-cleated ends and notched cleats; style 3 box has full-cleated ends and mitered joints; style 4 box has two exterior end cleats; style 4-1/2 box has two exterior end cleats; style 5 box has two interior end cleats; style 6 or lock-corner box.



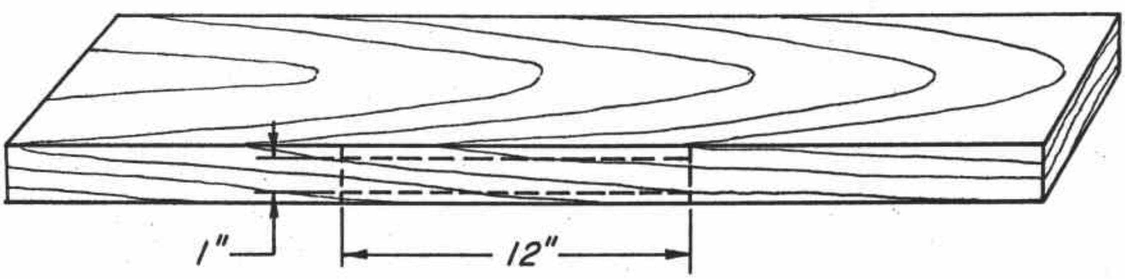
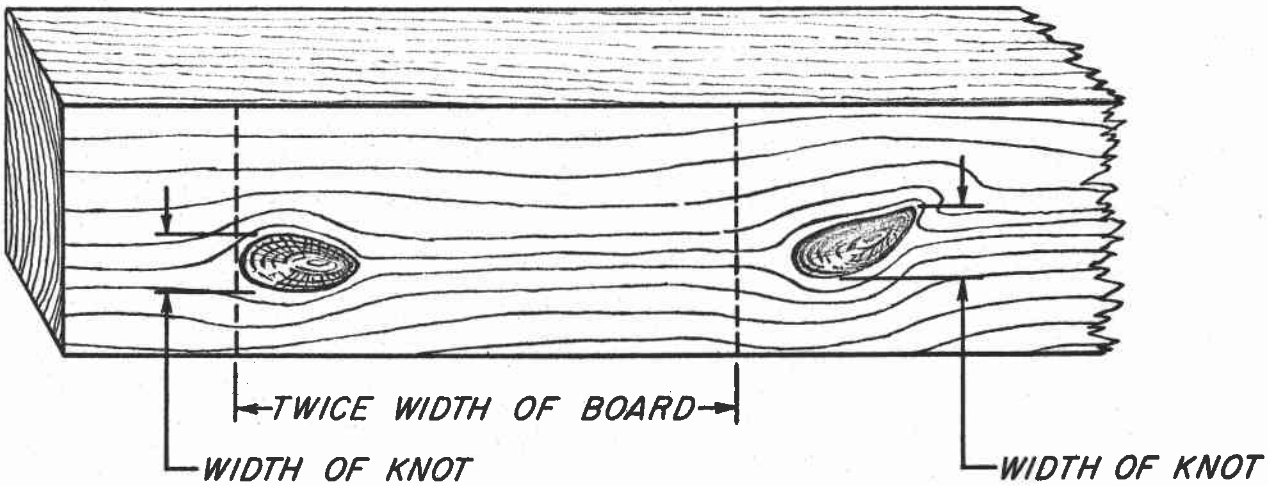


Figure 2.--How to measure cross grain. The cross-grained slope in these illustrations is 1:12.

A



B

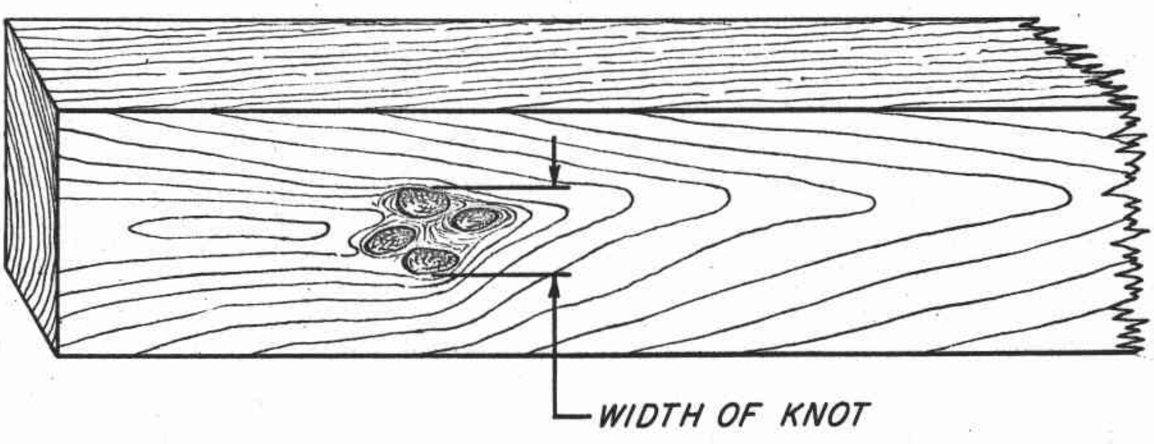


Figure 3. --How to measure the width of knots. Part A shows the measurement of single knots -- those separated from the next knot by a distance at least twice the width of the piece of lumber. Part B illustrates the measurement of a cluster of knots, where the wood is deflected around the entire unit.

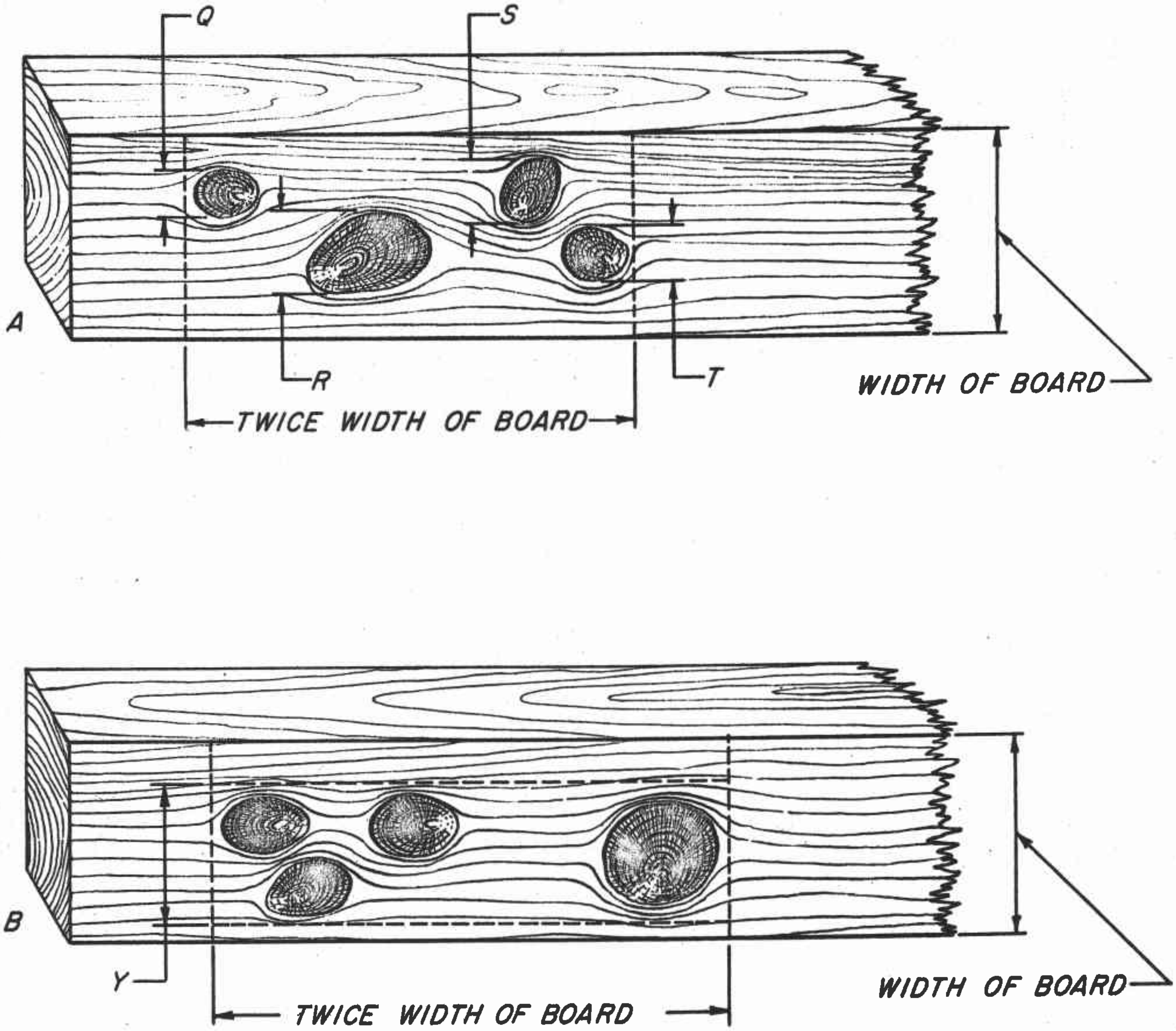


Figure 4.--In tandem knots, socalled because more than one knot occurs in a distance less than twice the width of the piece of lumber, the over-all knot width can be measured in two ways. By method A, tandem knot width is the sum of individual knot widths (Q+R+S+T). By method B, the outside edges of the outermost knots are noted as the tandem knot width, Y. The lesser width obtained by the two methods is to be used in determining the suitability of a piece of lumber for boxes.

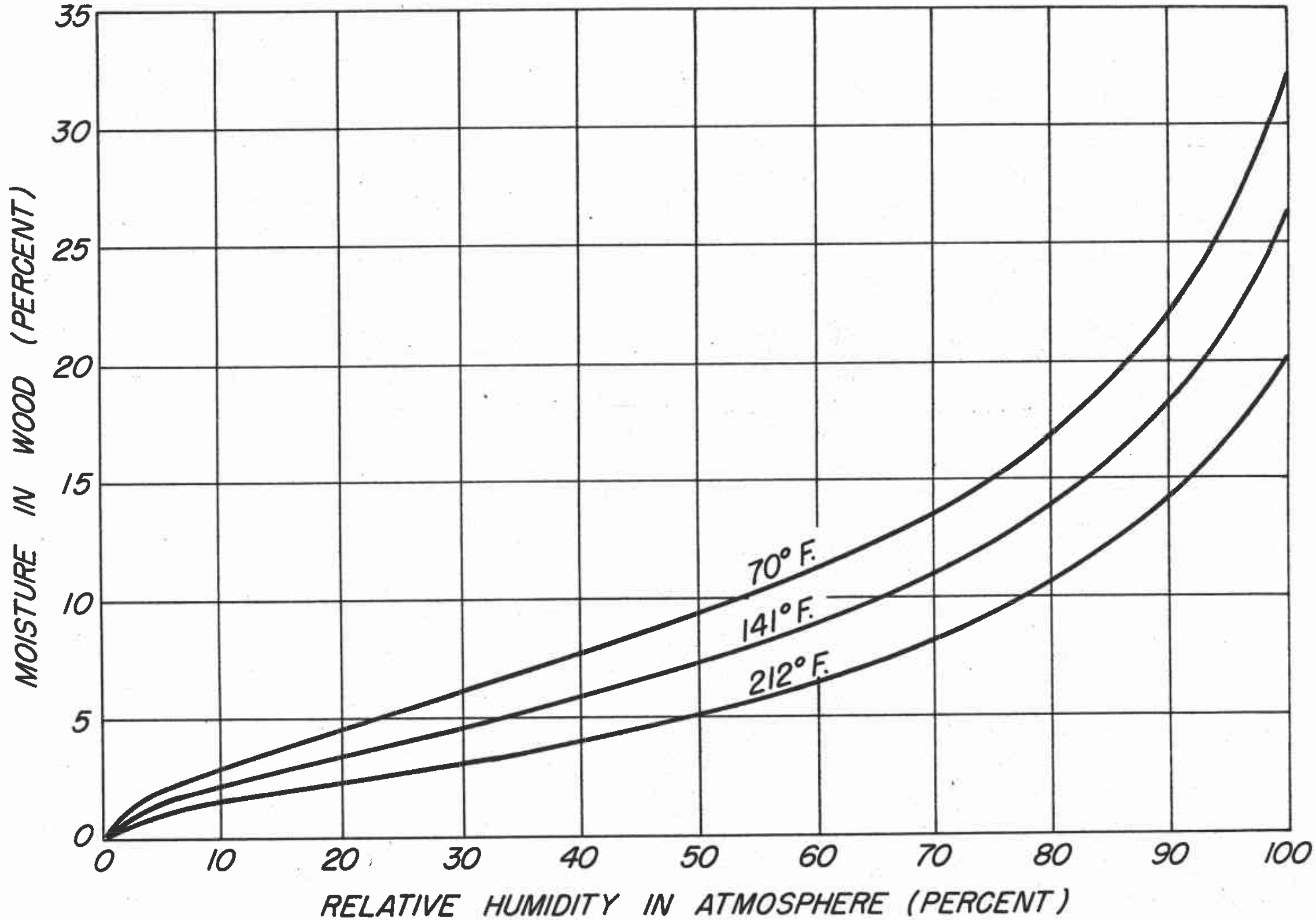


Figure 5. --Equilibrium moisture content of wood for various relative humidities at 70° F., 141° F., and 212° F.

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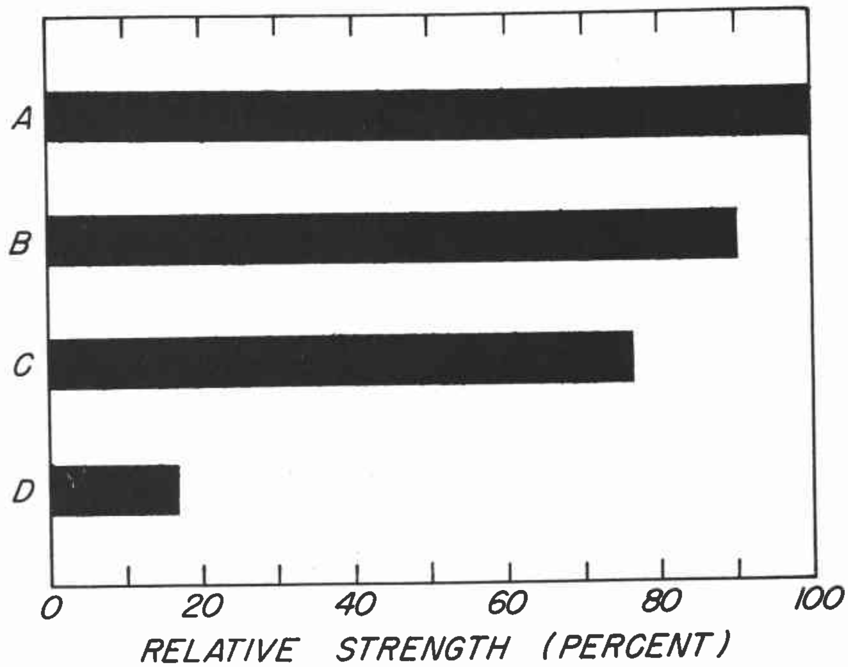

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Figure 6.--Weakening effect, as wood dries, on the strength of nailed wood boxes. Relative strength values are based on the strength value, A, of boxes nailed at 15 percent moisture and tested at once. B indicates strength value of boxes nailed at 30 percent moisture content and tested at once; C, boxes were nailed at 15 percent moisture, stored 4 months, and tested at 5 percent moisture; D, boxes were nailed at 30 percent moisture, stored 1 year, and tested at 5 percent moisture content.

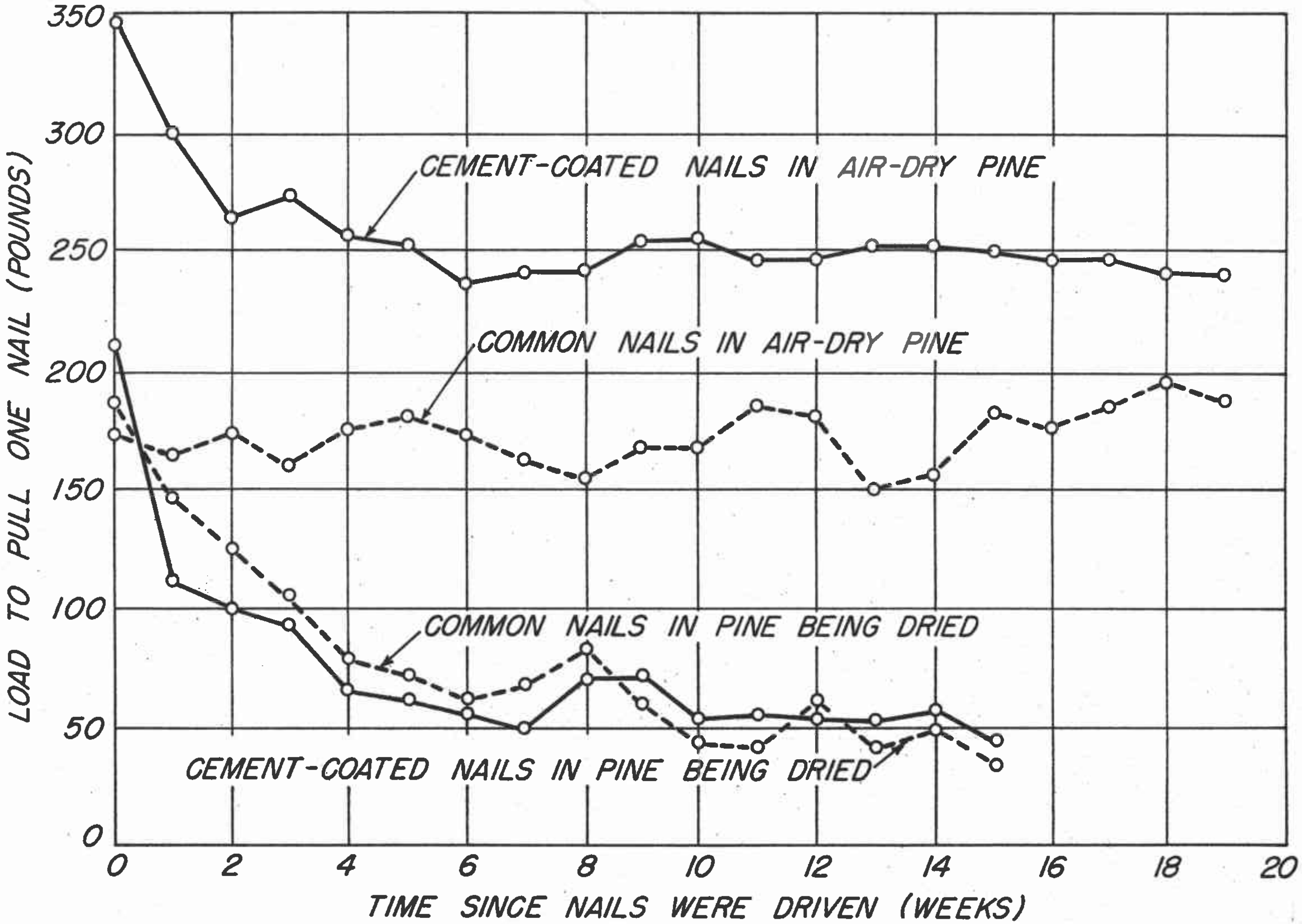

Figure 7.--Effect of changes in moisture content with time on holding power of sevenpenny nails driven to 1-1/8-inch depth.

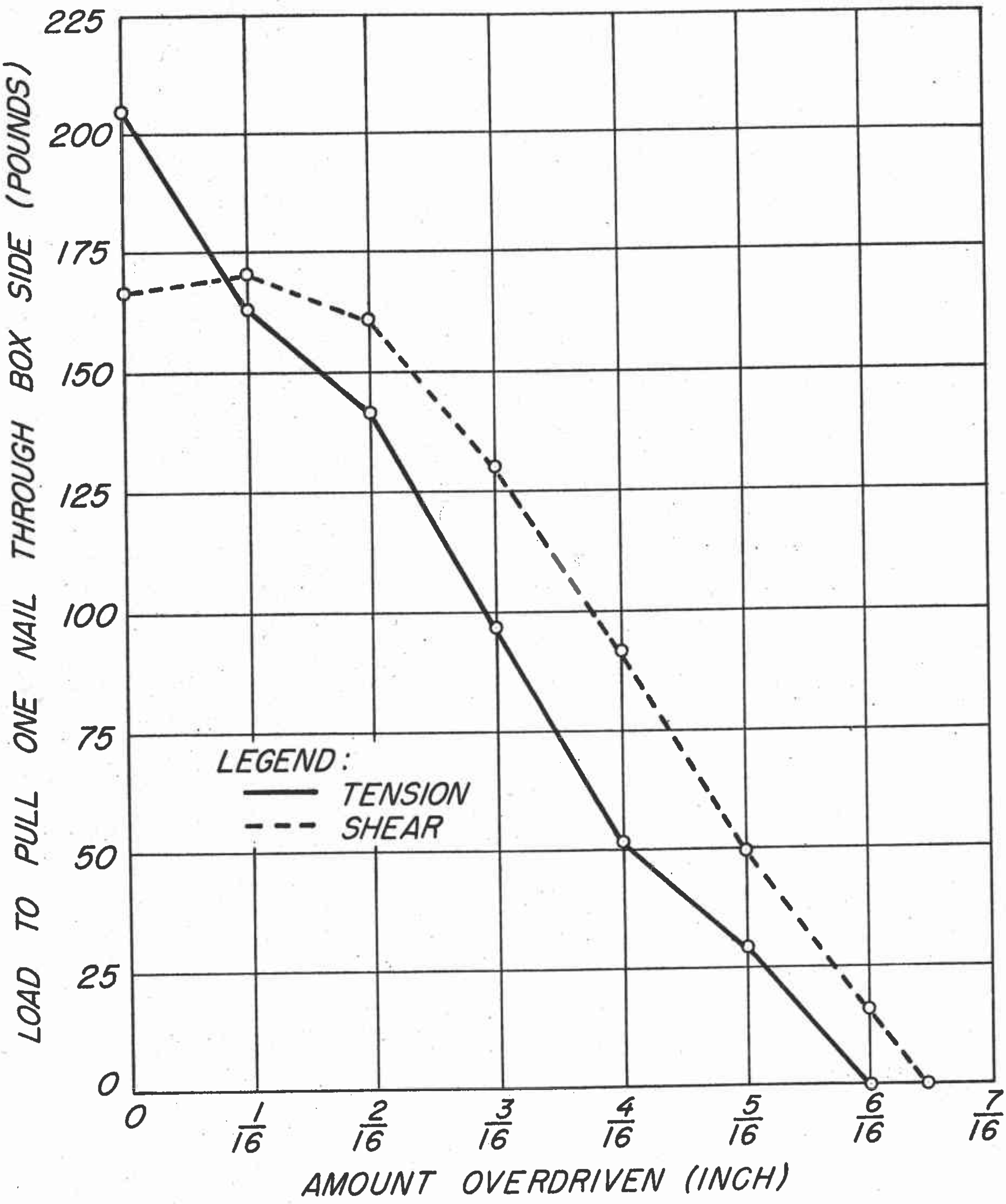

Figure 8. --Effect of overdriving nails in and through 5/16-inch box sides.

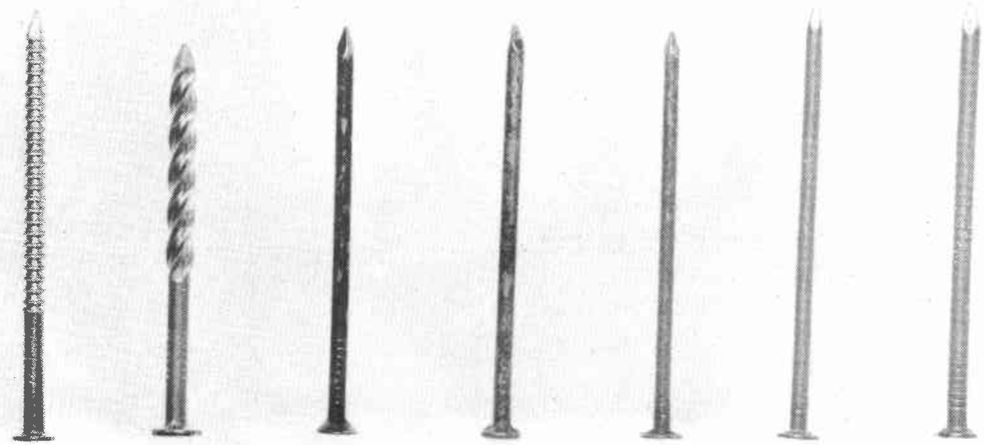

Figure 9. --Types of nails most frequently used for boxmaking. Type A, annular grooved nail; B, spirally grooved; C, a sinker; D, a cooler; E, cement-coated box nail; F, bright box nail; G, common nail.

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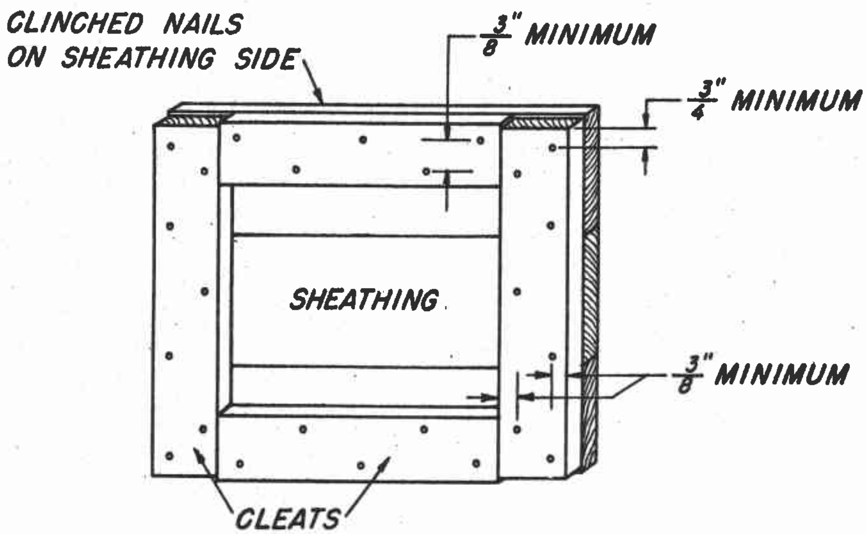

Figure 10. --Recommended nail pattern for nailing of box ends for a style 2 box.

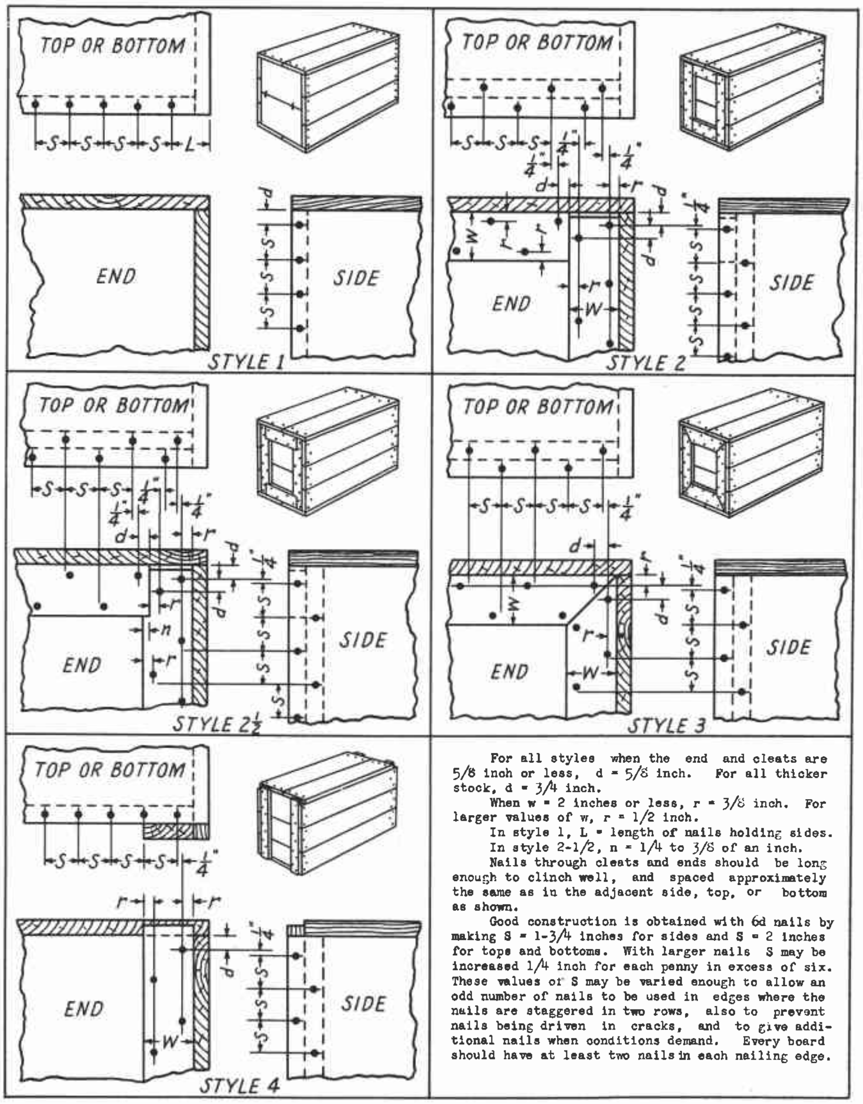

Figure 11.--Recommended nailing patterns for some common styles of wooden boxes.

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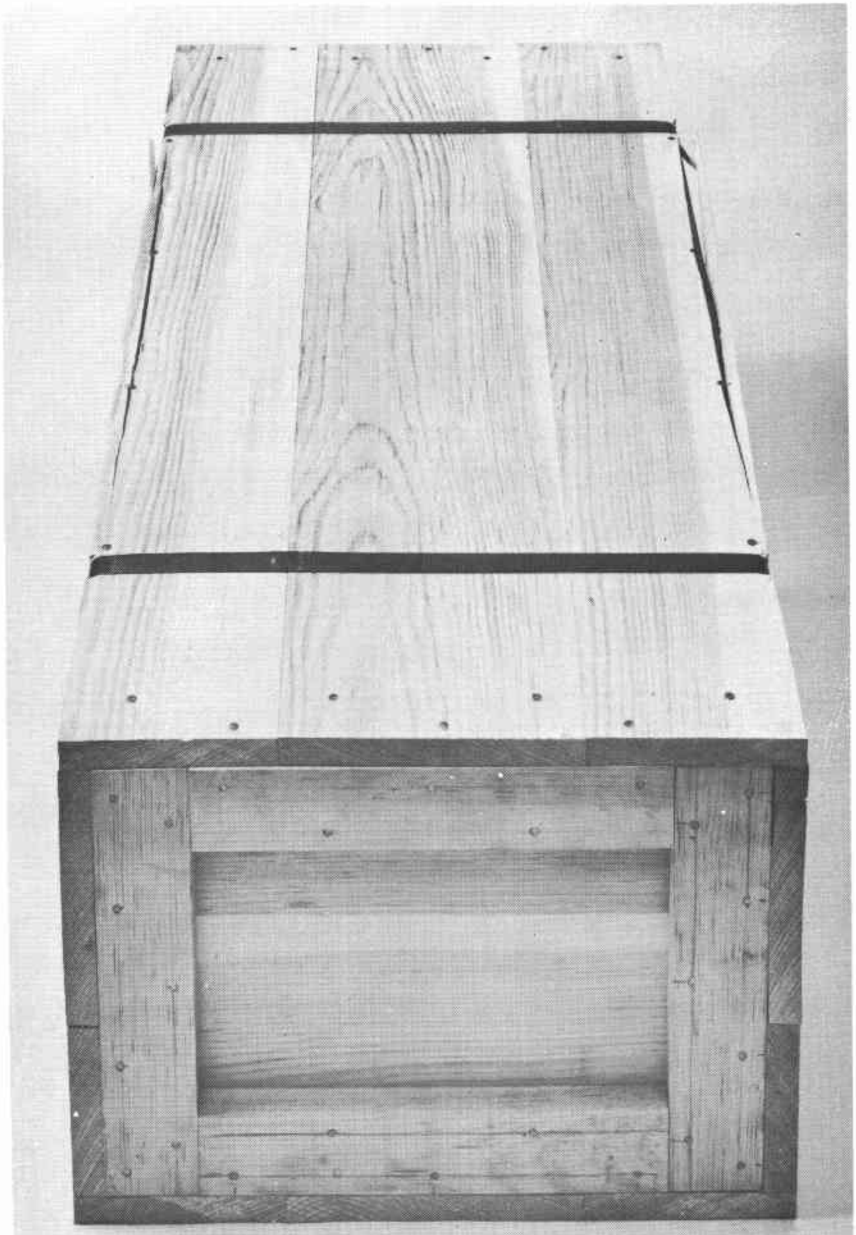

Figure 12. --Side nailing, through box tops and bottoms into the side edges, adds little to the strength of a box. Springing of the sides may cause the boards to split at these side nails, as shown here.

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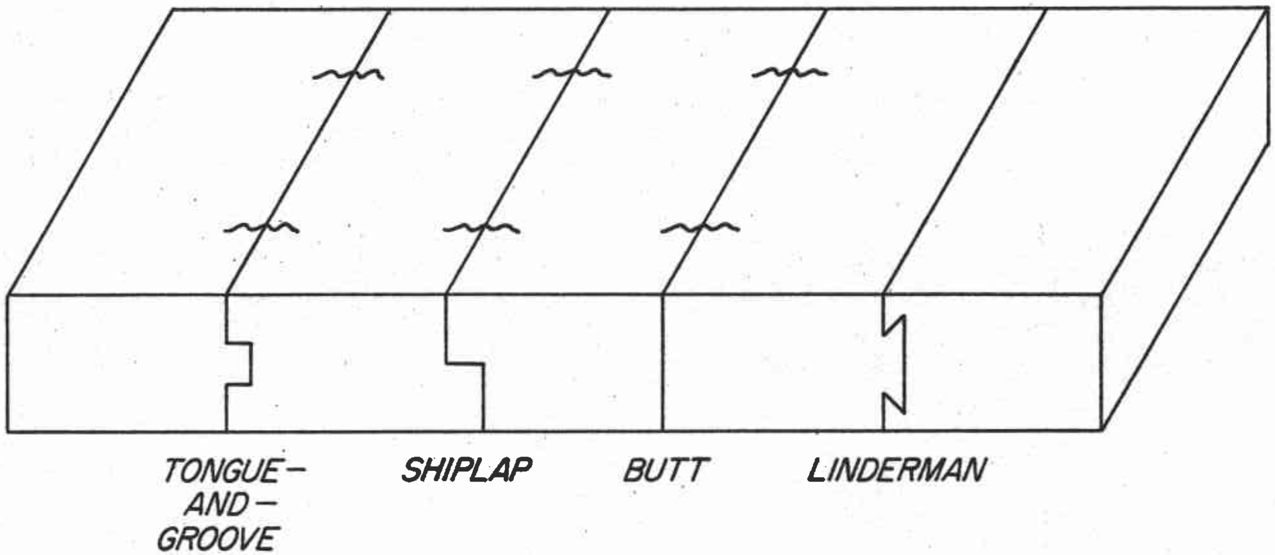

Figure 13. -- Types of edge joints for boxes. Here all except the Linderman joint are reinforced with corrugated fasteners, which hold the pieces until the glue on the joint dries.

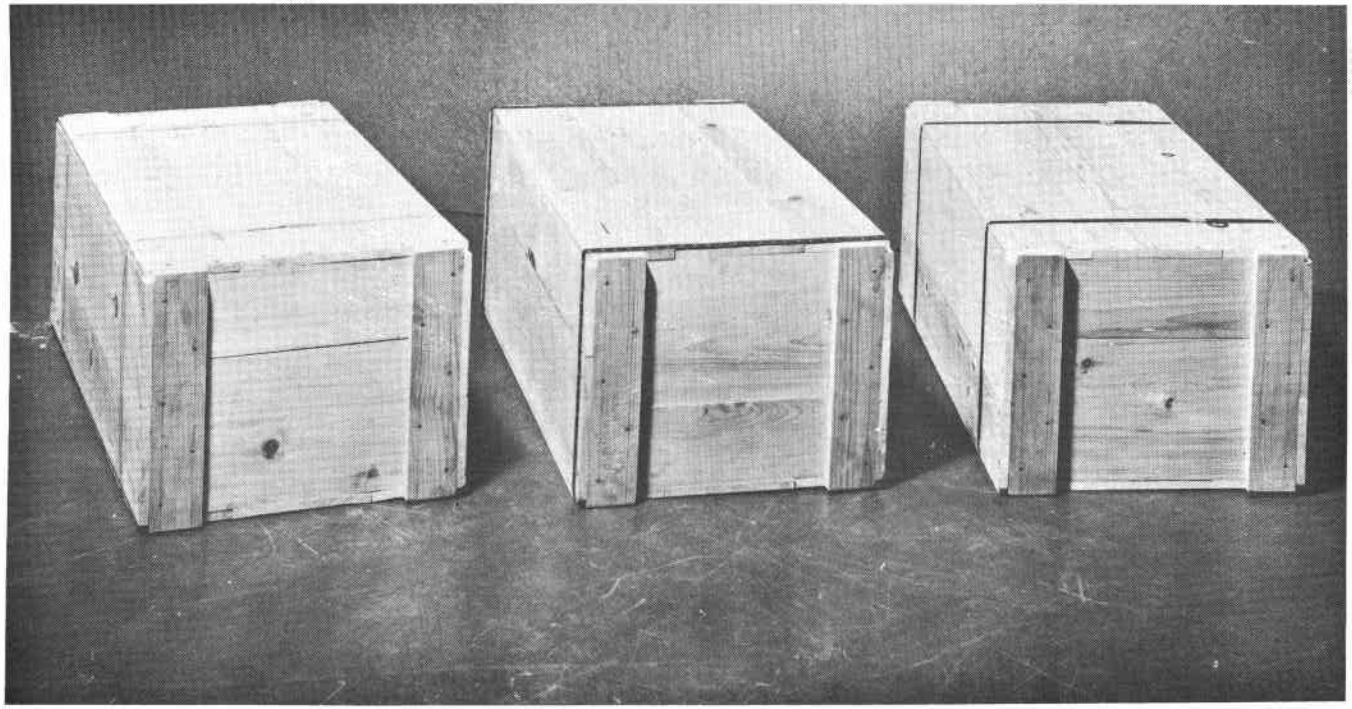

Figure 14. --Types of metal reinforcements for nailed wood boxes. The box on the left is a style 4 box, reinforced with twisted round wire; the center box is a style 4 box with nailed metal straps; and the box on the right is a style 4 box with a nailless metal strap.

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