PRINCIPLES OF BOX AND CRATE CONSTRUCTION

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FOREWORD

The container industry is very closely associated with industrial expansion, and the cost, weight, and efficiency of the container is often a large factor in the profitable market range of a commodity.

The forester and the timber owner are interested in containers because they are mostly manufactured from forest products and can

1 See p. 2 for footnotes 1 and 2.
be manufactured from mill waste and low-grade lumber, thus tending toward more efficient utilization of our forests. The ultimate consumer is vitally interested because efficient containers help to make available to him commodities from distant points and because the cost of the container, as well as loss and damage claims and unnecessary freight, are in the long run borne by him. Originally regarded as a side issue, container development lagged behind our general industrial and transportation expansions, but with wider distribution of commodities, with the demand for lighter and cheaper containers, and with the demand for better protection of the commodity, came the necessity for a fundamental study of the container. The Forest Products Laboratory has been making such a study for many years and has published various articles and reports in which the interpretation of the results has been limited to a specific problem.

This bulletin brings together the various principles involved in efficient box and crate construction and shows their interrelation. The application of the principles developed and recommended in this bulletin should aid in stabilizing the container industry, in reducing loss and damage, in making cheaper and more efficient containers, and in making possible the continued profitable use of great quantities of low-grade and waste material produced in the manufacture of lumber.

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INTRODUCTION

Our present consumption of forest products, because of its magnitude and urgency, can not be met or maintained by timber growing alone. It must be supplemented by vastly improved utilization. Through improved utilization, all the merchantable timber we now have, whether in virgin forests or second growth, must be made to go as far as it will. Since over 13 per cent of all the lumber cut annually goes into lumber for boxes and crates and in addition 7 per cent of the wood pulp produced annually is used for the manufacture of fiber containers, it is clear that a thorough understanding of the fundamental principles of box and crate construction will be reflected in the more efficient utilization of the wood of our forests.

1 This bulletin embodies the results of shipping-container investigations by the Forest Service that have extended over more than 20 years. It has been the author's privilege to draw without restraint upon the vast accumulation of information that has resulted from studies on shipping containers and allied subjects by various members of the Forest Products Laboratory staff. Other sources of information have also been freely drawn upon. The author particularly wishes to make acknowledgment to J. A. Newlin, who from the beginning has guided the container investigations of the Forest Products Laboratory, and under whose direction the work has progressed to its present status. In addition acknowledgment is made to the following members of the laboratory staff: T. R. C. Wilson, for assistance in the presentation and for critical review of the manuscript; J. M. Gahagan, for data on the holding power of nails and for other assistance; I. B. Lanphier, for many of the investigations on nailed wooden boxes, wire-bound boxes and crates, and plywood boxes; T. A. Carlson, for much of the data on corrugated and fiber boxes and for the design and development of the score-testing machine used in testing fiber containers, as well as for data on the suitability of various woods for boxes and on the effect of moisture content of wood on the strength of boxes; O. E. Heck, R. F. Luxford, and I. B. Lanphier, for those data in the bulletin relating to the use of knotty lumber in box construction; and to L. J. Markwardt, for the information in Table 7 on the comparative strength properties of container woods together with the description thereof. Specialized information on container woods, their production, and their preparation for use has been derived from Forest Products Laboratory investigations by Eloise Gerry, Arthur Koehler, G. M. Hunt, Rolf Thelen, and C. V. Sweet. Acknowledgment is made to D. L. Quinn, formerly of the Forest Products Laboratory, who from his broad experience in the application of the principles of container construction has given the author many valuable suggestions. It is a pleasure to acknowledge also the cordial and valuable assistance, so indispensable to the furtherance of the principles of box and crate construction, received from representatives of users and manufacturers of shipping containers and container materials and from members of transportation organizations. The abundance of assistance so received makes impractical separate acknowledgments.

2 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
The chief object of this bulletin is to present the principles of efficient box and crate construction which are based on extensive investigations and experiments at the Forest Products Laboratory, supplemented by study and observation of shipping containers in service. The leading conclusions have been confirmed by manufacturers and shippers after critical review and tests under actual service conditions.

The application of these principles to all types of containers for all classes of commodities is not discussed in detail; yet sufficient examples are included to show their practical significance and how they may be applied to specific problems. An effort is made to show that there are well-established principles of efficient box and crate design and that the correction of the troubles experienced with containers in service should be based on reasoning from principles. Particular attention is given to the kinds of failures to which each type of container is subject, and to the changes in construction that will overcome these failures or render their recurrence less likely. Broad distinctions among various classes of commodities and conditions of service are discussed.

Since the hazards that any container may encounter in service are so numerous and variable, no endeavor is made to set up standards of service or to designate the types of containers that are most suitable for specific commodities or conditions of service. To do so would be like designing a bridge without a knowledge of the loads to be carried.

Packing is as important as the design of the container, and the two are so interrelated that it is impossible properly to design the container without considering the method of packing. A brief discussion of the principles of internal packing, together with some examples of their application, is included. The appendices present information on the characteristics of the principal woods available for box and crate construction, the seasoning of lumber, container testing, formulas for the design of boxes, and standard specifications for boxes of various kinds.

HISTORICAL

Until the building of railroads and the resultant increase in trade the use of shipping containers was comparatively small. The wooden box was the first type of modern shipping container to be manufactured. Lumber was then so plentiful and cheap that box manufacturers, like nearly all other users of wood, demanded high grades and ignored inferior material. Waste in the woods and at the mills and box factories received scant consideration. Little attention was given to designing boxes so as to obtain the maximum strength for the minimum of materials. The constant lessening of forest area and the ever-increasing demand for lumber, however, raised the cost of the higher lumber grades and forced the box maker to use the lower and cheaper grades. More attention was given to using less lumber for the different box parts, and where formerly only a few kinds of wood were used for boxes, many kinds were brought into use. To-day several billions of feet of lumber are used annually by box manufacturers, and, for the most part, this material is of such low grade that if it were not consumed for this purpose it would be left as waste in the woods or at the mill.

Fiber boxes were comparatively unknown as shipping containers until the present century. They were first introduced as cartons, a
number of which were packed and shipped in a larger wooden box. The constantly increasing demand for lighter and cheaper containers soon caused competition between fiber and wooden boxes. In 1906 the fiber box had found a small use as a shipping container and was accepted by the western railroads with restrictions. Three years later three railway-classification committees accepted the fiber box interchangeably with the wooden shipping container for the smaller sizes and for weights of contents up to 90 pounds.

To meet the competition of the lighter and cheaper fiber box, and to reduce loss and damage and shipping costs, the wooden-box industry turned its attention to reducing the weight and cost of its product, to better proportioning the parts of the boxes and to various ways of reinforcement. Several new types of boxes, such as the wire-bound, cleated plywood, and hinge-corner boxes, were also developed.

The first recorded laboratory tests (8) for the improvement of shipping containers were made in 1905 by the Forest Service in cooperation with Purdue University, at Lafayette, Ind. The purpose of these tests was to determine the merits of different kinds of wood as box material. The method of test consisted of applying a load along the diagonal of a box to simulate the action which occurs when a box is dropped on one of its corners. These early investigations clearly demonstrated that the details of construction have far greater influence on the strength of a box than the species of wood used and indicated the need for extensive studies of the design of shipping containers.

After the establishment of the Forest Products Laboratory at Madison, Wis., in 1910, research on container design was greatly expanded and centered at this laboratory, where special testing machines and methods of testing have been developed. The chief endeavor of the laboratory in connection with shipping containers has been to develop the fundamental principles of design and the relationships of the various details necessary to produce containers that are balanced in strength. Other container-testing laboratories, patterned after that of the Forest Products Laboratory, have been established by box manufacturers, by associations of manufacturers, by shippers, and by box specialists. The chief function of these laboratories is to apply the fundamental principles and to adjust the various details of design to the needs of the individual shipper.

To further the movement for improvement in containers, the carriers, and manufacturers of containers and of container materials, together with other interested agencies, have organized to develop better practices. The efforts of these various interests have led to the recognition of the United States as the foremost country in the development of shipping containers.

**RELATION OF TRANSPORTATION CONDITIONS TO CONTAINERS**

In recent years the demand for the quick delivery of goods has resulted in longer and heavier trains, faster operations in distributing cars and making up trains, and more expeditious handling of packages at receiving, transfer, and delivery points. New equipment and new methods of handling are continually being introduced to speed
operations and to reduce costs. Such developments do not necessarily result in increased hazards to the commodities shipped; on the contrary, the hazards in many instances are reduced.

While with this development of transportation and handling methods has come remarkable progress toward the uniformity of the shocks incident to shipping, yet there is a wide variation in the intensities of the shocks that packages encounter under any particular combination of transportation and handling methods. Packages of miscellaneous commodities shipped in a car encounter shocks and stresses that are severer and of a greater variety than are encountered by packages of a carload lot of a single commodity. Furthermore, the shocks and stresses encountered differ between localities. Severely congested and less congested districts demand different facilities and methods of transportation; likewise different equipment and methods of handling are required at different water terminals. Shocks to containers in motor-truck shipment are less severe than in railway shipment; yet the severity of the weaving and wrenching strains may be greater in the motor truck.

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 from the tendency of cargo to shift in rough seas as well as those from varying climatic conditions 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 this occasions extremely severe handling.

A commodity in shipment may need protection against numerous other kinds of hazards. For instance, great losses sometimes occur from theft in transit; therefore certain products require containers that can not be readily opened and reclosed without detection. Again protection against vermin or severe weather is often important.

**RELATION OF THE COMMODITY TO CONTAINER DESIGN**

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

The protection needed varies from the mere holding together of a number of such units as railway spikes to elaborate protection of delicate X-ray 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 rim of a flywheel with slender spokes, and still others, such as acids and explosives, are a menace to life and property.

It is evident, therefore, that each commodity presents its own problem, and consequently neither weight, nor distance traveled, nor method of shipment taken alone constitutes an accurate criterion for designing a container. Even with the innumerable kinds of damage and hazards, however, relatively few kinds of stresses and fundamental principles of design are involved.
The following are the forces and stresses produced by shipping hazards: Crushing, bending, shearing, diagonal distorting, twisting, puncturing, and abrading. The principles involved in aiding the commodity to withstand any one of these stresses are the same regardless of the hazard that produces the stress, and frequently the same principle may be employed to prevent several different kinds of stresses. For instance, diagonal distorting, or twisting, may result in racking of the joints in a piece of furniture, rubbing of the finished surface against the container, breaking of thin plates of glass, or chipping of enamel ware. One of two principles may be employed in preventing these stresses and the consequent damage: (1) The container can be made rigid so that it can not distort diagonally in any direction, or (2) the container can be made nonrigid and the product so packed that the container can distort considerably without touching or without introducing stresses in its contents. The relation between the damage observed and the methods of overcoming any particular trouble are discussed under the different types of containers.

ECONOMIC FACTORS ENTERING CONTAINER DESIGN

The best container for a given service is one which will deliver the commodity satisfactorily at the minimum of total cost. Its design is subject to all the varying conditions of cost, value of the commodity, protection required, method of packing, transportation hazards, freight charges, personal and property damage likely to result from handling or from failures, inconveniences of making replacements, and facilities for handling and transporting packages.

A balanced container is one in which each part has strength in balance with that of every other part. Such a container, however, may not be the most economical because it may be made of high-grade expensive wood rather than of a low-grade inexpensive wood which would give equal service; it may require a multiplicity of sizes of material rather than a relatively few standard sizes or may be otherwise expensive to manufacture or to pack; it may not have sufficient strength to deliver its contents in a satisfactory condition, or it may contain more material and have greater strength than is necessary. Furthermore, the balancing of the construction depends upon the hazards to which the package is subjected and a container whose construction is so balanced that under one set of shipping conditions one kind of failure is just as likely to occur as another may under other conditions be subject to but a single kind of failure.

Containers and packing which deliver every unit in every package undamaged may be quite inconsistent with minimum total cost, since the ideal container will always be so light and fragile that occasional accidental rough usage will sometimes cause a small amount of damage. It should be borne in mind, however, that the economic loss resulting from delay, loss of good will, and the cost of making settlements is always greater than indicated by claims filed against the carriers. In addition, it must be recognized that all losses are reflected in the ultimate cost of the commodity to the consumers.
IMPORTANCE OF LABORATORY TESTS IN CONTAINER DESIGN

Consideration of the nature of the commodity and the economic factors involved leads to the conclusion that there can be no fixed standards of serviceability or fixed rules of design for containers. Some general principles and rules have been worked out experimentally and may be used to advantage in designing an original container or in correcting difficulties experienced in service, but it is impossible to make definite rules for designing boxes and crates which will have just sufficient strength to deliver the commodity without damage.

Tests and experiments that reproduce in the laboratory the stresses of transportation are of utmost value in determining the principles to apply in designing containers, in developing rules for the detailed application of these principles, and in showing how containers may be lightened and reduced in cost; yet such tests do not furnish a measure of the minimum resistance needed. Because of the lack of definite information on the requirements of service, it is seldom possible to find the best design of container and packing for a given commodity other than by making successive improvements as dictated by diagnosis of failures or damage occurring in service. Study of failures and damages experienced in service will usually reveal the nature of the stress and suggest the principles to apply. In some instances the cause of damage will be apparent, but in others neither the container nor packing may show evidence of failure, yet the character of the damage to the commodity may reveal that the stress resulted from such causes as the sides of the container springing in, diagonal distortion, twisting of the container, or the use of too rigid packing materials.

COOPERATION REQUIRED TO PRODUCE SATISFACTORY CONTAINER

The proper adjustment of all factors involved in designing containers requires the combined organized effort and close cooperation of laboratories, manufacturers, shippers, carriers, and consumers. The design of containers having the minimum required strength is complex, but to attain the most economical distribution of the commodity is still more intricate. Such distribution must be studied not only on the basis of designing the most economical containers for existing conditions but also on the basis of reducing the hazards of transportation and the cost of handling, of designing the commodity to better withstand shipment, and of eliminating unnecessary and expensive trade customs. It is evident, therefore, that what constitutes the most economical container will vary with improvements in container design and in methods of packing, with variations in transportation and handling methods, and with changes in economic conditions. Although the ideal container can never be attained, careful study will usually result in improving containers, lessening their cost, reducing transportation hazards, lowering costs of handling, and reducing loss and damage.

APPLICATION OF PRINCIPLES

Examples of the practical application of the fundamental principles of efficient box and crate construction contained in this bulletin are given in the specifications presented in Appendix G. Although primarily intended for the use of Government purchasing units, the
specifications may be employed by the manufacturer, the jobber, and the dealer. These specifications give detailed information on the construction of various sizes, kinds, and styles of boxes for different classes of commodities.

The principal purposes of the discussion given on pages 9 to 39, inclusive, are to afford the reader information that will be helpful in selecting the best type of container for a specific service and more particularly to show him how study of failures in containers in service may be made the basis of improving the container.

Although the formulas, rules, and specifications presented in Appendixes E and G are the best available guide to the design of container of any of these types for a specific service, it is seldom possible to determine the best design of container other than by making successive improvements to correct weaknesses developed in service. The following discussion of principles will serve as a guide in the making of such improvements.

**DESIGN AND CONSTRUCTION OF BOXES AND CRATES**

**TYPES OF CONTAINERS**

To satisfy the varying conditions of service, a number of well-defined types of containers, such as nailed wooden boxes, crates, fiber boxes, barrels, baskets, drums, plywood boxes, and wire-bound boxes, have been developed. Each of these, because of the very nature of its design and the materials of its construction, fulfills some particular purpose better than the others. In selecting a type of container for a specific use it should be remembered that what constitutes a weakness in a container for one commodity may be an advantage for another commodity. The characteristic strength and weakness of several types of boxes and crates and the construction details influencing their serviceability are discussed in the following pages.

**INFLUENCE OF SIZE AND FORM OF WOODEN MEMBERS ON THEIR STRENGTH AND STIFFNESS**

In designing any wooden box or crate a knowledge of the relation of the form and size of each part to its strength is necessary. 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 side 20 inches long will support twice as much static load as one 40 inches long; a side 8 inches wide will support twice as much load as one 4 inches wide; and a side 1 inch thick will support four times as much load as one one-half inch thick, the other dimensions and the quality of the lumber being the same in each case. The stiffness of a part varies inversely as the cube of the length, directly as the width, and directly as the cube of the thickness. The ability of a part to withstand shocks or blows without breaking varies directly as its length, its width, and its thickness; that is, the shock-resisting capacity of a box side increases in the same ratio as each of its dimensions. Resistance to splitting at the nails or to nails shearing from the end of the piece increases with its thickness and with the distance of the nails from the end of the piece.

Torsional rigidity of individual members varies inversely as their length, directly as the cube of their thickness, and approximately,
STANDARD STYLES OF NAILED WOODEN BOXES
A, Method of measuring knots; B and C, typical failures of side nailing
directly as their width. Torsional stresses are seldom considered in container design but are sometimes the cause of failure.

All of the foregoing relationships apply to plywood when they are properly modified for direction of grain and for the number and thickness of plies. (See p. 22.) Their application to fiber board requires a knowledge of the properties of the individual plies. (See p. 31.)

**NAILED AND LOCKED-CORNER BOXES**

The several styles of nailed and locked-corner wooden boxes shown in Plate 1 have been developed to meet the requirements of different commodities and conditions of service, and have been adopted by the National Association of Wooden Box Manufacturers. The end construction is the basis of the classification.

The outstanding characteristics common to all these styles are great resistance to crushing, puncturing, and mashing of the corners. They stack well, are easy to manufacture, and the strength of each may be readily adjusted to different service requirements by varying the details of construction.

**DETAILS OF CONSTRUCTION**

**THICKNESS OF SIDES, TOP, AND BOTTOM**

Although the joints and fastenings are actually the principal points of weakness in boxes, it is common belief that the thinness of material for sides, top, or bottom is limited by the breaking strength of the lumber. As a matter of fact the thicknesses of these parts are usually determined by nailing requirements rather than by the breaking strength of the lumber. Because the resistance of wood to withdrawal of nails, to splitting at nails, and to shearing at nails is low in comparison with its other strength properties, it is impractical with clear material to so proportion box ends and the fastenings at the joints that failure will be by breaking across the grain of the sides, top, or bottom.

The type of nail 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 part that holds 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 as a result of the contents of the box pulling directly on the nails. If boxes are properly nailed the two types of failure are about equally common when the slenderness ratio, that is, the 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 pull increase as this ratio decreases. In boxes with wide faces consisting of a number of narrow boards, the weaving of the box in service loosens the nails and produces the same type of failures as occur 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 in order to prevent nail failures. Box sides made of wide boards, especially single-piece sides, resist weaving of the box and loosening of the nails and require less
thickness to resist the nails shearing out at the ends of the boards than box sides having two or more pieces in the sides. Failures occur in such boxes, however, through the thrust of the contents knocking out the ends or through the direct pull of the contents on the nails.

Knots or knot holes slightly reduce the stiffness of the board in which they occur and reduce the breaking strength almost in the ratio of the width of the knot to the width of the board. By using boards containing knots or knot holes 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 of less than 60 to 1 in boxes where the knots or attendant cross grain does not prevent proper nailing, there is no reduction in strength for a knot or knot hole whose diameter (measured as indicated in pl. 2, A) does not exceed one-third the width of the board, or from knots or knot holes 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 in order to avoid the sides breaking across the grain, or to avoid loosening of the nails with the increased bending of the boards. The increased bending resulting from knots, however, may be readily offset by a very slight increase in thickness of sides.

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 severer handling than heavier packages, thicker lumber and better nailing in comparison to the weight of 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 weight and nature of the contents and with the size of the box. The thicknesses required for the sides, top, and bottom of a box may be approximated by the formulas given in Appendix E. Less thickness is required for the dense hardwood species having high-strength properties than for lightweight species having low-strength properties.

** Thickness of End and Size and Shape of Cleats **

The requirements for the thickness of box ends and the cross-sectional area of cleats are affected by many factors, a number of which counterbalance each other and thus make their consideration unnecessary in designing a box. For practical purposes the dimensions of the box ends and of the cleats are determined by the style of the box and by the thickness of the sides, which in turn is dictated by the nailing requirements. Uncleated ends require greater thickness in proportion to the thicknesses of the sides, top, and bottom than cleated ends of boxes for the same service. Ends or cleats that receive part, or all, of the nails that are driven through the box sides, top, and bottom, must resist both breaking across the grain and splitting at the nails and consequently must be thicker, and the cleats must also be of greater cross-sectional area, than when they receive only part or none of the nails. These facts are illustrated by the style 5 box (pl. 1), in which the ends receive all the nails and in the style 2 box, in which
the cleats receive a part or all of the nails. Cleats that do not receive the points of nails should not be excessively thin; otherwise they will fail to give stiffness to the box end, and they will break readily.

Varying the shape of the cleats is often an advantage in box construction. Triangular cleats in the box corners give greater rigidity to the box than rectangular cleats of the same cross-sectional area. Square cleats afford greater rigidity and greater resistance to splitting at the nails and to breaking by static loads than other shapes of rectangular cleats of the same cross-sectional area, but are less desirable where the cleats are placed outside of the box since the required length of sides and the displacement of the box are then increased.

Unless the cleats are defective, failure by breaking across the grain indicates that they are too thin or too small in cross-sectional area. Splitting of box ends or splitting of the cleats at the nails, provided the nailing is not at fault, indicates that the lumber is too thin.

Since box ends seldom fail by breaking across the grain, larger knots may be permitted in the ends than in the sides, tops, and bottoms. Provided they do not interfere with the nailing, knots, knot holes, or clusters of knots whose diameters, measured as illustrated in Plate 2, A, do not exceed one-half the width of the board in which they occur do not reduce the strength of the box. Only very small knots, however, should be permitted in the cleats.

**Size and Spacing of Nails**

Box parts may be of sufficient size to permit adequate nailing and to resist breaking across the grain, and yet failures at the joints may occur as the result of improper nailing. The nails may be of the wrong kind, size, or number, or they may be improperly spaced or carelessly driven.

If the nails are short and comparatively thick the weaving of the box and the bending of the box sides, top, and bottom will cause the nails to work back and forth to their full depth in the wood, thereby reducing the resistance to withdrawal, or the prying action will split the piece holding the nail points. On the other hand, if the nails are slender and are driven to a considerable depth the weaving of the box and the bending of the box parts in service will bend and break the nails between the parts that are joined. Splitting of the box ends and cleats at the nails may usually be overcome by using longer nails of smaller diameter. On the other hand, failures by the nails breaking between the parts united may be overcome by increasing the diameter and decreasing the length of the nails. Some bending of the nails is an advantage because it prevents them from working loose and absorbs some of the shocks that tend to cause the nails to shear out. Furthermore, resistance to shearing the nails out at the ends of sides, tops, and bottoms is increased slightly by the heads cutting into the wood. Shear failures may be overcome by increasing the number of the nails, which permits decreasing their size without causing other types of failures. If the nails pull out, either the number of nails or their length should be increased. If the heads pull through the wood, a larger number of nails or nails with larger heads in proportion to their length should be used. Figure 1 presents the results obtained in drum tests to show the relative amount of rough handling required to cause loss of contents in nailed boxes fastened with a different number of nails. A box with seven nails per nailing
edge is taken as the basis for comparison. Cement-coated nails (p. 49) normally offer greater resistance to withdrawal than barbed or uncoated smooth nails, but are of little advantage in preventing the nails from shearing out at the ends of the boards or the heads from pulling through.

Splitting of the sides, top, and bottom may occur in driving the nails if the nails are too large in diameter. Splitting of ends or cleats in nailing sides, tops, and bottoms to them may occur if the nails are too large in diameter or too long or if too many are placed in a row. Staggering of nails, as well as reducing their size and number, aids in overcoming such splitting.

"Side nailing," or nailing through the top and bottom into the edges of the sides, adds little to the strength of the box, since 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. (Pl. 2, B and C.) 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 are a danger to hands and clothing.

If the nails pierce two pieces and are clinched one-eighth to one-fourth inch at right angles to their shanks, fewer nails are required. The character of the shank of a clinched nail is relatively unimportant since the resistance to withdrawal depends upon the clinched end.

As previously indicated, the nailing required for a box varies with the thicknesses of the box sides, top, and bottom, and with the number of boards in each part. However, the maximum size of the nails that may be used satisfactorily is usually limited by the kind and thicknesses of the wood in the ends and in the cleats. If the sides, top, and bottom are of comparatively thin material, care should be taken not to overdrive the nails. Overdriving a nail (p. 51) crushes the wood fibers surrounding the nail and reduces the resistance to the nail head pulling through the wood and to the nail shank shearing out at the end of the piece.

Proper nailing is obtained when no one type of nail failure predominates and there is as much likelihood of one type of failure as of another.
Moisture Content of Lumber

Manufacturers and shippers often make boxes out of lumber that has not been properly seasoned. Although this lumber is termed "dry" it may contain 25 per cent or more moisture. The use of green or wet lumber of this kind is very poor practice because a box made of such lumber quickly loses most of its strength (3) and becomes decidedly inferior to one made of dry lumber. Shrinkage of the green lumber in drying loosens the nails so much that the weaving action during transportation often causes them to work out. Furthermore, the nails driven into the side grain of the box ends and cleats resist the shrinkage of the side, top, and bottom boards and cause the boards to split.

The weakening effect caused by the drying of the wood after the boxes have been nailed is indicated in Figures 2 and 3. It may be noted that boxes made of green lumber and subsequently dried in storage lose at least 75 per cent of their resistance to handling. Under such conditions the cement coating on the nails loses its effectiveness in preventing withdrawal. Barbed nails (p. 49) have greater holding power than either uncoated or cement-coated smooth nails after the wood into which they are driven has dried. It may be noted, however, that before the drying of the wood the barbed nails have less holding power than any of the other types.
The use of very dry lumber in boxes is objectionable because the driving of the nails breaks down the wood fibers more, and dry lumber splits more readily both in nailing and in service than lumber having a higher moisture content. A box made of lumber containing 12 to 18 per cent moisture will withstand ordinary storage conditions without a great loss in serviceability. However, even when boxes are to be made of lumber that has the proper moisture content, they should not be assembled with cement-coated nails until needed, since in time cement-coated nails lose part of their resistance to withdrawal even with no change in the moisture content of the wood into which they are driven (p. 52.)

Figure 3.—Effect of the drying of lumber after nailing, as shown by the resistance of boxes to rough handling. The boxes nailed at 15 per cent moisture and tested at once are taken as a base. The boxes were for 2 dozen No. 3 cans, nailed with seven cement-coated nails to each nailing edge. These results are the average of tests on boxes made from seven species of wood.

Number of Pieces

The number of pieces in the various parts of a box greatly 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 pieces united. 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. Wide stock also has the advantage over narrow stock in that larger knots may be permitted. 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 two or more boards in a box part may be overcome by securely joining the edges of the boards together. The Linderman joint (pl. 3, C) is the most satisfactory joint for boxes. It is most effective when tapered lengthwise, to produce a wedging action, and properly glued.

Great care is necessary to make a strong glue connection whether in plain butt, tongue-and-groove, or ship-lap joint. (Pl. 3.) The strength of a part built up in this manner depends entirely on the efficiency of the glued joint. Unless reinforced by other fastenings, glue in butt, tongue-and-groove, or ship-lap joints can not ordinarily be depended upon for strength since such joints are usually inaccurately fitted and poorly glued.

Corrugated metal fasteners (pl. 3, B) are also used for joining the edges of box parts. For best results corrugated fasteners should be driven alternately from the opposite faces of a box board. Common practice is to use corrugated fasteners in the ends of uncleated boxes: they are seldom used on the side, top, or bottom joints of a box, although they produce very good joints for this purpose. When glued joints are drawn together with corrugated fasteners immediately after spreading the glue the pieces are held together during the setting of the glue, and much stronger glued joints result.

All of the foregoing types of joints are less effective in material less than one-half inch in thickness than in thicker material.

ROTARY-CUT LUMBER AND PLYWOOD

One of the principal advantages of rotary-cut lumber and plywood for box construction is that these materials are produced in widths sufficiently great to permit almost any box part to be made of a single piece. Rotary-cut lumber for box construction is relatively thin, usually one-fourth inch or less in thickness, and has practically the same strength properties as sawed lumber of the same species of wood, grade, and thickness. Rotary-cut lumber is comparatively free from defects since it is usually produced only from relatively smooth logs. Consequently, the rotary-cut lumber used for boxes is usually of better quality than the sawed lumber. Like sawed lumber, its chief weakness is comparatively low resistance to splitting and to shearing along the grain. Plywood (p. 68) has a strength more nearly equal in all directions than rotary-cut or sawed lumber and has the additional advantage that it may be built up to any desired width or thickness. Plywood has much higher resistance to splitting, either at the nails or otherwise; to shearing out at the nails; and to puncturing, than has sawed lumber. It is extensively used for panel boxes, but is seldom used in the common styles of nailed wooden boxes, although it is well adapted for such boxes.

DIRECTION OF GRAIN

It is common practice in box construction to make the ends the small faces of the box and to place the boards of the end, sides, top, and bottom with their grain lengthwise of the face although in very large boxes the boards are sometimes placed with their grain running the short dimension of the box face. Boards placed with their grain running the short dimension of the box make a weaker box than
boards with their grain running lengthwise of the box. Such boxes require a greater number of boards, and since the boards are short they have less capacity to spring and thus relieve the direct pull of the contents on the nails.

**Styles of Boxes**

Style 1 (uncleated end) and style 6 (locked-corner and dovetail) (pt. 1) are neat and attractive constructions, but are suitable only for small boxes carrying relatively light loads, usually not over 60 to 100 pounds. The size of box and the weight of contents for which these styles may be used depends on whether the box has 1-piece sides and on whether the commodity is able to support the box against its characteristic weakness, which is its tendency to split entirely around parallel to the top and bottom. Such splitting is likely to occur if the box drops on its corners or edges or if its sides or ends are subjected to a puncturing action. When a box having joints in the sides drops on any of its corners or edges, the upper section of the box has a tendency to slide past the lower section. If this action is not prevented by the commodity itself it is resisted only by the strength of the box end in bending across the grain. The most effective method of strengthening an uncleated box (style 1 or 6) against such failures is the use of 1-piece sides.

The low holding power of the nails driven into the end grain of the box ends in comparison with that of nails driven into the side grain is also a source of weakness in the style 1 box.

The locked-corner and dovetail (style 6) construction in which the ends and sides of the box are joined by a series of glued tenons is more rigid than the nailed construction. In style 6 boxes failures occur not only through the ends and sides splitting but also through the tenons breaking or pulling apart. Because of the relatively thin ends and the small nails used, failures sometimes occur through the top and bottom pulling off. Locked-corner and dovetail boxes are usually most efficient when the sides are of single-piece stock and the ends of a slightly greater thickness than the sides. Style 6 boxes usually require for the same service somewhat thicker sides and thinner ends than the nailed boxes of style 1. The thicker sides are required so as to avoid pulling the tenons apart by springing of the sides.

Each end of boxes of styles 4 and 5 is reinforced with two cleats. The chief purposes of the cleats are to permit the use of two or more pieces in the ends, to prevent splitting of the box, and to make better nailing possible. Some of the nails are usually driven through the sides into the cleats and some into the ends, thus increasing the nail-holding power and adding rigidity to the box. Such nailing also reduces the likelihood of the nails shearing the wood out at the ends of the boards or of splitting the wood holding their points.

When the character of the contents permits, placing the cleats inside the box decreases the length of the sides. If in such construction the nails are driven through the sides and cleats and are clinched, the resistance to the sides pulling off is greatly increased.

Inside cleats should be shorter than the depth of the box, so that in the event that the box sides and ends shrink the cleats will not protrude and thus cause an opening of the box top and bottom. Outside cleats, however, should be long enough to come nearly
Different kinds of edge joints and fasteners: A, Use of corrugated fasteners; B, four types of corrugated fasteners; C, Linderman joint; D, coil of corrugated fastening material; E, tongue-and-groove joint; F, ship-lap joint.
A and B, Typical failure of the ends of styles 4 and 5 nailed boxes by splitting at the nails; C, failure of style 2 box by splitting of end at edge of cleat; D, 3-way corner or so-called hardware type of box; E, box reinforced with wooden battens.
Different kinds of edge joints and fasteners: A, Use of corrugated fasteners; B, four types of corrugated fasteners; C, Linderman joint; D, coil of corrugated fastening material; E, tongue-and-groove joint; F, ship-lap joint
A and B, Typical failure of the ends of styles 4 and 5 nailed boxes by splitting at the nails; C, failure of style 2 box by splitting of end at edge of cleat; D, 3-way corner or so-called hardware type of box; E, box reinforced with wooden battens
A, Standard boxes for fruits and vegetables; B, style 2 box with nailed metal straps; C, style 2 box with nailless metal straps; D, style 5 box bound with wires
A, Nailed box reinforced with nailed straps placed away from the ends; B, a long box with battens and nailed metal straps. Such double reinforcing is desirable when straps alone will not give sufficient resistance to bending of sides, top, and bottom.
Boxes made of lumber having 30 per cent or more moisture. These boxes were dried to 10 per cent moisture content, which resulted in the loose condition of the strapping.

Boxes A and C were made from 3/4-inch and 1/4-inch stock. Box B was made from 3/4-inch and 1/4-inch stock.
Standard styles of plywood boxes: A, Cleated plywood boxes; B, plywood box having parallel slats on one face; C, open-face box reinforced with diagonal brace
flush with the outer surface of the box top and bottom. They will thus increase the rigidity of the box top and bottom and assist in preventing the nails through the top and bottom from splitting the box ends. (Pl. 4, A and B.)

The two horizontal cleats on the ends of a style 2, 2½, or 3 box allow the nails holding the box top and bottom to be staggered in the box ends and cleats, thus increasing the rigidity of the top and bottom box faces 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, the likelihood of splitting the box ends by the nails in the box top and bottom is reduced. Since in boxes having horizontal cleats some of the nails driven into the box ends are spaced farther from the ends of the top and bottom boards, the likelihood of the nails shearing out at the ends of the top and bottom boards is reduced. The ends of the boxes of styles 2, 2½, 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. (Pl. 4, C.) 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. The styles 2 and 2½ boxes offer greater resistance to the foregoing type of failure than the style 3 box does, since more of the nails attaching the vertical cleats to the ends of the box may be placed close to the ends of these cleats. The style 2½ box has the 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.

Inasmuch as one of the chief functions of ends and cleats is to provide a means for adequately fastening the box parts together, it is desirable where maximum box strength is required to have the ends and cleats each of sufficient thickness to receive the nails. In order to save material, however, the ends of boxes of styles 2 and 2½ are sometimes made of relatively thin material 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 carrying relatively light loads.

The hardware type or 3-way corner box (Pl. 4, D) is very rigid. In this style of box the boards in all the faces are of the same thickness, and the edges of each face receive the nails holding the ends of the adjacent faces. Consequently it is necessary that the material be thick enough to prevent its being split by the nails. In service the hardware type box often strikes an object in such a manner that the entire weight of the commodity is transmitted to the nails as a direct pull, thereby loosening them. It is very difficult to nail boxes of this type so that the boards will not be knocked off in ordinary handling. The name "hardware type" appears to be a misnomer, since tests
and experience indicate that such a box is not well suited for the shipment of hardware or other heavy commodities. A further objection to the hardware type is that, in closing it, the nails must be driven into four edges and from three directions.

**Reinforcements**

A number of different kinds of reinforcements have been devised to secure lighter and cheaper boxes and to strengthen containers against pilfering and against exceptional hazards.

Wooden battens around the box are among the oldest forms of reinforcement and are still used to some extent on export packages. (Pl. 4, E.) They may be placed on the inner or the outer surface of the box, at the extreme ends, or at some distance from the ends. They are objectionable for export boxes when placed outside because they increase the displacement, are likely to be knocked off, and often interfere with stacking. Where wooden battens are placed some distance away from the box ends and on the outer surface of the box, the battens should always be fastened with clinched nails. When securely fastened to the sides, top, or bottom, battens assist in preventing shear at the joints between the boards in these parts and thus increase the rigidity of the box. They also increase the resistance to puncture and render pilfering of the box contents more difficult. Securely nailed metal strips often connect the ends of the battens on adjoining faces of the box, thus forming a continuous binding which aids in absorbing shocks.

Thin cleats (pl. 5, A) are usually stapled to the ends of thin sides, tops, and bottoms of boxes used for the shipment of fruits and vegetables. These thin cleats are effective in preventing the thin lumber from splitting at the nails which fasten it to the box ends, from breaking under the nail heads, and from pulling away from the nails.

Metal straps and wires are the most common reinforcements for nailed boxes. They are lighter than wooden battens, do not appreciably increase the displacement, and interfere less with sliding and stacking. Usually where metal bindings are placed around the extreme ends of the box they are nailed. (Pl. 5, B.) 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 (pl. 5, C) or are spot welded. Overlapping ends of wire are usually twisted together to form a seal. (Pl. 5, D.)

Metal straps or twisted wire of two or more strands properly nailed around the box at the extreme ends, retard the pulling out of the nails from the box ends; assist in preventing the nail heads from pulling through the sides, top, and bottom; and aid in preventing the nails from shearing out of the ends of side, top, and bottom boards. The additional nailing required by metal binding increases the rigidity of the box. However, full advantage of nailed strapping is obtained only when the strapping is fastened with nails of the same size as those used in making 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 absorb part of the shocks which 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 pull 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 also allow the use of lower grade side, top, and bottom material than straps placed at the ends. Straps placed thus, however, are not so effective in preventing diagonal distortion as those nailed at the end of the box and are therefore 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 (pl. 6, A) 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. (Pl. 6, B.) The nails at the box edges do not add sufficient strength to compensate for the weakening of the straps caused by the holes. Staples spanning the straps on large boxes are of value in holding the straps close to the box and preventing them from catching on objects.

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 of uncleated boxes add little strength to the 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 a 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 immediately 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. (Pl. 7.)

Both metal bindings and wooden battens are effective means of reducing the weight of the box without sacrificing serviceability. Experience shows that the sides, top, and bottom of a nailed wooden box that is properly bound with metal bindings may safely be made 20 to 40 per cent thinner than those of boxes without such bindings. 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 use of strapping on a box normally does not justify any reduction in the thickness of the box ends.

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 required for the box carrying heavy loads should be larger, the size of the straps required is not 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. Rules for the selection and application of strapping are given in Appendix E.
CLEATED PLYWOOD BOXES

A cleated plywood box consists of single-piece plywood sides, top, bottom, and ends nailed to cleats. Figure 4 and Plate 8, A illustrate styles of cleated plywood boxes that have been adopted as standard by the Plywood Box Manufacturers’ Association of America. The chief characteristics of cleated plywood boxes are: Light weight, high resistance to diagonal distortion, resistance to mashing at the corners, and capacity to withstand severe tumbling and dropping. Cleated plywood boxes are neat in appearance, easy to handle, almost dust-proof, and are difficult to pilfer. The thin plywood springs easily and thus absorbs many of the shocks which would otherwise cause damage to the contents. Styles A, B, and D are those most commonly used. Styles A and B have four cleats on each face of the box and are often called full-cleated panel boxes. Styles B, D, E, and G have 3-way-corner construction.
DETAILS OF CONSTRUCTION

The high strength and rigidity of cleated plywood boxes result from the use of single-piece stock in the ends, sides, top, and bottom, and from the high resistance of plywood to splitting and to shearing or tearing away from the fastenings.

If the plywood on any face is replaced by slats of lumber placed parallel with an edge (pl. 8, B), the high resistance of the box to diagonal distortion and twisting is destroyed. If the commodity is fastened to these slats near the four corners of the box face (pl. 8, B, a) and the box is dropped on a corner, the stresses tending to cause diagonal distortion are resisted by the commodity, and damage to it is likely to result unless the commodity is able to resist diagonal distortion stresses. If the open face is reinforced with a well-nailed diagonal brace as shown in Plate 8, C, the box has almost as much resistance to diagonal distortion as a box having all faces covered with plywood. If any one of the open faces is not braced by the commodity or otherwise the diagonal distortion that takes place in this unbraced face when the box drops on a corner will cause each of the faces to warp and the box to twist in a manner similar to the crate in Plate 20, A. A discussion of the influence of the commodity in preventing diagonal distortion and twisting of crates, given on page 35, applies also to plywood boxes.

NAILING

The nailing is one of the most important factors in the strength and rigidity of cleated plywood boxes. Much of the previous discussion of nailing on page 11 applies to cleated plywood boxes.

In making up the ends, sides, top, and bottom of most styles of cleated plywood boxes the plywood is attached to the wide faces of the cleats with nails or staples and in assembling the box the six panels so formed are nailed together. If too few fastenings are used in attaching the plywood to the cleats, the weaving of the box in service or the pressure of the contents or external objects on the plywood will either break the fastenings, pull them out, pull them through the plywood, or the plywood will split and shear away from them. If the nails or staples pass through the cleat and are clinched, they are not likely to pull out. Staples or large-headed nails are more difficult to pull through the plywood or to shear out than nails with small heads. Overdriving the staples or nails injures the plywood and reduces the strength of the joint.

If the nails holding the six panels together to form the completed box are of the wrong kind, number, or size, the box is weakened at the joints. The nails through the cleats and the plywood must be long enough to penetrate deep into the cleats on the adjacent box face; otherwise a greater number of nails will be necessary to prevent nail pull. Splitting of the cleats may be avoided by using nails as small in diameter as will permit driving.

Where nails are driven only through the plywood into the cleats on the adjacent face of the box, as in style D, the number of nails and the size of the nailhead are the important considerations in preventing the plywood from pulling away from the cleats. In such joints large-headed cement-coated roofing nails give good results. The loosening or pulling out of such nails may be overcome by using longer nails or...
a greater number of nails. Bending and breaking of the plywood at the nail line (pl. 9, A) may be decreased by increasing the number of nails. Failures because of the nailheads pulling through the plywood, or splitting or shearing the plywood out are also reduced by increasing the number of nails.

**SIZE OF CLEATS**

The primary functions of the cleats are to provide a means for securely fastening the box faces together and to reinforce the corners against mashing. Intermediate cleats are sometimes used, as in styles F and G, to reinforce the plywood against bending. The required sizes of the cleats along the edges of the box will vary with the nailing necessary to hold the box parts together. Such cleats should be free from defects that affect their nail-holding power or increase the tendency of the wood to split at the nails. Larger cleats are required where a single cleat is used along the edge of the box, as in style D, than where two cleats are used along each edge, as in styles A and B.

**THICKNESS OF PLYWOOD**

The thickness of plywood required will vary with the style of the box. The plywood in boxes with a single cleat along the edge bends under the impacts of the commodity and breaks at the nails fastening it to the cleats on the adjoining box side (pl. 9, A), whereas the plywood in a full-cleated box bends and breaks either along the inner edges of the cleats that are parallel to the face plies or at some distance from these edges. (Pl. 9, B.) The failures in plywood of a single-cleated box are localized around the nails, whereas in a double-cleated box the failures in the plywood are continuous along the edge of the cleat. Consequently a single-cleated box requires thicker plywood than a double-cleated one.

**DIRECTION OF PLYWOOD**

The best results in boxes having plywood consisting of three plies of the same thickness are obtained where the grain of the face plies for each box face is in the direction of the shortest dimension of that box face. This arrangement of the plies gives the plywood its greatest bending strength. In some boxes the bending of the plywood is an advantage because in bending the plywood absorbs shocks that would otherwise be transmitted to the box contents, but in other boxes the bending of the plywood is a disadvantage since it allows the contents to shift and to be damaged by rubbing. Plywood box sides having the grain of the face plies parallel with the width of the box face bend less under the impacts of the contents than if the grain is lengthwise of the face. The resistance of plywood to puncturing, shearing, splitting, and failure at the nails may be varied by changing the construction of the plywood (p. 68).

**WIRE-BOUND BOXES**

The wire-bound box is a lightweight type of shipping container that utilizes rotary-cut lumber, sliced lumber, or thin-sawed lumber in combination with cleats, wires, and staples. Unlike the sides of nailed boxes, the sides of wire-bound boxes are always of the same thicknesses as the box top and bottom, and usually the ends are of the same thickness as the sides. The thin material in the ends,
sides, top, and bottom, springs and thus absorbs the shocks that would otherwise be transmitted to the commodity. The springing action enables the wire-bound box to withstand severe handling. The wires and staples hold the parts together and make pilfering of the box contents difficult.

In making wire-bound boxes two or more binding wires spaced at a determined distance are stapled by special machines to the side, bottom, side, and top box parts, consecutively, to form a mat. The end staples on each part span the binding wires and pass through the sheet material and, usually, into the end cleats. The staples over the intermediate binding wires are clinched on the inner surface of the sheet material. A box in mat form as delivered to the shipper ready to be assembled with the end panels is shown in Plate 10, A. In assembling the box the mat is simply folded into position and the ends nailed or stapled to the inner surfaces of the side and bottom cleats. Closing the box consists of twisting together the ends of the binding wires. The box is easily opened by clipping the wires near the twist. The shape of the box may be readily varied to fit the contents. (Pl. 10, C.)

DETAILS OF CONSTRUCTION

The efficiency of a wire-bound box depends upon the combination of thicknesses of ends, sides, top, and bottom; number, size, and position of binding wires and staples; and end reinforcements. Failures in wire-bound boxes usually occur at or near the joints between the end cleats and the sides, top, and bottom, although occasionally failures are caused by the binding wires breaking, or the sides, top, and bottom puncturing or breaking between wires. The type of failure will determine which details of construction need to be changed to overcome the weakness.

STAPLING

The stapling of end binding wires is one of the most important features with respect to the strength of the box. If the staples are of the wrong number or size, or improperly positioned, they may pull out, shear out at the ends of the boards, or split the cleats; or the sides, top, and bottom may break under the staples. Over-driving of staples causes the binding wires to mash the wood, thereby reducing the resistance of the sides, top, and bottom to breaking across the grain at the staples and under the wires. Pulling out of staples from the cleats may be reduced by increasing the number of staples, by increasing their length, or by changing the position of the intermediate binding wires. Shearing out of the staples at the ends of the boards may be overcome by increasing the number of staples or the thickness of the sides, top, and bottom.

Splitting of the cleats at the staples is usually caused by the side pull on the staples of the wire and the sheet material. This failure is usually local and can sometimes be overcome by using more staples, thereby avoiding the localizing of the disturbing forces. In boxes carrying very heavy loads this type of failure may indicate that additional end reinforcements are needed.

The holding power of staples varies with the species of wood in the cleats and the moisture content of the wood, and with changes in moisture content after the staples are driven. (See p. 55.)
Proper positioning of staples over the end wires is important in order to prevent driving the staples into the joints since such driving causes splitting of the cleats or interference with the folding of the box. Since the staples over intermediate binding wires are clinched they are seldom a source of weakness, although they must be of proper length to provide a good clinch.

**Thickness of Sides, Top, and Bottom**

The thickness of sheet material required for a wire-bound box depends upon the species of wood, the spacing of the intermediate binding wires, the weight and nature of the contents, and the width of the box faces. If the material is too thin failures occur through the box mashing at the corners, through the sides, top, and bottom breaking across the grain at, or near, the end wires, or through the staples astride the end wires shearing out at the ends of the thin boards. In wire-bound boxes with wide faces the shocks of the contents, incident to rough handling, are distributed over a greater surface for the same gross weight, and consequently thinner sheet material may be used than in boxes with narrow faces. The wide faces also allow more stapling, so that failures caused by the staples pulling or shearing out at the box ends are less likely to occur.

The thickness of material required to prevent mashing at the box corners is determined largely by the weight of the contents, although the size of the box influences the stresses indirectly through its effect on the method of handling. The relation of the thickness of the box material to the species of wood, to the size of the box, and to the weight of its contents may be approximated by the equations given in Appendix E.

Damage to the commodity from the springing of the box sides, top, and bottom may be avoided by increasing the thickness of the material, by increasing the number of wires or changing their position, or by using intermediate rows of cleats, as shown in Plate 11, A. Such cleats also afford reinforcement against puncture. Intermediate rows of cleats are sometimes useful in preventing damage by serving as separators between units of the commodity. These cleats when serving as separators often permit decreasing the thickness of the box parts.

**Size and Spacing of Wires**

The size and the spacing of the wires are important in determining the thicknesses required for the sides, top, and bottom, and in holding these parts together. The intermediate wires reinforce the sides, top, and bottom against breaking across the grain and also against springing, thereby retarding the loosening, pulling out, and shearing out of the staples. If, however, too many intermediate wires are used the shocks in handling are not absorbed by the springing of box sides, top, and bottom. Greater stresses, therefore, are transmitted to the joints, and failures are more likely to occur through the knocking out of the ends or through the mashing of the box at the corners. The number of wires required for a satisfactory box depends upon the thickness of the sheet material, which, in turn, is determined by the size of the box, weight, and nature of its contents. The size of wires required varies with the number used, but the sum of their total cross-sectional area depends upon the weight of the box contents. The relation of the number and size of wires to the thickness of the
A, Characteristic failure of single cleated plywood box; B, characteristic failures of cleated plywood boxes.
A, Wire-bound box as delivered from fabricating machine ready to be assembled; B, standard tools for twisting the ends of wires in closing wire-bound boxes and crates; C, wire-bound boxes of various shapes
A, wire-bound box having intermediate rows of cleats; B, wire-bound box showing wires joined by "loop ties"; C, liners used to reinforce end boards; D, cleat joints commonly used in wire-bound boxes; (a) mortise and tenon; (b) plain miter; (c) step miter
A, Wire-bound box reinforced with metal strap lengthwise of box; B, wire-bound box made of low-grade resawed lumber
Wire-bound boxes with the grain of the sheet material in different directions: A, The grain of the boards in the sides, top, and bottom and end runs in the direction of the longest dimension; B, the grain of the boards in the sides, top, and bottom runs in the direction of the shortest dimension; C, the grain of the boards in the sides, top, bottom, and ends runs in the direction of the shortest dimension.
One-piece slotted fiber boxes: Corrugated fiber box A and solid fiber box B, folded flat and set up; C, double thickness corrugated fiber box.
material may be approximated by the equations and curves given in Appendix E.

Usually the end wires and the adjacent intermediate wires need to be spaced closer than the other wires. When placed near the box ends the adjacent wires are better able to absorb the shocks of the contents which tend to bend the thin boards in the sides, top, and bottom and to pull them away from the staples, or to break the sides, top, and bottom under the end-binding wires. Furthermore, the wires near the box ends are in a better position to relieve the direct pull of the contents on the staples astride the end wires. The exact positioning of the wires is dependent upon the nature of the box contents. The wires may sometimes need to be so spaced that when they are drawn tightly in closing the box they spring the box sides, top, and bottom against the commodity in such a way as to retard its shifting and thereby reduce the outward thrust on the box ends. Again, where the weight of the box contents is concentrated at points on the box faces instead of being uniformly distributed over these faces, the intermediate wires may need to be spaced in direct line with the points of contact so as to better reinforce the thin box sides, top, and bottom against springing and breaking across the grain.

Closing the Wire-Bound Box

Failures due to the wires pulling apart at the closure are usually the result of improper twisting. The best closures are obtained by using special tools which have been developed for twisting the wires. (Pl. 10, B.) The wire should be soft enough not to break when the ends are twisted together, and, as a precaution against pilfering, hard enough so that it can not be untwisted and re-twisted without breaking. After the twist is made it is bent down alongside the wire, as shown in Figure 5. This box may be readily opened for inspection and easily reclosed. The box is opened by clipping the wires either near the twisted ends or along the opposite top edge of the box. The top is then lifted like the lid of a trunk. The box is reclosed by splicing the wires with short pieces and twisting the ends together as in making the original closure. Figure 6 illustrates a convenient patented device for splicing the wire. The end of the wire on top of the box is inserted into the coiled end of the splicing wire and then bent to form a hook which fits into the other half of the coil and completes the splice. Plate 11, B illustrates a type of wire-bound box having the wires joined together when assembling the box by means of "loop ties" at their ends.

Ends, Cleats, Battens, and Liners

The end sheets of wire-bound boxes are usually of the same species and thickness of material as the sides, top, and bottom, although
thick ends are sometimes used in boxes carrying heavy loads. In order to facilitate the production of wire-bound boxes by special machines and to reduce the costs the dimensions of cleats have been standardized. Until recently one size for cleats, approximately $\frac{1}{8}$-inch by $\frac{3}{16}$-inch material, was commonly used for boxes of all sizes in combination with seven thicknesses of sheet material, four sizes of wires, and four sizes of staples. In 1928 improvements were made so that the machine for fabricating wire-bound boxes could be set up to use several sizes of cleats within the range of nine-sixteenths to $1\frac{1}{8}$ inches in thickness, and several lighter (one-sixteenth and one-twelfth inch) thicknesses of sheet material and sizes of wires and staples. The ends of the cleats are usually put together in a mortise-and-tenon joint, such as is shown in Plate 11, D, a, although the plain miter (pl. 11, D, b) and step miter (pl. 11, D, c) are sometimes used. Mitered joints permit driving the staples close to the corner of the box, thereby reducing the tendency for the wire to slip off at the corner.

Figure 7 illustrates various arrangements of battens for end reinforcements that have been adopted by the Wirebound Box Manufacturers’ Association. Styles A, C, D, F, T, and X are most commonly used. The A battens reinforce the top and bottom cleats against

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* Sizes of other parts commonly used are: Thickness of sheet material: One-eighth, one-sixth, three-sixteenths, seven thirty-seCONDS, one-fourth, five-sixteenths, and three-eighths inches. Binding wires: 12, 13, 14, and 15 gage (steel wire gage). Staples: Over end wires, 16 gage (steel wire gage) by $\frac{1}{8}$ inches and $\frac{1}{16}$ inches; over intermediate wires, 18 gage (steel wire gage) by $\frac{7}{16}$-inch and $\frac{3}{16}$-inch.
breakage. If nails are driven through the top and bottom cleats into the batten the end sheets are strengthened against breakage across the grain. The D battens reinforce the side cleats against breakage and permit long nails to be driven through the mat to reinforce the staples.

Battens sometimes have a tongue on the edge and on the ends to fit into grooves provided in the edges of the cleats.

The end boards are sometimes reinforced on the inner side and near their ends with thin strips of lumber called liners, through which the nails or staples are driven in attaching the box ends to the cleats. (Pl. 11, C.) These liners assist in preventing the end boards from splitting and the fastenings from pulling through the thin end boards or shearing out at the ends of these boards.

![Figure 7.—Arrangements of end battens for wire-bound boxes](image)

**STRAP REINFORCEMENTS**

Metal straps or wires placed around the box lengthwise (pl. 12, A) afford effective reinforcement of the ends and cleats. Straps applied in this manner prevent the ends from being kicked out, assist in preventing the pulling out of staples, and reinforce the ends and cleats against breakage across the grain. Straps may be applied lengthwise around boxes either with or without battened ends.

**NUMBER OF PIECES OF BOX PARTS**

The number of pieces in the sides, top, and bottom is the principal factor in the resistance of a wire-bound box to diagonal distortion. Since wire-bound boxes with a number of narrow pieces in the sides, top, and bottom distort easily they absorb the shocks of transportation and are consequently better adapted than boxes with wide pieces for shipping articles which are not damaged by shifting or rubbing.
Direction of Grain

Wire-bound boxes are usually made so that the grain of the boards in the sides, top, and bottom runs in the direction of the longest dimension of the box (pl. 13, A) although in large export boxes the grain of the boards is sometimes run parallel to the shortest dimension. (Pl. 13, B, and C.) Where the grain of the boards parallel one of the shorter dimensions the ends, cleats, and binding wires are longer and the sides, top, and bottom are wider than where it parallels the longest dimension. Placing the boards with the grain in the direction of one of the shorter dimensions increases the ability of the box to withstand outside pressure, such as from rope slings or from stacking, but reduces its resistance to the impacts by its contents. The cleats, being longer, are more easily broken, and consequently better end reinforcements are required.

Because of its many wire reinforcements the wire-bound box is well adapted to the use of low-grade sawed lumber either from hardwoods or softwoods. Plate 12, B illustrates a wire-bound box made with knotty resawed lumber in the ends, sides, top, and bottom and with clear hardwood cleats and battens.

Corrugated and Solid Fiber Boxes

Two types of fiber board, corrugated and solid, are in common use for making boxes. The single-thickness corrugated type consists of a sheet of paper board that after being corrugated, is pasted with silicate of soda (a mineral glue) between two outer flat sheets of paper board termed "test liners". Double-thickness corrugated-fiber board is a silicate-pasted assembly of three sheets of paper board and two sheets of corrugated board. Solid fiber board is formed by pasting one or more sheets of chip board between two test liners.

Corrugated fiber sheets are usually made from straw pulp or from pine or chestnut wood pulp. The outer plies or test liners of both corrugated and solid fiber boards contain comparatively long-fibered wood pulp, either new or repulped, and a variable proportion of shorter-fibered pulp obtained from the cheaper grades of waste paper. The inner plies of solid fiber board consist of chip board prepared from waste papers of the lowest grade. The strength of either type of fiber board can readily be adjusted within limits to different requirements through varying the thickness, number, and quality of the component plies.

In the manufacture of a box the corrugated or solid fiber board is slotted and is creased, or scored, to facilitate bending. Plate 14, A and B, shows a 1-piece slotted carton of each type folded flat for shipment and set up ready to receive its contents. The one vertical joint in a corrugated fiber box is made at the factory with gummed tape (generally cambric, but occasionally paper) and that in a solid fiber box with flat stitching wire.

Fiber boxes have certain characteristics that make them especially suitable for use in shipping a large variety of products. They are light in weight, easy to handle, neat and attractive, and almost dust proof. As received from the manufacturer in the knock-down condition they require small storage space and are easy to assemble. The corrugated is better adapted than the solid type for the shipment of glassware and other light and fragile articles because the corrugated
board absorbs shocks better than the solid. Boxes made of double-thickness corrugated boards (pl. 14, C) have greater shock-absorbing qualities than boxes made of single-thickness corrugated board. The solid fiber type, however, has greater resistance to rough handling and to wear as a result of sliding and is, therefore, better adapted for use in shipping heavier and less fragile articles. Fiber boxes are made in various styles, as shown in Figures 8 and 9. The 1-piece slotted carton, styles 1 and A, is in more general use than any of the other styles.
The strength of a corrugated or a solid fiber box when properly closed depends very largely on the quality of the fiber board and the moisture condition of the board at the time of scoring and the manner in which the board is scored. If the dies used to form the scores are of the wrong size or form and make the scores too deep or too shallow, or if the bends are too abrupt, the strength and serviceability of the box is greatly impaired. Any slight cracking or breaking along the scores when the box is folded into position indicates that the scoring has not been done properly, that the board did not have the proper moisture content at time of scoring, or that the test liner is of poor quality and the box will not have the maximum capacity to withstand rough handling. No matter how strong the fiber board may be nor how well it has been scored, failures in boxes that are properly closed usually occur at the longer scores of the smallest face (usually the horizontal end scores).
BOX AND CRATE CONSTRUCTION

DIRECTION OF GRAIN OF FIBER BOARD

A sheet of paper board has a definite direction of grain much like that of a piece of wood. This direction is determined by the position of the fibers, most of which arrange themselves parallel with the direction in which the sheet passes through the machine in the process of making the paper board. In the formation of paper board, either solid or corrugated, the component sheets are usually pasted with their grains parallel. As a consequence, fiber sheets and fiber boards are stronger in tension parallel with the grain than across it, and have greater resistance to tearing across the grain than parallel to it. Boxes made with the grain of the board perpendicular to the longer scores of the smallest face usually resist a greater amount of rough handling than those made with the grain of the board parallel to these scores. Solid fiber boxes made with the grain of the board perpendicular to the horizontal scores also resist greater stacking loads when stacked in the normal position than those made with the grain parallel to these scores. Because of the stiffening effect the corrugated-fiber boxes, however, resist greater stacking loads when the corrugations are perpendicular to the horizontal scores, although the grain of all the component sheets may be parallel to the horizontal scores.

SEALING OR CLOSING THE BOX

The proper sealing of a fiber box is as important as the design and construction of the box itself. Three methods of sealing the 1-piece slotted carton are in common use, (1) pasting the flaps together (usually with silicate of soda), (2) covering all outer seams with gummed paper tape, and (3) stitching the flaps together along all seams with metal staples. (Pl. 15.) The method of sealing is of little significance as regards the strength and serviceability of the box. The principal consideration is that the sealing must be done in a thorough manner.

When the sealing consists of pasting the flaps together, the properties of the adhesive should be such that it can be spread evenly over the entire surface of the flaps and permit the flaps to be brought together before it takes its initial set and can dry quickly thereafter. Unless pressure is applied to hold the flaps in contact while the adhesive sets, proper sealing will not obtain. Special machines are sometimes used for applying pressure in sealing with adhesives. The use of an excessive amount of adhesive prolongs the drying and the time the flaps must be kept under pressure.

Sealing tape (strips not less than 2 inches wide) applied at the seam of the outer flaps only, does not produce so good a seal as pasting the flaps together. Boxes with sealing tape applied at the seam of the outer flaps and also along the horizontal end scores, however, withstand more rough handling than boxes sealed only by pasting the flaps together. The lower rigidity of the seal reduces the stress on the scores, and the tape reinforces the scores. The tape-sealed boxes do not hold their shape so well as the boxes sealed with silicate of soda. Sealing tape is sometimes applied near the center of the box and at right angles to the seam of the outer flaps but is less effective in reinforcing the box than tape applied lengthwise of the seam.

Metal staples produce fully as good a seal for solid fiber boxes as either silicate of soda or sealing tape, provided all outer flaps are
stapled to inner flaps at or along all joints in the outer flaps and the staples are spaced not more than $2\frac{1}{2}$ inches apart. Corrugated boxes require staples of larger or wider wire than solid fiber boxes to prevent the staples from pulling through.

No matter what method of sealing is employed, failure at the seal rather than at the scored edges indicates that the sealing has not been properly done.

**Length of Flaps**

To obtain the maximum resistance to rough handling for a given quality of material, the ends of the outer flaps of fiber boxes should meet or overlap and the ends of the inner flaps should meet or the space between their ends should be filled with a sheet of fiber board which should be fastened securely to the outer flaps in sealing the box.

**Reinforcements**

Paper tape applied on the outside of the box and along the scores (pl. 16, A) reinforces the characteristically weak points of a fiber box and greatly increases the resistance of the box to rough handling. Taping scores on the inside is usually of less value as a reinforcement than tape applied on the outside. The resistance of the box to loss of contents through failure of the scored edges may be further increased by binding the boxes with metal straps (pl. 16, B) applied under tension. Damage to the contents through the box mashing at the corners or through the puncturing of the ends and sides may be readily reduced by corner or other interior pads or cushions that support and protect the commodity. (Pl. 16, C.)

**Recommended Practice**

The recommended designs of fiber containers for various uses are given in the specification set forth in Appendix G.

**Nailed Crates**

The two principal styles of nailed crates suitable for general use are the 3-way corner, and the box style. Both are shown in Plate 17, A and B. The outstanding characteristics of these constructions are great resistance to crushing and mashing at the corners and, where properly braced, high rigidity and high resistance to rough handling. They are easy to handle, easy to manufacture, and their strength and rigidity may be readily adjusted to different requirements by varying the details of construction.

**Details of Construction**

**Edge Members**

The edge members form the foundation upon which the rest of the crate is built. They must be of sufficient size and strength to permit adequate fastening of the various parts and to support the loads and shocks encountered in storage or transit. Edge members that are approximately square produce stronger crates than thin members of the same cross-sectional area. Square members allow the use of large nails and also permit the nails to be staggered, which reduces the chance of failure in service by splitting. Square members, however, increase the displacement of the crate and afford less protection.
Methods of sealing 1-piece slotted fiber boxes: A, Outer flaps glued to inner flaps; B, sealing tape applied on joint of outer flaps and along horizontal end scores; C and D, flaps stitched together with metal staples; E, sealing tape along joint of outer flaps only
Methods of reinforcing fiber boxes: A, Tape applied along edges; B, sealed metal strapping applied in two directions; C, interior pads to protect the commodity
Principal styles of nailed crates are A, the 3-way corner crate and B, the box-style crate; C, a recommended method of packing a cotton gin.
A, Box-type crate reinforced with metal straps; B, method of reinforcing 3-way corner crate with metal straps
Three-way corner crates: A, Without braces; B, with six braced faces; C, with two braced faces; D, with four braced faces
Pl. 20

A. Crate with five braced faces, showing girted twist when subjected to diagonally acting load. B. Crate with braces nailed to wide faces of edge members.
from external hazards than wide members of the same cross-sectional area; therefore more sheathing is required.

**Skids**

The lower horizontal frame members placed lengthwise of a crate usually form the skids, which support the contents, either directly or indirectly, through intervening members. Crates carrying heavy commodities are often provided with special skids to facilitate their movement and to reinforce the bottom edge members. Skids, when supported by rollers, dollies, or slings, are sometimes subjected to severe bending stresses, in which event their strength becomes an important consideration. Skids are usually beveled at their ends to facilitate sliding or their passage on to rollers.

**Sheathing**

The purpose of sheathing is to protect the contents from the elements and from injury by external objects, and to reduce the pilfering or loss of small parts from the contents. Securely nailed sheathing also strengthens a crate, especially if placed diagonally. Sheathing that is placed parallel to the edge members adds rigidity to the crate as long as the joints between the boards remain tight, but the shrinkage that ordinarily occurs in the boards causes the joints to open and the sheathing to become quite ineffective as bracing. Sheathing also makes possible the use of frame constructions that otherwise would be practically useless. For example, a crate such as is shown in Plate 17, C is commonly used and gives good results only because the frame members are fastened together by the sheathing.

The sheathing may be outside the frame members and bracing or it may be inside these members. A poorer grade of material can be used for sheathing than for other crate parts. Matched lumber is usually preferred for sheathing because it makes a tighter covering.

**Defects**

Knots and other defects in the edge members and braces very seriously reduce the strength of the crate, but in the sheathing, knots or knot holes having a diameter not greater than one-third the width of the piece in which they occur do not seriously reduce the serviceability of the crate except that knot holes reduce the tightness and the protection of the contents against the weather.

**Moisture Content**

Any decrease in the moisture content of the crate material after the crate has been built may cause loosening of the fastenings and joints, checking of the members, loosening of the internal blocking, and lessening of the effectiveness of the sheathing in preventing skewing and weaving. Crates made of lumber containing 12 to 18 per cent moisture will withstand ordinary storage conditions without any great loss in strength resulting from the shrinkage of the lumber.

**Crane Corner**

The corners are usually the weakest parts of any crate. An example of poor corner construction is shown in Figure 10, A.
holding one member are driven into end grain and therefore have comparatively low holding power. Another example of the same fault is shown in Figure 10, B. This construction may be greatly improved by lengthening the member to permit nailing into the side grain (fig. 10, C), thus forming the box-style construction. Where screws are used in place of nails, their holding power may be greatly increased if holes are bored to receive them.

The corner construction shown in Figure 10, D, is very weak, because the only nailing possible except toe-nailing is through one member into the end grain of the other two. This style of corner is frequently used in crates that are to be entirely covered with sheathing, but even then it is very weak.

The 3-way corner (fig. 10, E and F) has the advantage over other constructions in that at each corner each member is fastened by nails or bolts in two directions. If nails are used they are driven into side grain and consequently have greater holding power than if driven into end grain. If properly nailed or bolted, this style of corner has a considerable bracing effect. Another advantage of the 3-way corner is the arrangement of the members so that only one thickness of frame material intervenes between the contents and the outer surface of the crate, thereby minimizing the displacement.

Figure 11 shows sixteen possible arrangements of members to form a 3-way corner. A and I are the most practical unless an arrangement is desired to serve some special purpose, such as blocking the contents in position. In the box style of crate the nailing is principally into the side grain. This construction offers greater resistance than the 3-way corner to the ends being kicked out, and the sides, top, and bottom are more easily reinforced with metal bindings. (Pl. 18, A.) Without reinforcements the box-style corner is not so strong as the 3-way corner. Plate 18, B, illustrates a method of reinforcing the 3-way corner with metal straps.

**Bracing**

Proper arrangement of the crate members at the corners will not in itself produce a rigid crate. (Pl. 19, A.) The 3-way corner when properly fastened has considerable bracing effect, but no matter
how the corners are arranged some kind of bracing across the faces is necessary to produce sufficient rigidity to resist weaving. The requirements for really effective bracing are not generally understood. Diagonal braces on six sides, as shown in Plate 19, B, produce the maximum rigidity for a minimum of material and labor. Diagonal braces on a pair of opposite faces (pl. 19, C) produce rigidity in one direction only, on two pairs of opposite faces (pl. 19, D) they produce rigidity in two directions, and on all six faces (pl. 19, B) they produce rigidity in all directions. If an odd number of faces are diagonally braced, or if two or more adjacent faces are braced and the opposite faces left unbraced, the crate will twist when dropped on any of its corners. For example, if five sides of a crate are braced and the sixth is not, a drop on any corner of the crate will cause the unbraced side to distort diagonally. This action induces stresses that cause all the faces to warp, and the crate to twist. (Pl. 20, A.) If the commodity is fastened securely to any one of the crate faces, the stresses induced by twisting may cause damage to the commodity without the crate's coming in contact with it or without the crate's showing evidence of failure. If, however, the commodity is sufficiently rigid to resist diagonal distorting and twisting, and is fastened

![Diagram of possible arrangements of members at a 3-way corner](image-url)
securely to the face of the crate at three or more widely separated places not in the same line, bracing may sometimes be omitted from any one side in addition to the side to which the commodity is fastened. The action of the commodity in resisting twisting greatly reduces diagonal distortion of the unbraced side.

Slight diagonal distortion in one or more of the crate faces is often desirable because the crate is better able to absorb shocks which would be transmitted to the commodity, provided the distortion does not cause the crate to touch the commodity.

Sometimes diagonal distorting and twisting only slightly rack the joints in a piece of furniture, and the damage escapes notice at the time of unpacking, but afterwards a looseness may develop which renders the commodity unsatisfactory. This looseness is usually attributed to poor workmanship or to the use of improperly seasoned lumber in manufacturing the commodity rather than to damage caused in shipment.

It is not always essential or even desirable therefore that all faces of a crate be diagonally braced, but great care must be exercised in omitting braces since the damage resulting to the commodity is often concealed. The number and location of the faces to be braced depend upon the character of protection that the commodity requires.

The direction of a simple diagonal wooden brace on one side of a crate with respect to those on other sides is of little consequence. Braces on opposite faces may be placed in the same or in opposite directions with equally satisfactory results because they are likely to be stressed either in tension or compression. Double or cross bracing, as shown in Plate 21, A, produces greater rigidity than a single diagonal brace on each face, but is seldom necessary unless the braces are so thin that they buckle easily when stressed in compression. Cross bracing of metal straps is quite effective when the braces are properly applied and well nailed at the corners of the crate. Braces are most effective when placed at an angle of 45° from the edge members. However, the ends of the braces should be fastened as near the corners of the crate as possible so as to avoid unnecessary bending, splitting, and other stresses in the edge members of the crate. Long crate faces should be divided into approximately square panels by cross members connecting opposite edge members (pl. 21, C), and each panel should be diagonally braced to form a truss. The crate is then not only more rigid against twisting or diagonal distortion but has greater resistance to bending.

**Nails**

Inability to fasten the various crate members together in such a manner that their full strength in bending, tension, and compression is developed is the chief source of crate failures. Nails are the fastenings most commonly used in crates, and much of the discussion pertaining to the factors affecting the strength of nailed joints, given on pages 11 and 12, applies also to crates.

In crate construction particular attention should be given to avoiding the direct pull of the contents on the nails; such pull would occur in the hog crate illustrated in Figure 12. The weight of the hog is carried by direct tension on the nails driven through the bottom of the crate into the lower side slats. The holding power of these nails is very good when they are freshly driven, but it decreases rapidly,
A, Three-way corner crate showing cross bracing (a), diagonal bracing (b), and extra pieces (c) to make stronger skids which support the vertical members and which are scarfed at the ends to facilitate sliding or the insertion of rollers; B, method of cutting and nailing a diagonal brace with proper bearing surface at the toe of the brace; C, side view of long crate showing method of increasing resistance to bending by using several sets of bracing and cross members; D, properly constructed hog crate in which the weight of the animal is carried by a floor resting on skids.
A, Crate with braces nailed to reinforcing blocks and to narrow faces of edge members; B, heavy engine crate, frame members being joined by carriage bolts
A, Wire-bound crate without diagonal braces; B, wire-bound crate with parallel diagonal braces not joined by intermediate slats; C, wire-bound crates reinforced with parallel diagonal braces joined by intermediate slats; D, wire-bound crate having each face reinforced with two diagonal braces whose ends meet at the center of an end cleat.
A, Wire-bound crate reinforced with a single diagonal brace on each face. The brace is fastened near the corners of the crate and is stapled to the wires and the slats. B, Wire-bound crate reinforced with diagonal braces crossed on each face. The braces are fastened near the corners of the crate and are stapled to the wires and the slats. C, Wire-bound crates reinforced with crossed diagonal braces and intermediate rows of cleats.
especially if the wood changes in moisture content after the nails have been driven. In this crate as well as in many others the direct pull on the nails may be overcome by placing the bottom boards above the lower horizontal members, as illustrated in Plate 21, D. Such horizontal members also serve as skids. In the crate illustrated in Plate 21, D, a short vertical cleat is well nailed to each skid and to its side slats. By this means the bending strength of the side slats is utilized to support the skids, which may consequently be much smaller than those which would otherwise be required. Direct pull on the nails holding the side slats is avoided by placing these slats inside the frame members. A later addition to this crate was pieces of sheet metal bent around the crate corners and clinch-nailed to reinforce the attachment of the slats at the rear end, which resist the push of the animal against the end gate. A similar use of sheet metal, to secure the ends of the center vertical blocking, is illustrated in Plate 17, C.

Cement-coated nails are preferable in crate construction to uncoated nails because of their greater holding power. A slender nail is likely to hold better than a thick nail under the repeated shocks and constant weaving action to which crates are subjected in shipment, because the slender nail bends near the surface of the pieces joined without loosening the friction grip of the nail shank. Splitting of the wood may be reduced by staggering the nails. Boring holes to receive the nails also reduces splitting and increases the nail-holding power. The diameter of such holes should be slightly less than the diameter of the nail shank. Failures due to the nails pulling out or to the splitting of the piece holding the nail points, indicate that the nails are too short.

If the ends of the diagonal braces are fitted against the edge members of adjacent faces, as illustrated in Plate 21, B, the nails fastening the brace in place can be driven closer to the crate corner. Furthermore, such construction enables a greater proportion of the shocks received in service to be transmitted to the brace directly rather than through the nails. Consequently the stress on the nails and the tendency of the edge members to split is reduced.

It is frequently an advantage in crate construction to fasten the diagonal braces to the wider face of the edge members, as shown in Plate 20, B. This practice greatly reduces the likelihood of the nails splitting the edge members, permits more nails to be used, and makes a stronger joint, especially if the nails holding the brace are clinched. Another method of reducing the likelihood of splitting and of increasing the strength of the crate is to reinforce the edge members of the crate at the end of the diagonal braces with blocks, as shown in Plate 22, A. Nailing the diagonal braces to the edge members and to the reinforcing blocks almost doubles the strength of the crate in diagonal compression.
Bolts

Bolts are especially valuable for fastening large crate members. (Pl. 22, B.) If holes which are small enough for a snug fit are bored for bolts, the crate joints are more rigid than if the bolts are loosely fitted. In the event of shrinkage or splitting of the wood, bolts may be tightened, and they will continue to be very effective, whereas nails lose much of their holding power under such conditions.

Carriage bolts are usually preferred for crate construction because their heads are oval and consequently do not require countersinking to prevent them from catching on objects. Paint applied to the bolt threads after the nuts are tightened will assist in preventing the nuts from backing off.

Screws

Lag screws and wood screws are considered poor for crate fastenings because of the great care required in drawing them down so as to make a tight joint without stripping the threads formed in the wood.

Wire-Bound Crates

A wire-bound crate (pl. 23) is similar to a wire-bound box, the essential difference being that a crate has open spaces on the various faces and is sometimes reinforced with diagonal braces. Wire-bound crates have the same general characteristics as wire-bound boxes, but unless braced they are less resistant to diagonal distortion and weaving.

Details of Construction

Stapling

It is very desirable to fasten each slat of a wire-bound crate with at least two staples astride each binding wire; otherwise the slats and wires pivot about the point of stapling and offer but little resistance to the weaving of the crate. The staples are most effective in preventing weaving if placed near the edges of the slats because of the greater leverage thus afforded the staples, as each one of a pair resists pressure from a direction opposite to that of the pressure acting on the other.

Diagonal Braces

No matter how well the crate is stapled, the proper arrangement of diagonal braces greatly increases the resistance to weaving. The braces are most effective if placed at an angle of about 45° to the edges and if their ends are fastened near corners of the crate.

If two diagonal braces are placed parallel on the face of the crate with one end of each respective brace fastened near the center of one of two parallel end cleats (pl. 23, B), the rigidity of the crate is but slightly greater than if the slats or braces are parallel with the edges of the crate. (Pl. 23, A.) If intermediate slats are used with the braces to form a truss, as shown in Plate 23, C, or if the braces run at an acute angle with each other, their adjoining ends being fastened near the center of the same end cleat, as shown in Plate 23, D, the rigidity of the crate is much greater than that of crates without braces or that of the crates with braces and without intermediate slats to
complete the truss. The types of bracing shown in Plates 23, C and D, add approximately the same amount of rigidity (fig. 13) to the crate as single diagonal braces fastened near the corners of the crate. (Pl. 24, A.) The rigidity of the crate may be further increased by stapling the braces to the wires and intermediate slats so as to support the braces against bending when stressed in compression. Maximum crate rigidity for a minimum of material is obtained, however, by using crossed diagonals on each face, as shown in Plate 24, B. If crossed diagonals are used on each face, one diagonal of each pair is always in a position to act in tension. If their ends are fastened securely, diagonal braces of thin material such as is commonly used in wire-bound construction are much more effective acting in tension than in compression.

**Intermediate Cleats**

Intermediate rows of cleats (pl. 24, C) and styles A and D end battens (fig. 7) are commonly used to reinforce the slats and braces and to support the weight of the crate contents either directly or indirectly through supporting blocks which may be added. These cleats and battens also support the slats and braces against bending and breaking across the grain, thereby increasing the rigidity of the crate and permitting the use of thin lumber.

**Ends**

Various types of end construction are used for wire-bound crates. The ends are sometimes made of slats having the same width and thickness as the slats in the crate sides, top, and bottom, and in other instances they are made of thicker lumber. These slats are sometimes fastened to the inside and sometimes to the outside of the end cleats. Where the crate ends are made of thin slats they are sometimes reinforced with the various arrangements of battens shown in Figure 7. The type of end required for a wire-bound crate and whether it should be fastened inside or outside the cleats will depend upon the nature of the contents and the manner in which it is supported in the crate.
INTERNAL PACKING AND CAR LOADING

There are definite principles for packing commodities in containers just as there are definite principles for the design of the containers. Packing and container design are so interrelated that observance of correct principles in container design will not compensate for faulty packing, or conversely. In fact, for best results the design of the container and the design of the packing should go together, being considered as a single job.

Shocks to goods in transportation, such as those caused by the weaving, swaying, and rolling of transporting vehicles, and heavy static or quiescent loads sometimes supported by the packages in the bottom layer of cargo are inevitable, although by care they can be reduced.

In general, the container and packing should be so designed as either to absorb the shocks and relieve the forces by means of cushioning materials, or to distribute, localize, or transform the forces in such a manner that the commodity and container will be able to withstand them without damage.

Protection against shock is essentially the problem of bringing to rest a body that is in motion. This action involves two factors: (1) The force exerted and (2) the distance through which this force acts. Thus, if considerable distance is available for stopping a moving body it can be brought to rest by a small force, while if it must be stopped in a short distance a large force must be applied. This fact is illustrated by the use of thick pads of soft materials for packing very delicate articles and the use of comparatively thin pads of more rigid materials for packing articles that can withstand greater stresses. In the first case, the shock is absorbed by a small force acting through a long distance; in the second, a large force acts through a short distance.

One of the chief purposes of packing materials, such as excelsior, corrugated pads, and springs, is to decrease the magnitude of the force required to stop motion by increasing the distance through which it can act. Figure 14 illustrates the use of thin pieces of wood to absorb shock.

Fragile commodities shipped in heavy, rigid containers require greater spring in packing materials than when light flexible containers are used. This is because the rigid container transmits practically all the shocks to the packing materials, whereas the flexible container
Application of psychology to packing delicate articles: A, Method of packing mercury-vapor lamp tubes in a lightweight open crate; B, method of packing a mercury-vapor lamp tube in corrugated fiber box. Holes have been cut in the side of the box to expose the contents to view.
A, A method of localizing the stresses of transportation at the parts of the commodity best able to withstand them; B, containers for high-voltage porcelain insulators. Original (a) and improved (b) and (c)
A. Rear view of a crate for a dresser; B. Wire-bound box machine damaged in transit.
Methods of packing lamp chimneys: A, Poor method; B, improved arrangement of chimneys in pad; C, open bottom of loaded box.
dissipates the shocks by springing and by distorting its own parts. Also the light flexible container and packing has a psychological effect on the persons handling freight. The application of psychology to packing delicate articles such as X-ray tubes and mercury-vapor lamp tubes (29) is illustrated in Plate 25, A, and B, where the articles are exposed to view in a very light and flimsy-appearing open crate or in a corrugated box having holes cut in its sides. In some instances the container is provided with grips to facilitate handling and may also be equipped with shoes or other devices to keep it in an upright position.

Plate 26, B, illustrates some principles of absorbing and distributing shocks that would otherwise damage the commodity. The commodity is a porcelain electric insulator. If it is placed in a box without packing materials or if packed as illustrated in Plate 26, B, c, the impact when the box strikes flatwise is concentrated at a single point on each unit of the insulator, and breakage results. By fitting the box with two ladderlike frames (pl. 26, B, b and c) that support the insulators free from the sides of the container the shocks incident to the package dropping flatwise are transmitted to two points on each unit instead of to a single point. Furthermore, when the package strikes on its side the insulators wedge themselves between the rails and spring them apart. This wedging action and springing of the ladder, combined with crushing of the wood at the two points of support, reduces the shock that would otherwise be transmitted to the contents.

The practice of binding a number of barrels, or rolls of newsprint, together, and allowing them to slide as a unit on the car floor illustrates a method of absorbing shocks as applied to car loading. In this method part of the shock is absorbed by the individual units tipping partly over and in so doing rubbing against other units, and part by the friction of the entire mass sliding on the car floor. This principle of absorbing shock is also used in binding together several tons of sheet iron. In this instance, part of the shock is absorbed by the individual units sliding one on the other, and part is absorbed by the load sliding on the car floor.

Plate 17, C, is an example of transforming and distributing the stresses of transportation rather than absorbing them by cushioning materials. The crate illustrated is an exceptionally strong container for export shipment of machinery; yet, previous to the adoption of the methods shown, much damage occurred to the contents because of faulty packing. The crate was built with heavy frame members securely reinforced with 2 by 4 inch diagonal braces and crossties and was sheathed with ¾-inch tongue-and-grooved lumber. All joints were securely nailed, and the container was well strapped. The machine within the crate is a cotton gin. Its ends are cast iron and carry two large full-length shafts with heavy, rigidly attached parts. The other parts of the gin are mostly wood. The original method of packing consisted in bolting the skids of the machine securely to the crate and blocking between the machine and the ends and sides of the crate. The top of the crate was tight against the machine. As may be readily seen, the original method required a crate that would withstand the hazards of transportation with
practically no distortion, because any distortion would transmit the shocks of transportation directly to the machine or would allow the crate to skew away from the ends of the heavy shafts and thus permit the entire end thrust of the shafts to come on the ends of the machine, giving rise to severe bending stresses in the cast iron.

It is impossible to build a crate that is as rigid as cast iron, because wood itself is somewhat yielding and there is always some looseness at nailed joints. Consequently, when the corner of this crate struck a heavy, rigid object both the crate and the gin were skewed diagonally—necessarily so because the two were securely bolted and blocked together. Such distortion was sufficient to twist the ends of the machine and break the cast-iron legs. Again, if the crate were dropped on the top or bottom edge of the end, the machine would be distorted lengthwise, and failures would likely occur in the end casting where the shafts were fastened; also the weight of the shafts would tend to spring the end of the crate and allow a large portion of the end thrust of the shafts to come on the castings. This end thrust was sufficient in itself to cause failures in the end castings without any twisting. The machine is amply strong to withstand drops flatwise on the sides, top, or bottom or on the edges of these faces.

Overcoming the difficulty, obviously, was not a problem of building a more rigid crate but of blocking the machine so that the crate could distort slightly and absorb the shocks of transportation without transmitting them to the cast-iron ends in the form of severe bending or torsional moments. In the improved method of packing, the bolts fastening the machine to the crate were omitted, and each end of the machine was blocked with two 4 by 8 inch timbers placed at right angles to each other. The horizontal timber was placed across the end of the machine about midway between top and bottom and was fitted against the machine at several points, including the shaft bearings, which thus prevented the shaft from moving endwise. The horizontal timber was not fastened to the crate. The vertical timber was placed about in line with the center of gravity of the machine and was fastened securely to the top and bottom of the crate by sheet-metal angles. The purpose of this timber was to prevent the machine from moving endwise and to act as a pivoting block. The crate could distort without skewing the machine. The original blocking was used on the sides and top. This arrangement of the blocking allowed the end thrust to be distributed to the parts of the machine best suited to withstand it. The crate itself absorbed the diagonal stresses which formerly introduced skewing in the machine. The machine was thus required to withstand only the direct load and end thrust at points in such a manner that little bending and torsion were induced.

Plate 26, A, illustrates a method of localizing the stresses of transportation at the parts of the commodity best able to withstand them. The commodity packed is a calculating machine with the operating motor built in. The outer shipping container is a nailed box having single-piece ends and sides and wide boards in the top and bottom. This construction is used to protect the machine against diagonal distortion stresses. The cuter box is fitted on the inside with a corrugated box which acts as a cushion to absorb shock. The
machine when placed in the box is set on felt pads, which provide further cushioning against shocks. Blocks of wood are fastened against the base of the machine to prevent movement endwise or sidewise. A wood framework is built up and fitted between the box and the top of the machine at points best able to withstand stresses. A felt pad, not shown in the illustration, is placed over the top of this framework to assist the corrugated box in absorbing shocks.

The principle of transforming and distributing stresses is also applied in the packing of dressers, as illustrated in Plate 27, A. Here the dresser is supported so that the weight is not carried by the legs or other easily broken parts. The corners and edges of the dresser do not come in direct contact with the crate except on the one face that is fastened to the crate, and the dresser is fastened at only two points. The crate can undergo considerable diagonal distortion without coming in contact with the dresser and without introducing diagonal distortion stresses that tend to rack the joints in the furniture.

Plate 27, B, illustrates the kind of damage that sometimes results from not supporting the heavy parts of commodities so as to prevent their inertia from causing damage to the lighter parts. The machine was bolted to heavy skids and was amply covered to protect it from objects. It was loaded lengthwise of the car, and the skids were blocked to prevent sliding. The white lines mark the breaks that resulted from the apparent inability of the castings to withstand the large inertia of the top of the machine when the car received an abnormally heavy bump in switching. This unusual damage could have been prevented if the top had been braced diagonally to the far ends of the skids, or if the machine had been loaded crosswise of the car.

Another illustration of internal packing appears in Plate 28. A method of packing lamp chimneys that resulted in considerable breakage is shown in Plate 28, A. The chimneys were covered with individual corrugated-strawboard wraps and were packed in a double-faced corrugated box. The breakage was caused by the upper rows of chimneys crashing down upon the lower ones when the box was dropped flat on the end or side. Increasing the depth of the corrugations in the individual wraps and using boxes of double thickness and pads of various kinds reduced the breakage only slightly. Since the wraps offered very little resistance to collapse, such methods of packing did not materially reduce the amount of pressure exerted on the bottom layer of chimneys.

Suspending each individual chimney in die-cut pads made of double-faced corrugated fiber board, as shown in Plate 28, B and C, prevented practically all breakage. By this means each chimney is required to carry only its own weight and is so spaced that it does not come in contact with other chimneys or with the sides of the shipping container.

In packing goods for export, consideration should be given not only to the adequacy of the packing to protect the merchandise against loss or damage in transit but also to its effect on the transportation charges and the amount of duty that will be imposed upon the package at its destination. Ocean-transportation charges are based on both volume and weight of the package, and there are supercharges for single packages exceeding certain weights and
over-all dimensions. Sometimes the shipping costs may be greatly reduced by dismantling parts so as to reduce the size of the shipping containers. The savings thus made should of course be balanced against the cost of dismantling and the cost of assembling at destination. Complete information on the regulations in force in different countries with regard to assessment of duty on merchandise may be obtained upon request from the United States Department of Commerce, Bureau of Foreign and Domestic Commerce.
APPENDIXES

The purpose of the Appendixes A to H is to give specific information necessary in the application of the principles of the design and construction of shipping containers. They contain information on the properties of container woods and instructions as to their conditioning, formulas for design, descriptions of methods of testing, specifications, and statistics.

APPENDIX A. CHARACTERISTICS AND BEHAVIOR OF CONTAINER MATERIALS

The following are the principal requisites of container materials: Low cost, availability, lightness, ability to take fastenings and hold them securely, and resistance to breaking, splitting, buckling, and puncturing. With food containers it is important that the material should not impart taste or odor to the contents. The capacity to display lettering well and to stay in place is also important. Capacity to stay in place is most important when either the material or the container is to remain in storage for a long period of time or is to be exposed to severe changes of moisture or atmospheric conditions.

NAILING OF WOOD

NAIL-HOLDING POWER

The maximum of resistance to be overcome in withdrawing nails from wood by pulling along the nail shank is known as the nail-holding power. It depends on the friction between the nail shank and the wood fibers, and varies for ordinary sizes of nails with the density of the wood, the direction of the shank relative to the grain of the wood, the form of the point, the character of the shank, the diameter of the nail, the depth of penetration, the moisture content of the wood, and changes in moisture content after the nails are driven.

For clear, sound wood the nail-holding power varies with the density in the manner indicated in Figure 15 and almost directly with the depth of penetration (Table 1) and diameter of nail. In other words, the nail-holding power depends upon the amount of wood substance in contact with the nail. It is therefore evident that checks, splits, and rot very seriously reduce the nail-holding power. Table 3 indicates that the work or energy required to pull nails also varies with their size and with the density of the wood.

<table>
<thead>
<tr>
<th>Depth driven</th>
<th>Tests</th>
<th>Force required to start withdrawal</th>
<th>Depth driven</th>
<th>Tests</th>
<th>Force required to start withdrawal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Pounds weight</td>
<td></td>
<td>Number</td>
<td>Pounds weight</td>
</tr>
<tr>
<td>¼ inch</td>
<td>44</td>
<td>70</td>
<td>1¾ inches</td>
<td>42</td>
<td>216</td>
</tr>
<tr>
<td>1 inch</td>
<td>44</td>
<td>150</td>
<td>1¾ inches</td>
<td>44</td>
<td>268</td>
</tr>
<tr>
<td>1 ½ inches</td>
<td>38</td>
<td>195</td>
<td>1¾ inches</td>
<td>42</td>
<td>311</td>
</tr>
</tbody>
</table>
FIGURE 15.—Relation of specific gravity of wood to nail-holding power; sevenpenny cement-coated nails driven 1 4 inches into side grain and pulled at once

KEY TO SPECIES

1. Cedar, northern, white.
2. Cottonwood, eastern.
3. Cedar, western red.
5. Fir, lowland white.
7. Fir, California red.
8. Cottonwood, black.
10. Fir, silver.
11. Fir, white.
14. Spruce, red.
15. Poplar, yellow.
16. Hemlock, eastern.
17. Spruce, white.
20. Pine, western white.
22. Pine, jack.
23. Hemlock, western.
27. Gum, red.
28. Maple, silver.
29. Magnolia, cucumber.
30. Gum, tupelo.
32. Elm, American.
33. Pine, mountain.
34. Sycamore.
35. Pine, pond.
36. Larch, western.
37. Pine, shortleaf.
38. Pine, loblolly.
40. Ash, white.
41. Maple, sugar.
42. Pine, longleaf.
43. Oak, red.
44. Birch, red.
45. Beech.
46. Pine, slash.
47. Locust, black.
48. Oak, white.
49. Locust, honey.
50. Hop-hornbeam.
### TABLE 2.—Resistance to withdrawal of cement-coated nails of different diameters driven to 1 inch depth into side grain of air-dry western yellow pine

<table>
<thead>
<tr>
<th>Size of nail</th>
<th>Penny 1</th>
<th>Diameter in inch</th>
<th>Force required to start withdrawal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>13</td>
<td>0.0915</td>
<td>140</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>0.1205</td>
<td>167</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>0.1360</td>
<td>183</td>
</tr>
<tr>
<td>16</td>
<td>9</td>
<td>0.1483</td>
<td>214</td>
</tr>
</tbody>
</table>

1 Steel wire gauge (Washburn & Moen). 2 Each value represents tests on 80 nails.

### TABLE 3.—Work required to pull from dry wood different sized nails which were driven into side grain

<table>
<thead>
<tr>
<th>Size of nail</th>
<th>White pine Tests</th>
<th>Work of pulling per inch withdrawn</th>
<th>Douglas fir Tests</th>
<th>Work of pulling per inch withdrawn</th>
<th>Yellow birch Tests</th>
<th>Work of pulling per inch withdrawn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Inch-pounds</td>
<td>Number</td>
<td>Inch-pounds</td>
<td>Number</td>
<td>Inch-pounds</td>
</tr>
<tr>
<td>Fourpenny</td>
<td>12</td>
<td>59</td>
<td>30</td>
<td>66</td>
<td>12</td>
<td>72</td>
</tr>
<tr>
<td>Sixpenny</td>
<td>12</td>
<td>84</td>
<td>20</td>
<td>65</td>
<td>12</td>
<td>110</td>
</tr>
<tr>
<td>Eightpenny</td>
<td>20</td>
<td>83</td>
<td>12</td>
<td>83</td>
<td>11</td>
<td>427</td>
</tr>
<tr>
<td>Twentypenny</td>
<td>12</td>
<td>170</td>
<td>30</td>
<td>295</td>
<td>12</td>
<td>359</td>
</tr>
<tr>
<td>Sixtypenny</td>
<td>12</td>
<td>192</td>
<td>30</td>
<td>530</td>
<td>12</td>
<td>359</td>
</tr>
</tbody>
</table>

### DIRECTION OF NAIL SHANK

The resistance to withdrawal is greater if the nails are driven into side grain than if driven into end grain. (Table 4.) It may be observed that the difference between the resistance to withdrawal of nails from the end surface and from the side grain, which is the average of the radial and tangential surfaces, is greater for the lightweight woods, which are designated under Groups 1 and 2, than for heavier woods, which are designated under Groups 3 and 4. There is, however, no important difference in the resistance to be overcome in pulling nails from radial (edge-grain) and tangential (flat-grain) surfaces.

### TABLE 4.—Nail-holding power of various species of wood

[Sevenpenny cement-coated nails driven to a depth of 1½ inches and pulled at once]

<table>
<thead>
<tr>
<th>Group and species 1</th>
<th>Source of test material</th>
<th>Trees</th>
<th>Moisture content at test (%)</th>
<th>Specific gravity oven-dry based on volume when oven-dry</th>
<th>Holding power of nails driven into—</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUPT 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>End surface</td>
</tr>
<tr>
<td>Aspen</td>
<td>Colorado</td>
<td></td>
<td></td>
<td></td>
<td>Pounds weight</td>
</tr>
<tr>
<td>Aspen, large-tooth</td>
<td>Wisconsin</td>
<td>5</td>
<td>6.6</td>
<td>0.36</td>
<td>93</td>
</tr>
<tr>
<td>Basswood</td>
<td>Pennsylvania</td>
<td>5</td>
<td>6.6</td>
<td>0.41</td>
<td>157</td>
</tr>
<tr>
<td>Cedar, northern white</td>
<td>Wisconsin</td>
<td>5</td>
<td>6.5</td>
<td>0.32</td>
<td>138</td>
</tr>
<tr>
<td>Cedar, western red</td>
<td>Montana</td>
<td>10</td>
<td>7.6</td>
<td>0.41</td>
<td>103</td>
</tr>
<tr>
<td>Do.</td>
<td>Washington</td>
<td>10</td>
<td>7.6</td>
<td>0.34</td>
<td>118</td>
</tr>
<tr>
<td>Chestnut</td>
<td>Maryland</td>
<td>10</td>
<td>9.2</td>
<td>0.45</td>
<td>172</td>
</tr>
<tr>
<td>Do.</td>
<td>Tennessee</td>
<td>10</td>
<td>9.2</td>
<td>0.45</td>
<td>172</td>
</tr>
</tbody>
</table>

1 Data are not available on all species in each group.
TABLE 4.—Nail-holding power of various species of wood—Continued

| Group and species 1 | Source of test material | Trees | Moisture content at test | Specific gravity oven-dry based on volume when oven-dry | Holding power of nails driven into-
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>End surface</td>
<td>Radial surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pounds weight</td>
<td>pounds weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>surface</td>
<td>surface</td>
</tr>
<tr>
<td>GROUP I—continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cottonwood, black</td>
<td>Washington</td>
<td>5</td>
<td>5.9</td>
<td>.37</td>
<td>122</td>
</tr>
<tr>
<td>Cottonwood, eastern</td>
<td>Missouri</td>
<td>10</td>
<td>6.8</td>
<td>.34</td>
<td>143</td>
</tr>
<tr>
<td>Cypress, southern</td>
<td>Missouri</td>
<td>3</td>
<td>9.0</td>
<td>.37</td>
<td>100</td>
</tr>
<tr>
<td>Fir, California red</td>
<td>Idaho</td>
<td>5</td>
<td>5.3</td>
<td>.36</td>
<td>60</td>
</tr>
<tr>
<td>Fir, lowland white</td>
<td>Washington</td>
<td>5</td>
<td>4.9</td>
<td>.40</td>
<td>86</td>
</tr>
<tr>
<td>Fir, silver</td>
<td>California</td>
<td>8</td>
<td>8.0</td>
<td>.41</td>
<td>104</td>
</tr>
<tr>
<td>Fir, white</td>
<td>Tennessee</td>
<td>5</td>
<td>5.1</td>
<td>.52</td>
<td>233</td>
</tr>
<tr>
<td>Magnolia, cucumber</td>
<td>Wisconsin</td>
<td>5</td>
<td>7.6</td>
<td>.46</td>
<td>161</td>
</tr>
<tr>
<td>Pine, jack</td>
<td>Coloapopo</td>
<td>8</td>
<td>6.3</td>
<td>.44</td>
<td>141</td>
</tr>
<tr>
<td>Pine, northern white</td>
<td>Wisconsin</td>
<td>5</td>
<td>7.7</td>
<td>.39</td>
<td>136</td>
</tr>
<tr>
<td>Pine, Norway</td>
<td>do</td>
<td>5</td>
<td>7.4</td>
<td>.51</td>
<td>165</td>
</tr>
<tr>
<td>Pine, western white</td>
<td>Missouri</td>
<td>5</td>
<td>8.2</td>
<td>.45</td>
<td>134</td>
</tr>
<tr>
<td>Pine, western yellow</td>
<td>California</td>
<td>7</td>
<td>6.6</td>
<td>.44</td>
<td>122</td>
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<tr>
<td>Poplar, yellow</td>
<td>Oregon</td>
<td>5</td>
<td>7.3</td>
<td>.42</td>
<td>162</td>
</tr>
<tr>
<td>Poplar, Engelmann</td>
<td>Colorado</td>
<td>5</td>
<td>9.4</td>
<td>.36</td>
<td>136</td>
</tr>
<tr>
<td>Poplar, red</td>
<td>Tennessee</td>
<td>5</td>
<td>10.7</td>
<td>.41</td>
<td>148</td>
</tr>
<tr>
<td>Poplar, white</td>
<td>Wisconsin</td>
<td>5</td>
<td>7.6</td>
<td>.43</td>
<td>146</td>
</tr>
<tr>
<td>GROUP 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fir, Douglas</td>
<td>Oregon</td>
<td>28</td>
<td>6.3</td>
<td>.51</td>
<td>183</td>
</tr>
<tr>
<td>Hemlock, eastern</td>
<td>Washington</td>
<td>28</td>
<td>8.9</td>
<td>.42</td>
<td>127</td>
</tr>
<tr>
<td>Hemlock, western</td>
<td>Wisconsin</td>
<td>9</td>
<td>6.7</td>
<td>.46</td>
<td>149</td>
</tr>
<tr>
<td>Larch, western</td>
<td>Oregon</td>
<td>10</td>
<td>8.0</td>
<td>.59</td>
<td>179</td>
</tr>
<tr>
<td>Pine, loblolly</td>
<td>Florida</td>
<td>34</td>
<td>7.7</td>
<td>.64</td>
<td>244</td>
</tr>
<tr>
<td>Pine, longleaf</td>
<td>Louisiana</td>
<td>34</td>
<td>7.7</td>
<td>.64</td>
<td>244</td>
</tr>
<tr>
<td>Pine, mountain</td>
<td>Tennessee</td>
<td>5</td>
<td>7.1</td>
<td>.55</td>
<td>209</td>
</tr>
<tr>
<td>Pine, pitch</td>
<td>Tennessee</td>
<td>5</td>
<td>7.7</td>
<td>.55</td>
<td>235</td>
</tr>
<tr>
<td>Pine, pond</td>
<td>Florida</td>
<td>5</td>
<td>7.5</td>
<td>.57</td>
<td>211</td>
</tr>
<tr>
<td>Pine, shortleaf</td>
<td>Louisiana</td>
<td>6</td>
<td>7.2</td>
<td>.58</td>
<td>225</td>
</tr>
<tr>
<td>Pine, slash</td>
<td>Florida</td>
<td>5</td>
<td>7.0</td>
<td>.68</td>
<td>250</td>
</tr>
<tr>
<td>GROUP 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elm, American</td>
<td>Pennsylvania</td>
<td>5</td>
<td>8.2</td>
<td>.54</td>
<td>236</td>
</tr>
<tr>
<td>Gum, red</td>
<td>Arkansas</td>
<td>5</td>
<td>8.3</td>
<td>.51</td>
<td>192</td>
</tr>
<tr>
<td>Gum, tupelo</td>
<td>Louisiana</td>
<td>6</td>
<td>9.3</td>
<td>.52</td>
<td>233</td>
</tr>
<tr>
<td>Maple, silver</td>
<td>Wisconsin</td>
<td>5</td>
<td>6.8</td>
<td>.51</td>
<td>280</td>
</tr>
<tr>
<td>Sycamore</td>
<td>Tennessee</td>
<td>5</td>
<td>7.0</td>
<td>.55</td>
<td>270</td>
</tr>
<tr>
<td>GROUP 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, white</td>
<td>Arkansas</td>
<td>5</td>
<td>8.9</td>
<td>.64</td>
<td>385</td>
</tr>
<tr>
<td>Beech</td>
<td>Indiana</td>
<td>5</td>
<td>8.4</td>
<td>.67</td>
<td>338</td>
</tr>
<tr>
<td>Birch, black</td>
<td>Wisconsin</td>
<td>3</td>
<td>8.6</td>
<td>.66</td>
<td>331</td>
</tr>
<tr>
<td>Hop-hornbeam</td>
<td>Tennesse</td>
<td>3</td>
<td>8.5</td>
<td>.76</td>
<td>457</td>
</tr>
<tr>
<td>Locust, black</td>
<td>Tennessee</td>
<td>5</td>
<td>7.1</td>
<td>.71</td>
<td>404</td>
</tr>
<tr>
<td>Locust, honey</td>
<td>Indiana</td>
<td>1</td>
<td>6.5</td>
<td>.76</td>
<td>431</td>
</tr>
<tr>
<td>Maple, black</td>
<td>Tennessee</td>
<td>1</td>
<td>9.8</td>
<td>.69</td>
<td>357</td>
</tr>
<tr>
<td>Maple, sugar</td>
<td>Tennesse</td>
<td>4</td>
<td>8.5</td>
<td>.69</td>
<td>386</td>
</tr>
<tr>
<td>Oak, red</td>
<td>Arkansas</td>
<td>22</td>
<td>8.4</td>
<td>.66</td>
<td>312</td>
</tr>
<tr>
<td>Oak, white</td>
<td>Tennessee</td>
<td>10</td>
<td>8.6</td>
<td>.72</td>
<td>320</td>
</tr>
</tbody>
</table>

Nails driven either at an angle of 90° to the surface or driven at an angle somewhat less than 90°, as shown in Plate 29, have approximately the same holding power when pulled in a direction perpendicular to the surface of the board.
The straight-driven nails have approximately the same holding power as those driven at an angle when pulled in a direction perpendicular to the surface of the board shortly after driving.
Distortion of wood fibers by nails: A, Barbed nail (highly magnified); B, common smooth nail; C, blunt pointed nail
shortly after their driving. If drying occurs after the nails are driven, the slant-nailed joints begin to loosen at lower loads than the perpendicularly-nailed joints, although the loss in ultimate holding power is less than for the perpendicularly-nailed pieces. This indicates that slant nailing is an advantage in box or crate construction if considerable drying occurs after the nails are driven.

CHARACTER OF NAIL SHANK

The nail-holding power of wood also depends on the character of the nail shank. Cement coating (a composition of resin usually applied hot by nail manufacturers) increases the friction between the nail and wood and thereby increases the resistance to withdrawal. (Figs. 16 and 17.)

<table>
<thead>
<tr>
<th>Side grain</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain 7d</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>Cement-coated 7d</td>
<td>236 %</td>
<td></td>
</tr>
<tr>
<td>Barbed 7d</td>
<td>72 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End grain</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain 7d</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>Cement-coated 7d</td>
<td>254 %</td>
<td></td>
</tr>
<tr>
<td>Barbed 7d</td>
<td>91 %</td>
<td></td>
</tr>
</tbody>
</table>

Figure 16.—Comparative holding power of different types of nails driven to 134 inches in western yellow pine having 8 per cent moisture content and pulled at once. Values are adjusted on the basis of area of contact of a plain sevenpenny nail.

Barbed nails are so called because their shanks have a series of small barbs or teeth. When these nails are driven, the barbs distort or break off the wood fibers and pull the fibers down along the side of the nail. This action leaves the surface of the wood in contact with the shank more ragged than is the case with smooth nails. (Pl. 30, A and B.) For this reason the resistance to withdrawal of nails which are driven and pulled immediately is less for barbed than for smooth nails. If driven into green wood which is subsequently dried to a low moisture content, however, the barbed nails hold much better than smooth nails either plain or cement-coated. (Fig. 17.)
The practice of applying talc or graphite to cement-coated nails to facilitate their movement in nailing machines seriously reduces the holding power of these nails. (Fig. 18.)

**RESISTANCE TO SPLITTING**

The force required to split a piece of wood increases, as a rule, with the density. Nevertheless, the denser woods split more in nailing than the lighter woods because as the density of the wood increases its hardness and consequently the magnitude of the splitting force produced in driving nails increases faster than the resistance that the wood offers to splitting. The tendency of wood to split depends very largely upon the size of the nail and the character of the point; less splitting occurs with the smaller nails. Blunt-pointed nails, because of the manner in which they tear and otherwise distort the wood fibers (pl. 30, C), create less splitting force than sharp-pointed nails, which exert a wedging force in penetrating the wood. Blunt-pointed nails ordinarily offer less resistance to withdrawal, however, than sharp-pointed nails, provided no splitting occurs. (Fig. 19.)

Defects, such as knots, cross grain, checks, and shakes, increase the susceptibility of wood to splitting while interlocked grain has the opposite effect.

### Table: Effect of Change of Moisture Content in Wood on the Holding Power of Different Types of Nails Driven into Wood in a Green Condition

<table>
<thead>
<tr>
<th>Type of Nail</th>
<th>Side Grain</th>
<th>End Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain 7d</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Cement-coated 7d</td>
<td>134%</td>
<td>143%</td>
</tr>
<tr>
<td>Barbed 7d</td>
<td>80%</td>
<td>83%</td>
</tr>
<tr>
<td></td>
<td>58%</td>
<td>60%</td>
</tr>
</tbody>
</table>

*Legend*
- Nails driven into green western yellow pine and pulled at once.
- Nails driven into green western yellow pine, dried 104 days and pulled at 5 1/2% moisture content.

**Figure 17** — Effect of change of moisture content in wood on the holding power of different types of nails driven into wood in a green condition. Values were adjusted on the basis of area of contact of a plain sevenpenny nail, all nails being driven to 1 1/4 inches.
RESISTANCE TO SHEAR AT NAILS

The resistance that wood offers to the nails shearing the wood out at the ends of the boards and to the heads pulling directly through the boards varies with the species and density, the thickness of the boards, the distance of the nails from the ends of the boards, and the diameter of the nail head. Table 5 shows the influence of various sizes of heads in resisting these failures.

Overdriving nails or imbedding their heads in the wood crushes the fibers and reduces the resistance to the shanks shearing out and the heads pulling through thin boards almost directly in proportion to the amount the nail is overdriven. (Fig. 20.)

SIZE AND NUMBER OF NAILS

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

Table 5.—Effect of the size of nail head on the strength of a nailed joint

<table>
<thead>
<tr>
<th>Material</th>
<th>Size of nail</th>
<th>Diameter of head</th>
<th>Tension Load per nail</th>
<th>Heads broken</th>
<th>Shear Load per nail</th>
<th>Heads broken</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/6-inch rotary-cut red gum</td>
<td>6</td>
<td>Penny 0.36</td>
<td>212</td>
<td>0</td>
<td>186</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Inch 0.36</td>
<td>207</td>
<td>0</td>
<td>155</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Penny 0.36</td>
<td>213</td>
<td>100</td>
<td>158</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Inch 0.36</td>
<td>212</td>
<td>0</td>
<td>154</td>
<td>0</td>
</tr>
<tr>
<td>5/6-inch sawed white pine</td>
<td>4</td>
<td>Penny 0.36</td>
<td>239</td>
<td>83</td>
<td>173</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Inch 0.36</td>
<td>248</td>
<td>100</td>
<td>168</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Penny 0.36</td>
<td>222</td>
<td>0</td>
<td>158</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Inch 0.36</td>
<td>220</td>
<td>11</td>
<td>164</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Penny 0.36</td>
<td>194</td>
<td>0</td>
<td>139</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Inch 0.36</td>
<td>181</td>
<td>0</td>
<td>139</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Penny 0.36</td>
<td>178</td>
<td>33</td>
<td>138</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Inch 0.36</td>
<td>158</td>
<td>22</td>
<td>172</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Penny 0.36</td>
<td>149</td>
<td>0</td>
<td>142</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Inch 0.36</td>
<td>122</td>
<td>0</td>
<td>134</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Penny 0.36</td>
<td>164</td>
<td>22</td>
<td>161</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Inch 0.36</td>
<td>116</td>
<td>0</td>
<td>150</td>
<td>0</td>
</tr>
</tbody>
</table>

1 See Plate 41 for method of test.

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 and, with other combinations a small number of large nails. The length of the nail shank should be such as to prevent the nail from pulling and also to prevent any prying action from splitting the piece holding the point. Nails should be large enough to be driven easily without bending, but should not be so small that in service they will bend back and forth sufficiently to break.

Standard cement-coated "cooler" and "sinker" nails are well proportioned for general use. (See Appendix G, Table 12.) These are as slender as can be driven readily into hardwoods and are not so easily loosened from the wood by the strains caused by rough handling or weaving as are those of a larger diameter and of the same length, and do not break off easily. The heads of "cooler" or "sinker" nails are of sufficient diameter to prevent them from pulling through the wood except where the wood used is very thin.

INFLUENCE OF MOISTURE CONTENT ON THE NAILING QUALITIES OF WOOD

The nailing qualities of wood are influenced very materially by the seasoning condition. Nails can be driven into or withdrawn from green wood more easily than from dry wood. The nail heads also pull through the green wood, and the shanks shear out of the wood at the ends of the board more easily than with dry

1 See Plate 41 for method of test.
wood. On the other hand, green wood, because of its softness, is not so susceptible as dry wood to splitting when the nails are driven.

When a nail is driven into a piece of wood the fibers are broken and bent down along the side of the nail or are separated. (Pl. 30, B.) Where the fibers are dry and rigid, as in seasoned wood, the friction between the wood fibers and the nail shank is relatively high; but where the fibers are soft and flexible, as in green wood, the friction is lower. For western yellow pine the difference in friction for green and for dry wood causes approximately 25 per cent difference in nail-holding power.

The fibers which are bent down against the end grain in driving the nail exert a greater pressure against the nail than those which are pushed back against the side grain. This difference in pressure results from the difference in the end compressive strength and side compressive strength of the fibers immediately back of those in contact with the nail. If the wood dries after the nail is driven, the nail-holding power is seriously reduced because the shrinking of the fibers, which were bent down against the end-grain fibers, makes the hole larger in the direction of the grain, since the board itself practically does not shrink lengthwise. The shrinkage of the board across the grain tends to make the hole smaller in this direction and so maintains the side-grain pressure on the nail. The loss in nail-holding power of wood with drying and with lapse of time without drying is illustrated in Figure 21.

If nails are driven into dry wood that subsequently undergoes alternate wetting and drying, the fibers will lose their grip on the nails the same as in nails driven into green lumber that subsequently dries out.

**SCREW-HOLDING POWER**

Screws when properly driven are an admirable fastening for wood. Driving screws almost their full length with a hammer or overdriving them with screw
drivers, which is likely to happen in power driving, tears the wood fibers and seriously reduces their holding power. (Table 6.) For maximum efficiency screws should be twisted their full length into bored holes the diameter of which should be 70 to 90 per cent of the root diameter of the screw.

<table>
<thead>
<tr>
<th>Nails driven into side grain</th>
<th>Nailed and tested at once at 8% moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain 7d - common cone point</td>
<td>100%</td>
</tr>
<tr>
<td>Plain 7d - blunt point</td>
<td>42%</td>
</tr>
<tr>
<td>Plain 7d - cruciform point</td>
<td>59%</td>
</tr>
<tr>
<td>Nailed at 8%, stored 4 months and tested at 5%</td>
<td>168%</td>
</tr>
<tr>
<td>Plain 7d - common cone point</td>
<td>66%</td>
</tr>
<tr>
<td>Plain 7d - blunt point</td>
<td>74%</td>
</tr>
<tr>
<td>Plain 7d - cruciform point</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nails driven into end grain</th>
<th>Nailed and tested at once at 8% moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain 7d - common cone point</td>
<td>100%</td>
</tr>
<tr>
<td>Plain 7d - blunt point</td>
<td>75%</td>
</tr>
<tr>
<td>Plain 7d - cruciform point</td>
<td>97%</td>
</tr>
<tr>
<td>Nailed at 8%, stored 4 months and tested at 5%</td>
<td>218%</td>
</tr>
<tr>
<td>Plain 7d - common cone point</td>
<td>106%</td>
</tr>
<tr>
<td>Plain 7d - blunt point</td>
<td>105%</td>
</tr>
<tr>
<td>Plain 7d - cruciform point</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 19.**—Effect of type of nail point on the holding power of nails. The nails were driven to 1 1/4 inches in western yellow pine. Values were adjusted on the basis of the area of contact of a plain sevenpenny nail. (See Plate 30, C, for shape of blunt point.)

**Table 6.**—Resistance to withdrawal of No. 12 wood screws

[Screws 1 3/4 inches long, driven to 1-inch depth in holes 3/8 inch in diameter]

<table>
<thead>
<tr>
<th>Species of wood</th>
<th>Resistance to withdrawal when driven by--</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Screw driver</td>
</tr>
<tr>
<td></td>
<td>Pounds weight</td>
</tr>
<tr>
<td>Basswood</td>
<td>478</td>
</tr>
<tr>
<td>Southern yellow pine</td>
<td>1,144</td>
</tr>
<tr>
<td>Red gum</td>
<td>687</td>
</tr>
<tr>
<td>Birch</td>
<td>841</td>
</tr>
</tbody>
</table>

1 One final turn with screw driver.
FIGURE 20.—Effect of overdriving nails in and through 3/16-inch box sides.

FIGURE 21.—Effect of changes in moisture content with time on holding power of sevenpenny nails driven to 1½-inch depth.
LAG SCREWS

Holes should first be bored to receive lag screws, and extreme care should be exercised to prevent drawing the screws down so solidly as to strip the threads formed in the wood, since otherwise their holding power is materially reduced. It is usually best to bore a hole of two diameters, the lower portion of the hole being slightly less in diameter than the core of the screw and the upper portion of a diameter to fit the portion of the screw shank adjoining the head.

STAPLES

Staples are most valuable for fastening thin wood and for fastening in place both wire bands and flat metal straps. Their holding power is influenced by the same factors that influence the holding power of nails. Because of their form, staples are not pulled directly through the material or sheared out at the ends so easily as are nails with small heads. To secure good holding power, staples should be driven for a considerable depth into solid wood and, where practicable, they should be driven through and clinched. Staples have an advantage over nails in holding box straps in place because they do not weaken the strap by puncturing. They also hold the edges of a strap down and, on account of the curvature of the staple head, they do not catch the straps on other boxes.

BOLTS

Bolts, where their use is practicable, are the most dependable fasteners for container construction. Their holding power is usually limited by the resistance of the wood to splitting and shearing. A number of small bolts will produce a more rigid and otherwise stronger joint than a lesser number of larger bolts.

STRENGTH PROPERTIES OF WOOD

The strength properties of wood at right angles to the grain are quite different from the properties parallel to the grain (15). The bending strength may be twenty or more times as high when stressed by forces parallel to the grain as when stressed perpendicular to the grain. This difference must be recognized in all wood construction, and the size of parts and fastenings should be such as to utilize to the best advantage these characteristics in wood. The magnitude of the different properties (15) varies greatly with different species of wood and for different boards of the same species; in extreme cases some pieces will be more than twice as strong as others of the same species. Nevertheless, half of the clear material of a species usually has strength values within 12 to 20 per cent of the average for the species, the deviations from averages varying with the property and the species under consideration. Average values of various strength and related properties of different species (12) are listed in Table 7. A discussion of the significance of the figures in the table, together with examples of their application to various container problems, is given in Appendix F.
<table>
<thead>
<tr>
<th>Common and botanical name of species</th>
<th>Tree tested</th>
<th>Specific gravity, oven-dry, based on volume when green</th>
<th>Weight per cubic foot at 12 per cent moisture content</th>
<th>Shrinkage from green to oven-dry condition based on dimensions when green</th>
<th>Composite strength values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Green</td>
<td>Radial</td>
<td>Tangential</td>
</tr>
<tr>
<td>Alder, red (Alnus rubra)</td>
<td>6</td>
<td>0.37</td>
<td>46</td>
<td>98</td>
<td>4.4</td>
</tr>
<tr>
<td>Ash, Biltmore white (Fraxinus biltmoreana)</td>
<td>5</td>
<td>0.51</td>
<td>45</td>
<td>35</td>
<td>4.2</td>
</tr>
<tr>
<td>Ash, black (Fraxinus nigra)</td>
<td>11</td>
<td>0.46</td>
<td>53</td>
<td>34</td>
<td>5.0</td>
</tr>
<tr>
<td>Ash, blue (Fraxinus quadrangulata)</td>
<td>5</td>
<td>0.53</td>
<td>46</td>
<td>40</td>
<td>3.9</td>
</tr>
<tr>
<td>Ash, green (Fraxinus pennsylvanica lanceolata)</td>
<td>5</td>
<td>0.53</td>
<td>43</td>
<td>36</td>
<td>6.7</td>
</tr>
<tr>
<td>Ash, Oregon (Fraxinus oregona)</td>
<td>3</td>
<td>0.50</td>
<td>45</td>
<td>40</td>
<td>6.3</td>
</tr>
<tr>
<td>Ash, pumpkin (Fraxinus profunda)</td>
<td>5</td>
<td>0.48</td>
<td>46</td>
<td>35</td>
<td>4.7</td>
</tr>
<tr>
<td>Ash, white (Fraxinus americana)</td>
<td>23</td>
<td>0.55</td>
<td>46</td>
<td>42</td>
<td>4.9</td>
</tr>
<tr>
<td>Ashes, commercial white (average of four species)</td>
<td>43</td>
<td>0.54</td>
<td>48</td>
<td>41</td>
<td>6.9</td>
</tr>
<tr>
<td>Aspen (Populus tremuloides)</td>
<td>11</td>
<td>0.35</td>
<td>47</td>
<td>32</td>
<td>5.5</td>
</tr>
<tr>
<td>Aspen, largetooth (Populus grandidentata)</td>
<td>10</td>
<td>0.35</td>
<td>48</td>
<td>37</td>
<td>3.3</td>
</tr>
<tr>
<td>Basswood (Tilia glabra)</td>
<td>22</td>
<td>0.22</td>
<td>41</td>
<td>26</td>
<td>6.6</td>
</tr>
<tr>
<td>Beech (Fagus grandifolia)</td>
<td>17</td>
<td>0.56</td>
<td>54</td>
<td>45</td>
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</tr>
<tr>
<td>Beech, blue (Carpinus caroliniana)</td>
<td>12</td>
<td>0.53</td>
<td>55</td>
<td>48</td>
<td>6.5</td>
</tr>
<tr>
<td>Birch, Alaska white (Betula neoalaskana)</td>
<td>10</td>
<td>0.49</td>
<td>49</td>
<td>36</td>
<td>6.5</td>
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<tr>
<td>Birch, gray (Betula populifolia)</td>
<td>5</td>
<td>0.45</td>
<td>46</td>
<td>35</td>
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</tr>
<tr>
<td>Birch, paper (Betula papyrifera)</td>
<td>10</td>
<td>0.48</td>
<td>50</td>
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<tr>
<td>Birch, sweet (Betulina lenta)</td>
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<td>0.60</td>
<td>57</td>
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<tr>
<td>Birch, yellow (Betula lutea)</td>
<td>17</td>
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<td>57</td>
<td>43</td>
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<td>Buckeye, yellow (Aesculus octandra)</td>
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<td>49</td>
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<tr>
<td>Butternut (Juglans cinerea)</td>
<td>10</td>
<td>0.36</td>
<td>46</td>
<td>27</td>
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</tr>
<tr>
<td>Species</td>
<td>Figure Number</td>
<td>Relative Hardness</td>
<td>Specific Gravity</td>
<td>Modulus of Rupture</td>
<td>Tension Modulus of Elasticity</td>
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<tr>
<td>----------------------------------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>------------------</td>
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<tr>
<td>Spotted Gum (Eucalyptus maculata)</td>
<td>60</td>
<td>4.5</td>
<td>0.55</td>
<td>130</td>
<td>212</td>
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<tr>
<td>Cottonwood (Populus trichocarpa)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Oak, black (Quercus alba)</td>
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<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Oak, canyon live (Quercus chrysolepis)</td>
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<td>4.7</td>
<td>0.64</td>
<td>130</td>
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</tr>
<tr>
<td>Oak, California black (Quercus kelloggii)</td>
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<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Oak, bur (Quercus macrocarpa)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Oak, red (Liquidambar styraciflua)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Oak, white (Quercus alba)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, pignut (Hicoria cordiformis)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, bitternut (Hicoria alba)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, mockernut (Hicoria alba)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, nutmeg (Hicoria myristiciformis)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, bigleaf shagbark (Hicoria laciniosa)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickory, shagbark (Hicoria ovata)</td>
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<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
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<tr>
<td>Hickory, water (Hicoria aquatica)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickories, pecan (average of four species)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
<tr>
<td>Hickories, true (average of four species)</td>
<td>66</td>
<td>4.7</td>
<td>0.64</td>
<td>130</td>
<td>212</td>
</tr>
</tbody>
</table>

1 Based on tests of small clear specimens, 2 by 3 inches in section except radial and tangential shrinkage which are based on width measurements of pieces 1 inch thick, 4 inches wide, and 1 inch long. Bending specimens are 30 inches long. This is for use in comparing species in either of the form of clear lumber or in grades containing like defects, except structural material. Structural material which conforms to American lumber standards should be compared by means of allowable working stresses.

2 For derivation of composite values see Comparative Strength Properties of Woods Grown in the United States (12).

3 Fraxinus lanuginosa, Fr. quadrangulata, Fr. pennsylvanica lanceolata, Fr. pennsylvanica pennsylvaniae, Fr. pennsylvanica quadrifolia, Fr. pennsylvanica serrata.

4 *Hicoria cordiformis, H. myristiciformis, H. aquatica, and H. pecan.

5 *Hicoria lanicina, H. alba, H. glabra, and H. ovata.

6 Species under footnotes 4 and 5 combined.

7 For derivation of composite values see Comparative Strength Properties of Woods Grown in the United States (12).
### Table 7.—Average properties of container woods grown in the United States—Continued

[Based on tests of small, clear specimens. For definition of terms and discussion of table see explanation of table in Appendix F]

#### HARDWOODS—Continued

<table>
<thead>
<tr>
<th>Common and botanical name of species</th>
<th>Trees tested</th>
<th>Specific gravity, oven-dry, based on volume when green</th>
<th>Weight per cubic foot</th>
<th>Shrinkage from green to oven-dry condition based on dimensions when green</th>
<th>Composite strength values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trees</td>
<td>Green</td>
<td>At 12 per cent moisture content</td>
<td>Radial</td>
<td>Tangential</td>
</tr>
<tr>
<td>Oak, pin (Quercus palustris)</td>
<td>5</td>
<td>0.58</td>
<td>63</td>
<td>44</td>
<td>4.3</td>
</tr>
<tr>
<td>Oak, post (Quercus stellata)</td>
<td>10</td>
<td>0.60</td>
<td>63</td>
<td>47</td>
<td>5.4</td>
</tr>
<tr>
<td>Oak, red (Quercus borealis)</td>
<td>33</td>
<td>0.56</td>
<td>63</td>
<td>44</td>
<td>4.0</td>
</tr>
<tr>
<td>Oak, Rocky Mountain white (Quercus utahensis)</td>
<td>3</td>
<td>0.62</td>
<td>62</td>
<td>51</td>
<td>4.1</td>
</tr>
<tr>
<td>Oak, scarlet (Quercus coccinea)</td>
<td>5</td>
<td>0.60</td>
<td>62</td>
<td>47</td>
<td>4.6</td>
</tr>
<tr>
<td>Oak, southern red (Quercus rubra)</td>
<td>4</td>
<td>0.52</td>
<td>62</td>
<td>41</td>
<td>4.5</td>
</tr>
<tr>
<td>Oak, swamp red (Quercus rubra pagodaeolia)</td>
<td>3</td>
<td>0.61</td>
<td>63</td>
<td>48</td>
<td>5.2</td>
</tr>
<tr>
<td>Oak, swamp chestnut (Quercus prinus)</td>
<td>4</td>
<td>0.60</td>
<td>65</td>
<td>47</td>
<td>5.9</td>
</tr>
<tr>
<td>Oak, swamp white (Quercus bicolor)</td>
<td>1</td>
<td>0.54</td>
<td>69</td>
<td>50</td>
<td>5.5</td>
</tr>
<tr>
<td>Oak, water (Quercus nigra)</td>
<td>3</td>
<td>0.56</td>
<td>63</td>
<td>44</td>
<td>4.2</td>
</tr>
<tr>
<td>Oak, white (Quercus alba)</td>
<td>20</td>
<td>0.60</td>
<td>62</td>
<td>48</td>
<td>5.3</td>
</tr>
<tr>
<td>Oak, willow (Quercus phellos)</td>
<td>2</td>
<td>0.56</td>
<td>67</td>
<td>49</td>
<td>5.0</td>
</tr>
<tr>
<td>Oaks, commercial red (average of nine species 7)</td>
<td>70</td>
<td>0.56</td>
<td>64</td>
<td>44</td>
<td>4.2</td>
</tr>
<tr>
<td>Oaks, commercial white (average of six species 8)</td>
<td>45</td>
<td>0.59</td>
<td>63</td>
<td>47</td>
<td>5.3</td>
</tr>
<tr>
<td>Oaks, commercial red and white (average of 15 species 9)</td>
<td>115</td>
<td>0.57</td>
<td>63</td>
<td>45</td>
<td>4.7</td>
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<tr>
<td>Pecan (Hicoria pecan)</td>
<td>5</td>
<td>0.60</td>
<td>61</td>
<td>47</td>
<td>4.9</td>
</tr>
<tr>
<td>Poplar, balsam (Populus balsamifera)</td>
<td>10</td>
<td>0.50</td>
<td>60</td>
<td>45</td>
<td>3.0</td>
</tr>
<tr>
<td>Poplar, yellow (Liriodendron tulipifera)</td>
<td>11</td>
<td>0.38</td>
<td>38</td>
<td>28</td>
<td>4.0</td>
</tr>
</tbody>
</table>

**Notes:**
- Average properties based on tests of small, clear specimens.
- For definition of terms and discussion of table, see explanation of table in Appendix F.
Sycamore (Platanus occidentalis) ........................................... 10 .46 52 35 5.1 7.6 136 74 76 129 64 78 93
Willow, black (Salix nigra) .................................................. 10 .34 50 26 2.5 7.8 126 45 41 70 35 91
Willow, western black (Salix lasiandra) .................................. 5 .39 50 31 2.9 9.0 132 67 63 127 50 104

SOFTWOODS

Cedar, Alaska (Chamaecyparis nootkatensis)................................. 8 .0.42 36 31 2.8 6.0 91 80 87 126 53 93
Cedar, incense (Libocedrus decurrens) ..................................... 8 .35 45 26 3.3 5.7 81 70 81 97 47 53
Cedar, Port Orford (Chamaecyparis lawsoniana) .......................... 14 .40 36 29 4.6 6.9 106 82 90 168 48 70
Cedar, eastern red (Juniperus virginiana) ................................ 5 .44 37 33 4.7 7.8 87 60 87 80 61 114
Cedar, western red (Thuja plicata) ........................................... 15 .31 27 23 2.4 5.0 76 60 74 106 38 52
Cedar, northern white (Thuja occidentalis) ....................................
Cedar, southern white (Chamaecyparis thyoides) .........................
Hemlock, mountain (Tsuga mertensiana) .................................. 10 .31 26 23 2.8 5.2 83 53 61 93 35 41
Hemlock, eastern (Tsuga canadensis) ....................................... 26 .42 50 32 3.8 6.2 104 79 92 156 52 76
Douglas fir (Pseudotsuga taxifolia) (Coast type) .........................
Douglas fir (Pseudotsuga taxifolia) (Inland Empire type) ............. 10 .41 37 31 4.1 7.6 112 80 90 159 58 72
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type) ........ 10 .40 30 30 3.6 6.2 103 75 83 142 52 67
Fir, alpine (Abies lasiocarpa) ............................................... 5 .31 28 23 2.5 7.1 92 51 57 92 33 36
Fir, balsam (Abies balsamea) ................................................ 5 .34 45 26 2.8 6.6 103 59 67 91 31 50
Fir, corkbark (Abies amabilis) ............................................. 10 .28 29 21 2.4 7.4 90 51 57 104 27 38
Fir, lowland white (Abies grandis) ....................................... 10 .37 44 28 3.2 7.2 105 72 82 156 43 72
Fir, noble (Abies nobilis) .................................................... 9 .35 36 26 4.5 8.3 126 74 76 150 39 68
Fir, California red (Abies magnifica) ..................................... 5 .37 48 27 3.8 6.9 114 74 74 134 52 72
Fir, silver (Abies amabilis) .................................................. 6 .35 36 27 4.5 10.0 114 70 76 147 37 70
Fir, white (Abies concolor) ................................................. 20 .35 47 26 3.2 7.0 95 72 73 127 42 60
Fir, white (average of four species) ...................................... 45 .35 41 26 3.8 7.9 110 72 76 141 41 69
Hemlock, eastern (Tsuga canadensis) ..................................... 20 .38 50 28 3.0 6.8 98 72 79 121 51 67
Hemlock, mountain (Tsuga mertensiana) ................................ 10 .43 44 33 4.4 7.4 114 81 88 131 64 99
Hemlock, western (Tsuga heterophylla) .................................... 18 .38 41 29 4.3 7.9 120 74 84 144 50 73
Juniper, alligator (Juniperus pinchonii) ................................ 3 .48 42 26 2.7 3.6 73 63 70 107 43 61
Larch, western (Larix occidentalis) ...................................... 13 .48 48 36 4.2 8.1 129 89 104 163 64 81
Pine, jack (Pinus banksiana) ................................................ 5 .39 50 30 3.4 6.5 102 64 73 111 48 78
Pine, Jeffrey (Pinus jeffreyi) ............................................... 5 .37 47 28 4.4 6.7 103 68 71 116 43 63
Pine, limber (Pinus flexilis) ................................................ 2 .37 39 28 2.4 5.1 80 69 69 107 39 54
Pine, loblolly (Pinus taeda) ................................................. 10 .50 54 38 5.5 7.5 127 93 104 166 62 93
Pine, lodgepole (Pinus contorta) ......................................... 28 .38 39 29 4.5 6.7 114 67 74 128 41 60
Pine, longleaf (Pinus palustris) ......................................... 34 .45 50 41 5.3 7.4 124 106 123 185 76 103
Pine, mountain (Pinus pungens) .......................................... 5 .49 54 37 3.4 6.8 107 91 93 151 64 92
Pine, northern white (Pinus strobus) .................................... 18 .34 36 25 2.3 6.0 83 63 67 119 35 55
Pine, Norway (Pinus resinosa) ........................................... 5 .44 42 34 4.6 7.2 116 85 91 163 46 84

1 Quercus ellipsoidalis, Q. laurifolia, Q. palustris, Q. borealis, Q. coccinea, Q. rubra Q. rubra, papyrifera, Q. nigra, and Q. phellos.
2 Quercus macrocarpa, Q. montana, Q. stellata, Q. prinus, Q. bicolor, and Q. alba.
3 Species under footnotes 7 and 8 combined.
4 Abies grandis, A. mobilis, A. amabilis, and A. concolor.
### Table 7: Average properties of container woods grown in the United States—Continued

<table>
<thead>
<tr>
<th>Common and botanical name of species</th>
<th>Trees tested</th>
<th>Specific gravity, oven-dry, based on volume when green</th>
<th>Weight per cubic foot</th>
<th>Shrinkage from green to oven-dry condition based on dimensions when green</th>
<th>Composite strength values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Green</td>
<td>At 12 percent moisture content</td>
<td>Radial</td>
<td>Tangential</td>
</tr>
<tr>
<td>Pine, pitch (Pinus rigida)</td>
<td>10</td>
<td>.45</td>
<td>50</td>
<td>34</td>
<td>4.0</td>
</tr>
<tr>
<td>Pine, pond (Pinus rigida serotina)</td>
<td>5</td>
<td>.50</td>
<td>49</td>
<td>38</td>
<td>5.1</td>
</tr>
<tr>
<td>Pine, sand (Pinus clausa)</td>
<td>5</td>
<td>.45</td>
<td>38</td>
<td>34</td>
<td>3.9</td>
</tr>
<tr>
<td>Pine, shortleaf (Pinus echinata)</td>
<td>12</td>
<td>.49</td>
<td>51</td>
<td>38</td>
<td>5.1</td>
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<tr>
<td>Pine, slash (Pinus caribaea)</td>
<td>10</td>
<td>.64</td>
<td>56</td>
<td>48</td>
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<tr>
<td>Pine, sugar (Pinus lambertiana)</td>
<td>9</td>
<td>.35</td>
<td>51</td>
<td>25</td>
<td>2.9</td>
</tr>
<tr>
<td>Pine, western white (Pinus monticola)</td>
<td>14</td>
<td>.36</td>
<td>35</td>
<td>27</td>
<td>4.1</td>
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<tr>
<td>Pine, western yellow (Pinus ponderosa)</td>
<td>31</td>
<td>.38</td>
<td>45</td>
<td>28</td>
<td>3.9</td>
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<tr>
<td>Spruce, black (Picea mariana)</td>
<td>5</td>
<td>.38</td>
<td>32</td>
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<td>4.1</td>
</tr>
<tr>
<td>Spruce, Engelmann (Picea engelmannii)</td>
<td>10</td>
<td>.31</td>
<td>39</td>
<td>23</td>
<td>3.4</td>
</tr>
<tr>
<td>Spruce, red (Picea rubra)</td>
<td>11</td>
<td>.38</td>
<td>45</td>
<td>23</td>
<td>3.8</td>
</tr>
<tr>
<td>Spruce, Sitka (Picea stichtensis)</td>
<td>25</td>
<td>.37</td>
<td>33</td>
<td>29</td>
<td>4.3</td>
</tr>
<tr>
<td>Spruce, white (Picea glauca)</td>
<td>15</td>
<td>.37</td>
<td>35</td>
<td>25</td>
<td>4.7</td>
</tr>
<tr>
<td>Spruces (average of red, white, and Sitka)</td>
<td>51</td>
<td>.37</td>
<td>34</td>
<td>28</td>
<td>4.3</td>
</tr>
<tr>
<td>Tamarack (Larix laricina)</td>
<td>5</td>
<td>.49</td>
<td>47</td>
<td>37</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Percentage estimated probable variation of species average when based on five trees:
- Pine, pitch: 2.1%
- Pine, pond: 5.2%
- Pine, sand: 4.0%
- Pine, shortleaf: 3.9%
- Pine, slash: 2.5%
- Pine, sugar: 3.3%
- Pine, western white: 3.2%
- Pine, western yellow: 2.8%
- Spruce, black: 5.0%
- Spruce, Engelmann: 6.0%
- Spruce, red: 7.0%
- Spruce, Sitka: 8.0%
- Spruce, white: 9.0%
- Spruces: 10.0%

Percentage estimated probable variation of an individual piece:
- Pine, pitch: 8.0%
- Pine, pond: 12.0%
- Pine, sand: 14.0%
- Pine, shortleaf: 16.0%
- Pine, slash: 18.0%
- Pine, sugar: 20.0%
- Pine, western white: 23.0%
- Pine, western yellow: 25.0%
- Spruce, black: 28.0%
- Spruce, Engelmann: 30.0%
- Spruce, red: 30.0%
- Spruce, Sitka: 32.0%
- Spruce, white: 35.0%
- Spruces: 37.0%

For percentage estimated probable variation when based on different number of trees see Comparative Strength Properties of Woods Grown in the United States (16).
The properties for which values are given in Table 7 are important factors in the design of boxes and crates, but the choice of species is seldom based upon them alone but is based upon the combination of these properties with cost, availability, nail-holding power, tendency to split in nailing, tendency to check and warp in seasoning or with changes of moisture content subsequent to seasoning, color, odor, taste, and other properties and characteristics that can not be expressed numerically.

WEIGHTS OF LUMBER

The unit weight or density is an important consideration in selecting wood for a particular use. Weight not only directly influences the cost both of handling and of transportation, but the weight of dry wood per cubic foot is a very good measure of its strength (11) and nail-holding power. Density or weight of dry wood per cubic foot also roughly indicates the shrinking and warping likely to occur with changes in moisture content. Heavy, dense woods are especially desirable where high nail-holding power is important but require more care in nailing to prevent splitting and are less desirable where shrinking and warping must be avoided. The lighter woods, as a rule, give less trouble in seasoning, manufacture, and in storing as lumber, shooks, or completed containers, and may, therefore, be more desirable.

The weight of dry lumber per thousand board feet varies from about 1,800 pounds for very light woods to over 4,000 pounds for very heavy woods. A definite way of expressing the weight of wood is in pounds per cubic foot or per square foot of a specified thickness at a given moisture content or degree of dryness. The approximate average weights of various woods per cubic foot and per square foot of different thicknesses are given in Table 8 for convenience in making comparisons and in estimating weights of containers.
<table>
<thead>
<tr>
<th>Common name of species</th>
<th>Weight per cubic foot</th>
<th>Weight per square foot for actual thickness in inches of—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>GROUP 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspen</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Aspen, latifolius</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Basswood</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Beeche</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cedar, northern white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cedar, Port Oxford</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cedar, western red</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Chesnut</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cottonwood, black</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cottonwood, western</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Cypress, southern</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, alpine.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, balsam.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, California red.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, lowland white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, noble.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, silver.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Fir, white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Magnolia, cucumber</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Magnolia, eucalyptus</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, jack</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, lodgepole.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, northern white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, Norway.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, sugar.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, western white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Pine, western yellow</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Poplar, yellow.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Redwood</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Spruce, Engelmann</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Spruce, red.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Spruce, Stika.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Spruce, white.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Willow, black.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Willow, western black.</td>
<td>25</td>
<td>2.25</td>
</tr>
</tbody>
</table>

**GROUP 2**

<table>
<thead>
<tr>
<th>Common name of species</th>
<th>Weight per cubic foot</th>
<th>Weight per square foot for actual thickness in inches of—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fir, Douglas.</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Hemlock, eastern</td>
<td>25</td>
<td>2.25</td>
</tr>
<tr>
<td>Tree Type</td>
<td>Group 3</td>
<td>Group 4</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Ash, black</td>
<td>34</td>
<td>49</td>
</tr>
<tr>
<td>Ash, pumpkin</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Elm, American</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Gum, black</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>Gum, red</td>
<td>34</td>
<td>44</td>
</tr>
<tr>
<td>Gum, tupelo</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>Maple, silver</td>
<td>33</td>
<td>44</td>
</tr>
<tr>
<td>Sycamore</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>Ash, green</td>
<td>40</td>
<td>49</td>
</tr>
<tr>
<td>Ash, white</td>
<td>42</td>
<td>49</td>
</tr>
<tr>
<td>Beech</td>
<td>45</td>
<td>49</td>
</tr>
<tr>
<td>Birch, sweet</td>
<td>46</td>
<td>49</td>
</tr>
<tr>
<td>Birch, yellow</td>
<td>43</td>
<td>49</td>
</tr>
<tr>
<td>Elm, rock</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>Elm, slippery</td>
<td>37</td>
<td>49</td>
</tr>
<tr>
<td>Hackberry</td>
<td>37</td>
<td>49</td>
</tr>
<tr>
<td>Hickory, pecan and true (average of eight species)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Maple, black</td>
<td>40</td>
<td>49</td>
</tr>
<tr>
<td>Maple, sugar</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>Oak, red</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>Oak, white</td>
<td>48</td>
<td>49</td>
</tr>
</tbody>
</table>
FACTORS THAT INFLUENCE THE WEIGHT OF WOOD

Even in the same species of wood there is considerable variation in the weight of lumber because of differences in density. Pieces containing a high percentage of summer wood, which is the harder layer of the annual-growth ring, have more wood substance and are therefore denser and heavier than pieces containing a lower percentage of summer wood. The swelled butts of trees of some species, such as red gum, tupelo gum, and ash grown in swampy soil, usually contain very light wood with low-strength properties, while higher in the same trees the wood is heavier and stronger.

The water in green wood often weighs more than the wood itself, but in thoroughly air-dry lumber the weight of water is usually 12 to 15 per cent of the weight of wood free of moisture (oven-dry) and in kiln-dry lumber it is often as low as 5 per cent of the weight of wood.

The weight of some pieces of certain species, such as southern yellow pine, western larch, and Douglas fir, is often materially increased by the presence of resin or gum.

FACTORS INFLUENCING THE STRENGTH OF WOOD

The term "strength" as here used is the capacity to resist stress of a single kind, such as strength in tension, strength in compression parallel or perpendicular to the grain, in shear, and strength in bending or shock-resisting capacity.

SPECIFIC GRAVITY

Either the specific gravity or the dry weight of wood furnishes a ready means of estimating the comparative strength of two pieces of wood. Practically all the strength properties increase with the specific gravity of the wood but do not all increase in the same ratio (II).

MOISTURE CONTENT

The moisture content is one of the principal factors affecting the strength of wood. As wood dries, most of its strength properties are increased. This increase in strength, however, does not take place until the drying has reached the fiber-saturation point, the condition in which the cell cavities are empty but the cell walls are fully saturated, which is usually at from 25 to 30 per cent moisture content. Figure 22 shows the relation between moisture content and some of the strength properties of a single species. Clear material of the thicknesses ordinarily used for containers, dried to 12 per cent moisture content, may be fully twice as strong in bending as green material, and when kiln dried to 5 per cent its bending strength may be tripled. All the strength properties do not increase in the same ratio with decrease in moisture below the fiber-saturation point. While the average bending strength increases about 4 per cent for each 1 per cent decrease in moisture content at or near 12 per cent, the stiffness increases only 2 per cent. The average shock resistance usually changes but little with change in moisture content.

COMPARISON OF VERTICAL GRAIN WITH FLAT GRAIN

It is common belief that quarter-sawed lumber is stronger in bending than plain-sawed or flat-grain lumber. In tests made by the Forest Products Laboratory, however, no difference of significance in either static bending strength or shock resistance was found between quarter-sawed and flat-grain pieces. Investigation has also shown that in general sapwood is neither stronger nor weaker than heartwood of the same grade, species, and density.

COMPARISON OF SAWED LUMBER WITH ROTARY-CUT LUMBER

Investigations by the Forest Products Laboratory have demonstrated that it is practically impossible to detect any difference in the bending strength or stiffness parallel to the grain of sawed lumber and rotary-cut lumber of the same grade and thickness.

DEFECTS IN CONTAINER MATERIAL

A defect is any irregularity occurring in or on wood that may lower some of the strength, durability, or utility values. Boxes and crates are ordinarily made of low-grade lumber containing defects, some of which seriously affect
A, Bottom view, and B, side view of a typical bending failure caused by cross grain; C, cross section through a honeycombed plank; D, collapse in boards of different thicknesses
Variations caused by changes in moisture content

<table>
<thead>
<tr>
<th>Moisture per cent</th>
<th>Crushing strength at max. load</th>
<th>Modulus of rupture</th>
<th>Modulus of elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>30</td>
<td>1.04</td>
<td>1.03</td>
<td>1.01</td>
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<tr>
<td>25</td>
<td>1.25</td>
<td>1.19</td>
<td>1.10</td>
</tr>
<tr>
<td>20</td>
<td>1.48</td>
<td>1.36</td>
<td>1.17</td>
</tr>
<tr>
<td>15</td>
<td>1.77</td>
<td>1.55</td>
<td>1.25</td>
</tr>
<tr>
<td>10</td>
<td>2.19</td>
<td>1.75</td>
<td>1.31</td>
</tr>
<tr>
<td>5</td>
<td>2.76</td>
<td>2.08</td>
<td>1.37</td>
</tr>
<tr>
<td>0</td>
<td>3.45</td>
<td>2.40</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Figure 22.—Effect of moisture content of wood on strength of small clear specimens of western hemlock.
the strength properties important in containers. Defects that do not appreciably affect the properties important in container material should be allowed in order that waste and cost may be kept at a minimum.

**CROSS GRAIN**

Cross grain (28), in which the wood cells or fibers do not run parallel with the axis or sides of a piece, is one of the most serious defects affecting box and crate material. It reduces the strength in bending and also increases the susceptibility of wood to splitting when nails are driven. Such cross grain occurs in three distinct ways: (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) by sawing lumber at an angle to the axis of the tree. Cross grain is often very difficult to detect except where checks, which invariably follow the grain, are present. Cross grain having a slope from the edge of the board not exceeding 1 in 12 does not materially affect the strength of the piece for container purposes if the piece is used for crate members or as cleats for box ends. For box sides, tops, and bottoms the slope of the grain may be 1 in 10 without impairing the strength of the box. The slope, however, should not exceed these ratios. A typical bending failure in a piece of wood containing excessive cross grain is illustrated in Plate 31, A.

**KNOTS**

Knots are the most common defects in lumber. Their weakening of the bending strength of lumber is practically proportional to their effective diameter as measured across 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 the piece. 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 running out into the limb and those passing around the limb and continuing in the main body produce cross grain. Because of the difference in the strength of wood parallel to and perpendicular to the grain, the weakening effect of knots results mainly from the cross grain around them. Checks also develop in knots during seasoning and thus further reduce the strength of knotty lumber. Knot holes and encased knots have no more effect on the bending strength of lumber than intergrown knots because they are accompanied by less cross grain.

**DETERIORATION IN SEASONING**

Many of the defects, such as checking, warping, and decay, that cause weaknesses in containers, occur while the lumber is in storage or during the process of seasoning (21). The extent of such deterioration depends upon the kind of wood, the conditions of seasoning, and the care exercised in piling the lumber. Some of these defects can be prevented entirely, while others can be eliminated only in part.

**CHECKING**

Checking is due to stresses set up by nonuniform shrinkage. End checking is caused by the wood drying more rapidly at the ends than away from the ends where the drying takes place from the sides only. End checking can often be avoided by painting or coating the ends (21) to retard their drying or by reducing the circulation of air around them. Checks reduce the holding power of nails and may develop into splits running the full length of the piece. Surface checks result from the surface drying faster than the interior. Frequently surface checks, formed during the early stages of drying, close up and become invisible during the latter drying. Shrinkage of the central portion of a piece of wood after the surface has dried and set may cause the core or center to check, forming honeycomb. (Pl. 31, C.) These difficulties can be largely overcome by preventing too rapid drying of the surface.

**CUPPING**

By cupping is meant the curvature of lumber across the grain or width of a piece, which gives it a troughlike appearance. It may be caused by one side drying more rapidly than the other, in which event it is usually temporary. When plain-sawed lumber is dried with insufficient weight on it or is improperly stickered, permanent cupping takes place. In plain-sawed lumber the side that has been toward the center of the tree shrinks less than the other side and thus has a tendency to cause such lumber to cup in drying.
BOWING AND TWISTING

Bowing and twisting are often caused by spiral or by interlocked grain, by differences in longitudinal shrinkage between different parts of the piece, and by other irregularities in structure. These troubles can be prevented to some extent by piling carefully, using sufficient stickers of proper quality and well aligned, leaving no unsupported ends, and weighting the boards both during and after drying.

CASEHARDENING

Casehardening or surface hardening in lumber is caused by too rapid surface drying. It results in stresses being set up in the piece which may cause warping, when the lumber is resawed.

COLLAPSE

An abnormal type of shrinkage that occasionally takes place in drying certain kinds of lumber is called "collapse." The surfaces of collapsed lumber have a caved-in or corrugated appearance when it has been dried. (Pl. 31, D.) Collapse, which occurs only in a few species, results from the cells of the wood collapsing as the water leaves them during the drying process. It does not occur in the sapwood or at the ends or edges of the lumber where air can readily enter the wood to replace the water and thus prevent it. Avoiding collapse is very difficult, although it is more likely to occur in wood green from the saw that is dried in kilns at high temperatures than in air seasoning or in kiln drying at lower temperatures.

BLUE STAIN

Blue stain, or sap stain, is a blue discoloration of the sapwood. It is very common in the pines and red gum and occurs also in the sapwood of other species. Blue stain is due to a fungus that lives on the sap in the cells. It does not destroy the wood or injure its strength, and is objectionable chiefly on account of the discoloration it produces. Its presence, however, is an indication that the material has been subjected to conditions conducive to the growth of wood-destroying fungi. Bad staining may make the presence of decay hard to detect.

Blue stain may occur in the log or in freshly sawed lumber. The fungus which produces blue stain can thrive only as long as the sapwood is moist; therefore converting logs into lumber promptly and piling the lumber so that it will season as rapidly as possible greatly arrests, though it does not prevent, this discoloration (20). Under such conditions the stain may penetrate all of the sapwood in a few days. If lumber is not blue stained when placed in a kiln, kiln drying will prevent blue staining, provided the lumber is subsequently kept dry. Kiln drying the lumber immediately after sawing, however, is ordinarily done only with the higher grades, although some mills also run the lower grades of lumber through a kiln. Another preventive measure, although not always completely effective, consists in dipping the lumber as it comes from the saw in an antiseptic solution, such as sodium bicarbonate. Occasionally, blue-stained lumber is dipped in stains of various colors to give it a more pleasing appearance.

BROWN STAINS

Brown stains are brown discolorations occurring in wood. They occur during both air seasoning and kiln drying and are sometimes called yard brown stain and kiln brown stain. The yard brown stains occur as a yellow to dark-brown discoloration, chiefly in air-seasoned sapwood and heartwood stock of sugar pine, western yellow pine, and northern white pine. The kiln brown stain is also yellow to dark brown in color and develops during kiln drying of the heartwood and sapwood stock of the species just mentioned. Kiln brown stain is of a chemical nature. The brown stain occurring during air seasoning, while definitely known in some cases to be due to a chemical reaction, in other cases may be due to fungous action. The cause of the chemical brown stains is not positively known. When brown stain occurs, it is usually just below the surface of rough boards and is therefore seldom detected until after planing. The foregoing brown stains do not injure the strength of wood, nor are they an indication that decay might be present. There are, however, brown discolorations due to both wood-destroying fungi and to too high kiln temperatures, both of which are injurious to the strength properties of wood.
Decay is a disintegration of the wood substance resulting from the action of wood-destroying fungi (17). Decay is sometimes found in low-grade material used for containers. It very seriously affects the strength properties and nail-holding power of the wood and should not be allowed in parts where strength is important.

In order that decay may take place, the wood must be moist and the temperature not too low. Wood dried below 20 per cent moisture content and kept from reabsorbing moisture rarely decays; therefore, box and crate lumber dried to a moisture-content range from 12 to 18 per cent practically does not decay as long as it remains in that condition. Although decay is not so rapid in action as sap stain, it may seriously reduce the strength of some woods in three or four months during warm weather, especially when close piled. Decay, including the so-called dry rot, can be prevented in stored lumber (9) by piling it properly under sanitary conditions and keeping it dry.

**INSECT ATTACK**

Certain woods are subject to insect attack in the green lumber, some in dry lumber, and some in insufficiently seasoned lumber. The sapwood of some seasoned hardwoods is subject to attack by an insect known as the powder-post beetle. Hickory, ash, and oak are most subject to this injury, but maple, butternut, elm, poplar, sycamore, and other species are also attacked. The chestnut lumber that is available for boxes and crates almost always contains small wormholes (7). These, however, have only a very slight effect on the strength, and if the material is otherwise sound, it is quite satisfactory for this purpose. Some countries in order to avoid the introduction of injurious pests prohibit the entrance of products made from lumber which has been attacked by insects.

**PLYWOOD**

In designing shipping containers it is not always possible to so proportion the dimensions of lumber as to obtain uniformly the necessary strength. This is caused by the difference in the strength properties of the wood parallel to and perpendicular to the grain. The difficulty can, to a large extent, be overcome by building up plywood to obtain greater equality of properties in the two directions. A symmetrical plywood construction with minimum tendency to warp may be produced by gluing an odd number of sheets of veneer or rotary-cut lumber together with the grain of each piece at right angles to that of the piece next to it.

The strength properties of plywood depend upon the species of wood and the number and thicknesses of the plies. Table 9 affords data on the effect of the number of plies on the strength properties of plywood of the same total thickness. This table shows that increasing the number of plies decreases the strength parallel to the face plies and increases the strength perpendicular to the face plies. Consequently, the strengths in the two directions become more nearly equal as the number of plies is increased. Table 9 shows also that the resistance of plywood to splitting increases rapidly with the number of plies. When plywood is composed of a very large number of plies of the same thickness or if the middle layer of 3-ply stock is about seven-tenths the total thickness, the bending strength is about the same either parallel or perpendicular to the grain of the face plies (4, 5).

### Table 9.—Effect of the number of plies on the strength properties of plywood of the same total thickness

<table>
<thead>
<tr>
<th>Number of plies</th>
<th>Bending strength</th>
<th>Strength in tension</th>
<th>Resistance to splitting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parallel</td>
<td>Perpendicular</td>
<td>Ratio of perpendicular to parallel</td>
</tr>
<tr>
<td></td>
<td>Per cent</td>
<td>Per cent</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
<td>167</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>72</td>
<td>185</td>
<td>54</td>
</tr>
<tr>
<td>9</td>
<td>51</td>
<td>182</td>
<td>72</td>
</tr>
</tbody>
</table>

1 "Parallel" means with stress parallel to grain of face plies.
2 "Perpendicular" means with stress perpendicular to grain of face plies.
A further advantage of plywood is that its dimensions change very little with changes in moisture content. A glued joint is more likely to fail where plywood is made of thick plies than where it is made of thin plies because greater stresses in the thick material are occasioned by the tendency to shrink or swell with changes in moisture content. Plies one-tenth inch or more in thickness are likely to fail either in the glue or in the wood under such stresses.

**Comparison of Kiln Drying and Air Drying**

The relative merits of kiln drying lumber as compared with air drying it depend upon a number of considerations. Therefore, no general statement can be made in favor of the one or the other process that will hold for all conditions. Enough experimental work has been done, however, to indicate that with proper care all kinds of lumber can be dried in a kiln with results fully as good in quality of output as those that can be obtained with air drying. Although low-grade lumber is used for boxes and crates the strength properties are of prime importance and improper kiln drying will render the lumber unsuitable for this purpose. (See Appendix C.)

The two principal advantages of kiln drying over air drying are that it reduces the time required to dry the lumber and that the lumber can be dried to the desired moisture content even during damp weather without detriment to strength. Lumber 1 inch thick requires from two months to a year for air drying, but green stock of this thickness can, as a rule, be kiln-dried for box purposes in 15 days or less. Veneer or rotary-cut lumber three-sixteenths inch thick requires from 6 to 12 days for air drying; the same material can be kiln-dried in about 12 hours.

**Special Requirements of Container Woods**

**Taste and Odor**

Containers for some kinds of food must be free from taste or odor that will taint the contents. There is little systematic information on the taste and odor imparted to foodstuffs by various woods (2, 10, 22, 26). Seemingly, a wood may be entirely satisfactory for one commodity but may seriously taint another commodity. Some woods have a very strong odor when green that is not present when the wood is dry. It is advisable to thoroughly test woods for objectionable tastes and odors before using them for food containers.

**Capacity to Stay in Place**

Shrinking, cupping, bowing, and twisting are occasioned by the drying of lumber but do not occur until the wood has reached the fiber-saturation point. Woods containing cross or interlocked grain bow or twist more with drying than straight-grained wood. The softwoods or coniferous species usually shrink and swell less with changes in moisture content and therefore stay in place where built into a container better than the hardwoods. Twisting and cupping of the lumber place additional stress on the nails, thereby reducing the effective strength of the container in withstanding the hazards of transportation.

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**Appendix B. Container Woods**

**Distribution of Container Woods**

The chief factors influencing the choice of species of wood for shipping containers are cheapness, availability (9), light weight, and freedom from splitting, and for some commodities lack of imparting taste and odor. Boxes and crates are usually manufactured from the lower grades of lumber. In some of the Eastern States mill-run second-growth stock is used for box construction, and in the Western States the log run cut from certain of the little-used species is sometimes used. In all regions of the United States many boxes and crates are manufactured of rotary-cut lumber or veneer from very high-grade logs.

The species and grade of lumber used in any region is determined by economic conditions including the transportation facilities available. Some of the largest box-manufacturing States produce little of the lumber used for boxes. In some States this situation is occasioned by a lack of local timber. In other States local species are available to meet the needs for containers, but are not used
because of the large amount of low-grade lumber produced in other States, which is shipped in and sold at a price below that of the local species.

Large quantities of nailed and locked-corner boxes and some wire-bound boxes are manufactured in the New England States from second-growth northern white pine. Birch plywood from virgin stands and spruce cleats from second-growth stands are also manufactured in the New England States in large quantities for use in boxes. In Virginia and North Carolina second-growth southern yellow pine furnishes most of the wood for nailed boxes and red gum most of the rotary-cut lumber for plywood boxes. Georgia and Florida produce much rotary-cut southern yellow pine that is used locally for fruit and vegetable containers. The States in the lower Mississippi Valley not only supply material for their own containers but also supply much rotary-cut and sawed red gum and southern yellow pine to the box industry of the North Central States. In the Pacific coast and Rocky Mountain regions, western yellow pine, Sitka spruce, western hemlock, Douglas fir, and white fir are the woods most used for boxes and crates. The northern Central States use large quantities of their local species, but these do not meet all their needs. Northern white pine is the principal local species used in the northern Central States for boxes and crates though smaller quantities of eastern hemlock, basswood, aspen, beech, birch, and maple are used. The beech, birch, and maple are used principally for crating, for resawed wire-bound boxes, and for plywood boxes.

New Jersey, Illinois, New York, and Pennsylvania are among the largest box-manufacturing and box-consuming States; yet they produce relatively little box lumber. Ohio, Maryland, and Indiana are of medium rank in box manufacturing, yet they also produce little box lumber. Colorado has an abundant stand of local timber; yet most of the box shooks used there are shipped in from the Pacific coast and the Inland Empire. The annual combined cost of material used for packing boxes and for fruit and vegetable packages in the United States (13,24) for 1925 is illustrated graphically in Figure 23. The States in the lower Mississippi Valley and those on the Pacific coast, which are the largest lumber-producing States, consume a relatively small amount of the lumber used for boxes and crates.

To satisfy the demand in the northern Central and Eastern States for containers, large quantities of box lumber and box shooks are brought from distant points. From the region south of the Ohio and Potomac Rivers box lumber moves northward to consuming points in two general currents, separated by the

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Figure 23.—Annual percentage of cost of material for the manufacture of packing boxes and fruit and vegetable packages, by regions, for 1925

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Appalachian Mountains; second-growth loblolly and other southern yellow pine from Virginia and the Carolinas goes northward east of the Allegheny Mountains as far as Rhode Island and Connecticut, while from the Central and Gulf States species such as southern yellow pine, red gum, cypress, and cottonwood move approximately northward. Illinois, Indiana, Ohio, and southern Michigan are common meeting grounds for competition among woods from different regions. Northern white pine from the Lake States, principally Minnesota, Wisconsin, and northern Michigan, goes into Chicago and its vicinity in competition with southern yellow pine and red gum from the South, and western yellow pine and Sitka spruce from the Pacific coast. These western species are also shipped through the Panama Canal to the Atlantic seaboard.

CLASSIFICATION OF CONTAINER WOODS

To facilitate the selection of species of wood for use in box design, the principal woods used for shipping containers have been divided into four groups, as listed on pages 103 and 104. Many of the woods included in this classification are available only in limited quantities; however, many of them may be mixed together to furnish boxes in large quantities, and it is therefore important to know which species may be mixed for use as a single species in design.

Of the 32 species of wood listed, probably 10 furnish less than 5 per cent of the total lumber used for boxes and crates; however, even this small percentage of these species amounts to more than 150,000,000 board feet of lumber annually for boxes and crates.

In classifying these woods, consideration has been given to their nail-holding power, tendency to split in nailing, strength as a beam, and shock-resisting capacity. In any classification of this sort there are certain to be some kinds of wood that are on the border line between two groups in some particular property; therefore no classification will accurately fit all species. This grouping does not mean that the species within a group are equal in every respect for containers, nor does it mean that the woods in one group are better for all containers than the woods in another group, but it does mean that the woods in each group as a whole possess outstanding characteristics that make them the best for particular types of containers and conditions of service. This is also true to some extent for species within a group, but, in general, specifications that produce a well-balanced container from one species will likewise produce a well-balanced container from other species within the same group. In other words, the species within a group may be mixed together or used interchangeably under the same specification without any great error.

Group 1 embraces the softer woods of both the coniferous and the broad-leaved species. These woods are relatively free from splitting in nailing, have moderate nail-holding power, moderate strength as a beam, and moderate shock-resisting capacity. They are soft, light in weight, easy to work, hold their shape well after manufacture, and, as a rule, are easy to dry.

Group 2 consists of the heavier coniferous woods and includes no hardwood species. These woods usually have a pronounced contrast in the hardness of the spring wood and the summer wood. They have greater nail-holding power than the Group 1 woods, but are more inclined to split and the hard summer wood bands often deflect the nails and cause them to run out at the side of the piece.

Group 3 consists of hardwoods of medium density. No coniferous species are included. These woods have about the same nail-holding power and strength as a beam as the Group 2 woods, but are less inclined to split and shatter under impacts. Group 3 species are the most useful woods for box ends and cleats. They also furnish most of the rotary-cut lumber for wire-bound and plywood boxes.

Group 4 woods are hardwood species. They have both the greatest shock-resisting capacity and the greatest nail-holding power, but, because of their extreme hardness, they present difficulties with respect to the driving of nails and also have the greatest tendency to split at the nails. They are the heaviest and hardest domestic woods and are quite difficult to work. They are especially

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6 This classification of species of wood was first made in 1913. It has been widely accepted by interested organizations, such as the American Society for Testing Materials, various box manufacturers' associations, Bureau of Explosives, Commodity Freight Classification Committee, Railway Express Agency, Freight Container Bureau, National Canners' Association, National Wholesale Grocers' Association, U. S. War Department, and Federal Specification Board. It has been included in practically all principal specifications for boxes and crates as a basis for defining requirements both for thicknesses of box and crate parts and for nailing.
useful where high nail-holding power is required, and many of them make excellent rotary-cut lumber for wire-bound and plywood boxes.

In selecting container woods it is well to know not only to what extent the species possess the different properties on which the grouping is based but also their availability and those of their general characteristics that are not indicated by this grouping or by the tabulated figures given in Tables 1, 2, 3, 4, 7, and 8. The following is a brief description of the availability and general characteristics of the more important container woods.

DESCRIPTION OF BOX AND CRATE WOODS

For convenience of comparison, the woods most similar in appearance (11) and in the properties essential for box construction are considered together. The forest regions in parenthesis following the names of the species refer to the regions in which the trees grow as indicated in Figure 24. Although the geographical distribution of each species extends beyond the limits of the regions indicated (18), these regions are the principal sources of supply of the lumber.

The comparative strength properties of the species used for containers are given in Table 7, and the nail-holding power of some of these species is given in Table 4.

GROUP 1

Group 1 includes two subgroups, as follows:

CONIFERS (SOFTWOODS)

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>COMMON NAME</th>
<th>COMMON NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar, western red.</td>
<td>Fir, white.</td>
<td>Redwood.</td>
</tr>
<tr>
<td>Fir, lowland white.</td>
<td>Pine, sugar.</td>
<td></td>
</tr>
</tbody>
</table>

Species names used in this bulletin are according to Check List of Forest Trees of the United States (18). Scientific names are given in Table 7.
BOX AND CRATE CONSTRUCTION

BROAD-LEAVED (HARDWOODS)

COMMON NAME

Aspen, largetooth. Cottonwood, black. Willow, black.
Butternut. Magnolia, cucumber. The names in parentheses refer to the forests in which the trees grow as indicated in Figure 24.
Buckeye, yellow. Magnolia, evergreen.

The Group 1 species furnish about one-half of the total lumber used for boxes and crates. Most of the lumber furnished by the group is northern and western white pine and western yellow pine. Jack pine, lodgepole pine, Norway pine, the spruces, and the true firs are other species of Group 1 that resemble the white pines and western yellow pine in general appearance and in some properties.

The most effective way to describe species is to classify them into small groups and to compare them within such groups as follows:

The greatest production of northern white pine box lumber is in the New England States. The wood from the white pines is light colored and straight grained, and the annual growth rings are distinct even though they are without a pronouncedly harder and denser summer-wood band. The heartwood of the northern white pine and western white pine is cream colored to light reddish or yellowish brown, but the heartwood of sugar pine is light brown and seldom reddish. The wood from the white pines has a slight, pleasantly resinous odor, but the wood is almost tasteless except that the sugar pine may have resinous exudations, which give it a sweetish taste. The wood of sugar pine often has a slightly coarser texture than that of the other white pines. The white pines shrink and swell less than most woods. The old-growth northern white pine warps the least of any of the native softwood species.

Jack pine (northern portion of northern forest).
Lodgepole pine (northern and central portions of Rocky Mountain and upper portion of Pacific forests).
Norway pine (northern portion of northern forest).
Western yellow pine (Rocky Mountain and southern portion of Pacific forests).

The pines listed above are similar in appearance and properties to the white pines. Western yellow pine in merchantable stands has the widest geographical distribution of any species in North America. Most of the box lumber from western yellow pine is produced in the Pacific Coast States and in Idaho. The wood from the jack, lodgepole, Norway, and western yellow pines is light colored and straight grained. The annual rings of the young trees have a distinct band of summer wood, whereas the summer-wood layers in the outer annual rings of the old trees may be narrow and inconspicuous. These pines have a resinous odor but are almost tasteless. The wood shrinks and swells slightly more than the white pines but is harder and holds nails better. Lodgepole pine is not generally used for containers but will no doubt be more in demand in the future. There is evidence that boxes made of this wood when properly dried are equivalent in strength to those made of western yellow pine.

Engelmann spruce (Rocky Mountain forest).
Red spruce (eastern half of northern forest).
Sitka spruce (upper half of Pacific forest).
White spruce (northern portion of northern forest).

The wood of the foregoing species resembles that of the white pines in texture, but has a silky sheen. The heartwood of the white, red, and Engelmann spruce is as light colored as the sapwood, but the heartwood of the Sitka spruce has a reddish tinge. The annual rings of the spruces are clearly defined by a distinct band of summer wood. The pocked or dimpled appearance on the split tangential surfaces of Sitka spruce serves to distinguish it from the reddish-tinged pieces of Douglas fir, a Group 2 wood. The nailing qualities and the strength properties of the spruces are similar to the properties of the white pines except that the spruces are tougher. The spruces are practically tasteless and odorless.

Alpine fir (Rocky Mountain and upper half of Pacific forests).
Balsam fir (northern forest).
California red fir (lower half Pacific forest).
Lowland white fir (upper halves of Rocky Mountain and Pacific forests).
Noble fir (upper half of Pacific forest).
Silver fir (upper half of Pacific forest).
White fir (lower halves of Rocky Mountain and Pacific forests).
The wood from the true firs just listed is whitish in color and often has a reddish-brown tinge, which is especially noticeable in the summer-wood bands. This condition produces a sharp color contrast in each ring, which is a distinctive characteristic in most of the woods of the true fir group. The wood is nearly uniform in density. The firs, though somewhat lighter in weight, resemble in general appearance the eastern and the western hemlocks, which are Group 2 woods. The difference in color between the spring-wood and summer-wood bands of the firs is usually sufficient to distinguish the firs from the more uniformly colored hemlocks. Alpine fir has a distinctly rank odor even when a fresh cut is made in dry wood, and white fir has a very rank odor when green. The other true firs are without marked characteristic odor or taste. Many of these firs when green contain high percentages of moisture and are more difficult to dry than the pines and the spruces. The true firs warp more and have a greater tendency to split at the nails than the white pines, spruces, and the softer yellow pines.

Northern white cedar (northern portion of northern forest).
Port Orford cedar (Pacific forest restricted range, southwest Oregon and northwest California).
Western red cedar (upper half Pacific forest).

The cedars furnish less than 1 per cent of the total lumber used for boxes and crates. The northern white cedar and western red cedar are among the softest and weakest native woods; they have very low nail-holding power and are not readily split by nails. The heartwood of red cedar is reddish brown and has a characteristic odor and a somewhat bitter taste. The annual rings are distinct, moderate in width, with a thin, but well-defined, band of summer wood. Northern white cedar often has very narrow annual rings; it resembles western red cedar in odor and taste but averages lighter in weight, has slightly lower strength properties, and usually lacks the reddish hue. Both these species are relatively free from splitting at the nails, and for best results they should be fastened with slightly larger nails than other Group 1 woods. The wood of Port Orford cedar is lighter in color, heavier, less spongy, and has higher strength properties and nail-holding power than the other cedars. It has a pronounced odor, and its taste is sometimes compared to that of ginger. The cedars are easy to dry and have low shrinkage.

Cypress and redwood are quite variable in color and weight. Commercially, the common cypress is classed as "white," "yellow," "red," or "black," although it is almost all derived from the same botanical species. The wood of the cypress and of the redwood somewhat resembles that of the cedars in appearance. The redwood, however, is tasteless and odorless, whereas the cypress, though practically tasteless, has a rancid odor when green very unlike the aromatic odor of the cedars. The odor of dry cypress is less pronounced, but is noticeable in sawing. The annual rings of cypress usually are irregular in width and outline. The summer wood is distinct and narrow, although sometimes it is wider than the summer wood in the cedars. The heartwood of the redwood, as a rule, is a deep reddish brown; the dense bands of summer wood make its annual rings very distinct. Redwood varies somewhat more than most species in density and strength properties. It is considered difficult to nail without splitting.

Aspen (northern, hardwood, Rocky Mountain, and Pacific forests).
Aspen, largetooth (northern and north portion of southern forests).
Basswood (northern and hardwood forests).
Buckeye, yellow (hardwood forest).
Cottonwood, black (Pacific forest).
Cottonwood, eastern (northern portion of northern forest, and hardwood and southern forests.)
Willow, black (northern and southern forests).
Willow, western black (Pacific and southern Rocky Mountain forests).

The species named are the softest of the native hardwoods, and are softer than many of the coniferous species or so-called softwoods, from which they are readily distinguishable by their minute structural characteristics. Cottonwood, aspen, basswood, and buckeye collectively furnish about 7 per cent of the total lumber used for boxes and crates. These four woods are light colored, fairly straight grained, and without very marked odor or taste, except for the basswood, which has a characteristic odor. The annual rings are not clearly defined, and there is no pronounced difference in color between the sapwood and heartwood in any of these species except basswood, in which the heartwood may have a cream-brown color. Basswood may also show black or brownish spots or streaks. Aspen fir, a Group 2 wood, is not a true fir.
BOX AND CRATE CONSTRUCTION

and cottonwood generally grow rapidly. The aspen, however, commonly develops heart rot as it grows older and is, therefore, often cut when small. The cottonwood, in contrast, often grows to a large size and is generally solid to the center. Its logs therefore make good veneer. Cottonwood resembles in appearance tupelo gum, a Group 3 wood, but is usually lighter in both weight and color and has a coarser texture. The aspens, cottonwoods, basswoods, and yellow buckeye are relatively easy to dry and to work. The cottonwood, willow, and basswood are especially resistant to splitting in driving nails. Cottonwood is used extensively for egg cases.

Magnolia, cucumber (hardwood, southern, and eastern portion of northern forests). Magnolia, evergreen (hardwood, and southern forests). Poplar, yellow (hardwood, southern, and eastern portion of northern forests).

These three species of the Group 1 hardwoods just named grow in mixed stands and frequently together. The wood of any one of the three is very difficult to distinguish from that of the others. Both magnolias average somewhat higher in weight and in strength than the yellow poplar. They have about the same strength properties as the average for the Group 3 woods, but they usually split less at the nails. The strength properties of yellow poplar are near the lower limit of the Group 3 woods. Yellow poplar has less nail-holding power and less tendency to split at the nails than the Group 3 woods. It is assigned to Group 1 because it will take the larger nails that are used with Group 1 woods and will consequently make a better box than if it is used as a Group 3 wood. The wood cut from comparatively young yellow poplar trees is white in appearance and is sometimes sold as white poplar. This wood is comparatively hard and tough, and is often confused with basswood or with tupelo gum, a Group 3 wood. Evergreen magnolia and cucumber magnolia also take the Group 1 nailing. Because of the difficulty of distinguishing these woods from yellow poplar, they, too, are placed in Group 1. These woods are of fine texture, are straight grained, and without marked odor or taste. The heartwood, like that of yellow poplar, varies from light to moderately dark yellowish or olive brown with a greenish tinge and sometimes has a purplish tinge or streaks. The annual rings are bordered by light-colored lines. These species are easy to dry and easy to work. The wood cut from old yellow poplar trees holds its shape after drying better than most other woods, whereas the magnolias warp somewhat with changes in moisture content.

Chestnut (hardwood, southern, and eastern portion of northern forests). Butternut (northern and hardwood forests).

Chestnut and butternut are somewhat similar in color, but are easily distinguished by the broad band of porous spring wood that is present in the annual rings of the chestnut. The wood of both species is moderately light and is usually straight grained. Butternut resembles black walnut in structure but is lighter in weight, softer, and lighter colored, somewhat resembling in appearance black ash, a Group 3 wood. It is without marked odor or taste. The heartwood of chestnut is grayish brown, and has a slightly astringent taste. Chestnut ordinarily has a very narrow band of sapwood, and consequently the lumber is for the most part heartwood. The butternut and chestnut have small shrinkage and ordinarily warp only slightly if at all. These species are in great demand for furniture backing and other uses in which low shrinkage is important. Only small quantities of the lowest grades of butternut are used for boxes and crates.

The chestnut trees are being exterminated by a fungus known as "chestnut blight," which attacks the bark. If the lumber from a blight-killed tree is used before it begins to deteriorate on account of checking, insect injury, and decay, it is as strong as, and for practically all purposes as good as, that from healthy living chestnut. Chestnut trees, however, are very susceptible to attack by insects (7). Pin-hole worms bore into the tree but do not kill it. The stock sawed from such trees produces lumber of a grade known as "sound wormy chestnut."

GROUP 2

The species included in Group 2 are as follows:

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>COMMON NAME</th>
<th>COMMON NAME</th>
</tr>
</thead>
</table>

The Group 2 woods constitute about 28 per cent of the total lumber used for boxes and crates. Of this amount, about 70 per cent comes from the southern
yellow pines, of which there are several species. The southern yellow pines are among the leading woods used for heavy crating and are also used both as rotary-cut veneer and sawed lumber for boxes.

The Group 2 woods are further classified into the following small groups in order to make their description more effective:

<table>
<thead>
<tr>
<th>Woods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loblolly pine (southern forest)</td>
<td></td>
</tr>
<tr>
<td>Longleaf pine (southern forest)</td>
<td></td>
</tr>
<tr>
<td>Pitch pine (hardwood and northern forests)</td>
<td></td>
</tr>
<tr>
<td>Shortleaf pine (southern and hardwood forests)</td>
<td></td>
</tr>
<tr>
<td>Slash pine (southern forest)</td>
<td></td>
</tr>
</tbody>
</table>

The southern yellow pines enumerated above are usually heavier, harder, more resinous, and contain a wider and harder layer of summer wood than the white pines. Wood cut in the Atlantic coast region from loblolly and shortleaf pines and second-growth pine trees of other species is often termed "North Carolina pine," and the shortleaf pine in Arkansas is termed "Arkansas pine." The lumber of these woods is frequently softer and has wider sapwood than true longleaf and slash pines, which average the heaviest and hardest of the pines. Some of the hardest lumber from these species, however, may closely resemble longleaf pine in appearance and properties. The southern yellow pines, although similar in appearance, vary greatly in density and in strength properties both among species and among individual pieces of the same species. Although different types of southern yellow pine lumber are recognized in the lumber trade, it is impossible to distinguish accurately among the species after the logs have been worked into lumber. Because of the wide variation in the properties of southern yellow pine, the selection for boxes should be based upon the specific gravity or density of the wood rather than upon the species.

The southern yellow pines and Douglas fir are somewhat similar in appearance and properties, but Douglas fir usually has a distinct reddish hue and the resin ducts scattered through the wood are less prominent. The dense material of both the southern yellow pines and the Douglas fir splits badly at the nails, and the nails have a tendency to follow the softer wood between the hard bands of summer wood, often running out at the sides of the board, but the lightweight soft pieces nail almost as easily as some of the Group 1 woods. This dense material is stronger and holds nails better than the lighter-weight stock, consequently smaller nails should be used. The same nail-holding power is thus obtained, and the tendency to split or run out is reduced. The dense material is well suited for crate skids and other members in which a high degree of strength is required.

Douglas fir (Rocky Mountain and Pacific forests).

Douglas fir is the most important commercial species of the Pacific Northwest. The stands of Douglas fir exceed in volume those of any other species in the United States. The amount of Douglas fir cut in 1925 was exceeded only by that of the southern yellow pines, which was cut from the several species. Douglas fir is now less important as a box wood than southern yellow pine, mainly because, owing to its region of growth, it has to compete with readily available species that are softer and have less tendency to split at the nails, such as western yellow pine, spruce, and western hemlock.

Douglas fir is not a true fir or pine, but belongs to a different genus, one as distinct from the others as the spruces and the pines are distinct from each other. However, it has the same general structure as the other coniferous woods. Its wood differs from the true firs in that it is more resinous, heavier, stronger, and has a darker heartwood and denser summer wood. Douglas fir resembles the southern yellow pines in strength properties and in tendency to split at the nails. Like the southern yellow pines, it is decidedly variable in density and has corresponding variations in strength properties. The Rocky Mountain type of Douglas fir differs in its properties from the Pacific coast type almost as markedly as if the two were different species of trees. The Rocky Mountain type is a short, branchy tree and yields lighter and weaker lumber than the Pacific coast type. Douglas fir when dry is practically tasteless and odorless. It is reported that it is unsuitable for apple boxes because of a scald that is produced on fruits with which Douglas fir comes in contact (6).

Hemlock, eastern (northern and hardwood forests).
Hemlock, western (upper halves of Rocky Mountain and Pacific forests).

The woods from these species are similar in general appearance but differ considerably in a number of strength properties. The species resemble the true firs in appearance, but there is no sharp distinction in color between the spring wood and summer wood; the two colors, which are closely similar gradually
merge into each other. There also is little difference in color in the hemlocks between sap wood and heartwood, although the latter may have a somewhat pale-brown or reddish hue. The western hemlock is somewhat heavier and stronger than the eastern hemlock, is less subject to shakes and checks, has higher nail-holding power, and has less tendency to split in nailing. In addition, western hemlock is cut from large trees, which make it possible to obtain box parts of single-piece stock. When fresh, hemlock has a characteristic sour odor, but this disappears when the wood is dry. The western hemlock is a satisfactory wood for butter containers and is also much used for fresh fruits and vegetables. One-fourth of all western hemlock cut goes into boxes, furnishing about 8½ per cent of all softwood used for this purpose.

Larch, western (upper halves of Rocky Mountain and Pacific forests).

Tamarack (northern forest).

Larch lumber is obtained from two species, the tamarack, growing in the Eastern States, and the western larch, growing in the Western States. The heartwood of tamarack has a russet color, while that of western larch sometimes also has a reddish-brown tinge; both vary from a coarse to a fine, even straight grain. The annual growth rings in western larch are narrower and more nearly uniform in width than in tamarack, and consequently less difficulty is experienced in nailing western larch. The annual rings are marked by a distinct band of summer wood. The butt logs of western larch are often shaky and contain large amounts of gum. This material, however, is usually left in the woods. Western larch and tamarack are not considered suitable for food containers but are quite satisfactory for crates or heavy boxes in which strength is important.

GROUPS 3 AND 4

The Groups 3 and 4 woods, all of which are from hardwood species, are, for convenience, discussed together. The following are the species included:

GROUP 3

<table>
<thead>
<tr>
<th>COMMON NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, black.</td>
</tr>
<tr>
<td>Ash, pumpkin.</td>
</tr>
<tr>
<td>Elm, American.</td>
</tr>
<tr>
<td>Gum, black.</td>
</tr>
<tr>
<td>Gum, red.</td>
</tr>
<tr>
<td>Gum, tupelo.</td>
</tr>
<tr>
<td>Maple, silver.</td>
</tr>
<tr>
<td>Sycamore.</td>
</tr>
</tbody>
</table>

GROUP 4

<table>
<thead>
<tr>
<th>COMMON NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash, green</td>
</tr>
<tr>
<td>Ash, white.</td>
</tr>
<tr>
<td>Beech.</td>
</tr>
<tr>
<td>Birch, sweet.</td>
</tr>
<tr>
<td>Birch, yellow.</td>
</tr>
<tr>
<td>Elm, rock.</td>
</tr>
<tr>
<td>Elm, slippery.</td>
</tr>
<tr>
<td>Hackberry.</td>
</tr>
<tr>
<td>Hickory.</td>
</tr>
<tr>
<td>Maple, black.</td>
</tr>
<tr>
<td>Maple, sugar.</td>
</tr>
<tr>
<td>Oaks, red.</td>
</tr>
<tr>
<td>Oaks, white.</td>
</tr>
</tbody>
</table>

For descriptive purposes the Group 3 and Group 4 woods are subdivided into small groups as follows:

Black ash (northern and hardwood forests).
Green ash (northern, hardwood, southern, and Rocky Mountain forests).
Pumpkin ash (hardwood and southern forests).
White ash (northern, hardwood, and southern forests).

The white and the green ash are Group 4 woods. The black ash and the pumpkin ash are Group 3 woods. Black ash has about the same bending strength as pumpkin ash but is much tougher. The heartwood of white ash and of green ash is a light grayish brown in color, sometimes with a reddish tinge. The heartwood of black ash is somewhat darker; hence its name. The sapwood of all four species is white. In the white and the green ashes it is several inches wide as a rule, although in black ash rarely over 1 inch. The ashes are without marked odor or taste. The woods of the white and of the green ash are very much alike in appearance and strength properties, and are sold as white ash or ash. The lighter-weight grades of white ash and of green ash are commercially classified and sold as pumpkin ash.

Beech (northern, southern, and hardwood forests).
Birch, sweet (northern, hardwood, and southern forests).
Birch, yellow (northern and hardwood forests).

The woods of the birches resemble the beech and the hard maples in appearance and in strength properties. The wood is heavy, fairly straight grained, and without characteristic odor or taste. Birch has more cross grain than maple and
does not hold its shape so well. Beech usually produces lower-grade lumber than birch or maple. It is cross-grained, difficult to season, and warps and checks excessively.

American elm (northern, hardwood, and southern forests).
Rock elm (northern and hardwood forests).
Slippery elm (northern, hardwood, and southern forests).

The woods of the several elms are very similar in appearance but differ considerably in weight and in strength properties. The elms have a brownish heartwood tinged with red. The sapwood is white. American elm is a Group 3 wood, whereas rock elm and slippery elm are Group 4 woods. All the elms are without marked odor or taste. Rock elm and slippery elm are heavier than American elm and have correspondingly higher strength properties. The elms have excellent shock-resisting capacity and nail-holding power and are exceptionally free from splitting with nailing. They are especially good for containers that are to be used a number of times. All the elms are difficult to dry and to work. They dress smoothly, but often fuzz and become ragged when steamed or placed in hot water and then subjected to rough handling as are, for instance, milk-bottle boxes. The elms make good veneers for cheese boxes. The elms, however, warp more with changes in moisture content than many other species.

Black gum (hardwood, southern, and eastern half of northern forests).
Red gum (hardwood, southern, and lower eastern portion of northern forests).
Tupelo gum (southern and lower portion of hardwood forests).

Red gum is the principal container wood of Group 3. Before the World War more than 50 per cent of the total amount of red-gum lumber used in the United States went into box construction. Although the demand for red-gum for furniture has probably reduced this proportion, probably 10 per cent of the total quantity of box lumber is red gum (including sap gum). It is the leading veneer wood used in wire-bound and plywood boxes. The wood of the red gum trees may vary from nearly all red wood to nearly all white wood. The red-gum lumber that is cut from the white sapwood of the tree is termed commercially “sap” gum and that which is cut from the reddish-brown heartwood is termed “red” gum. The sapwood is often blued by sap stain. It is difficult to distinguish tupelo gum and black gum from the sapwood of red gum. The wood usually has interlocked grain and is of such uniform structure that the annual rings are inconspicuous. The gums are difficult to dry but may be worked with considerable ease. The strength properties of material from the upper parts of tupelo gum trees are very similar to those of red gum; the wood from the swelled butt, however, is often light and spongy, low in strength, and does not hold nails securely. Light, spongy wood should be excluded from the ends and cleats of boxes and when used for sides, top, and bottom should be used in the thicknesses required for Group 1 woods. All the gums are practically tasteless and odorless and are so similar in strength properties that there is little need to differentiate one from the other.

Hackberry (northern, hardwood, and southern forests).

Hackberry is not plentiful, but its range of growth is extensive. It grows with the ashes and the elms and in appearance bears so close a resemblance to them that it is seldom sold separately. The wood of hackberry is moderately heavy and is generally straight grained. The heartwood is light gray, tinged with green, which distinguishes it from the elms. It is without characteristic odor or taste. Hackberry is approximately the equal of ash for boxes and crates but is slightly inferior to rock elm.

Hickory (southern and southern portion of northern forests).

Small quantities of hickory are mixed with other species and used for boxes and crates. The heartwood is reddish brown, often with darker streaks. The sapwood, which is from one to several inches wide, is white. Hickory is very heavy and hard, has excellent shock-resisting capacity, and is classed as a Group 4 wood.

Black maple (northern and hardwood forests).
Silver maple (northern, hardwood, and western portion of southern forests).
Sugar maple (northern, hardwood, and southern forests).

There are a number of maples, the most important of which are the sugar maple and the silver maple, often known respectively as the hard and the soft maples. The wood of sugar maple is heavy, hard, of uniform texture, and difficult to drive nails into and to cut across the grain. The hard maples are classed as Group 4 woods. The softer maples are lighter in weight and have cor-
respondingly lower strength properties and lower nail-holding power than the hard maples; the softer maples also have less tendency to split and are easier to nail. They are classified as Group 3 woods. The sapwood is white in all maples, and the heartwood is light-reddish brown. The maples are without characteristic odor or taste. They wear smoothly and for this reason are excellent woods for milk-bottle boxes, which are exposed to hot water or steam in sterilizing the bottles.

Red oak group (northern, hardwood, and southern forests).

White oak group (northern, hardwood, and southern forests).

The oaks are heavy, hard, and when dry are without characteristic odor or taste. The annual rings are very distinct in both the white and the red oaks. The most characteristic feature of all oak woods is the broad wood rays, which are very conspicuous as light-colored lines on the end surface of oak lumber and appear on the radial surface as silvery patches. The size and distribution of the large rays distinguishes the oaks from all other woods. The oaks are among the most difficult species to dry without degrade. They furnish but small quantities of lumber for boxes and crates.

No distinction need be made between the various red oaks and white oaks unless they are to be used for containers carrying liquids, in which event the white oaks are preferable, owing to their imperviousness.

Both groups are heavy and hard, and have excellent nail-holding power but split rather easily when nailed. The oaks when dry stay in place well and change slowly in shape with changes in moisture content. The oaks produce excellent rotary-cut veneer and are at times used in combination with gum and ash for wire-bound boxes.

Sycamore (northern, hardwood, and southern forests).

Sycamore is easily identified by means of its conspicuous rays and interlocked grain. Sycamore is quite similar in strength properties to the gums and is often sold mixed with them. It resembles beech and maple in appearance but is lighter in weight and its rays are more conspicuous. Sycamore trees in large sizes are subject to ring shake. The heartwood is reddish brown and the sapwood is somewhat lighter in color. It is the favorite wood for plug-tobacco boxes.

APPENDIX C. SEASONING OF BOX LUMBER

Except for the rotary-cut stock used in plywood and wire-bound construction, boxes are for the most part made from the lower grades of lumber and hence furnish an outlet for large quantities of such stock. Heretofore, a large proportion of the lumber for boxes has been seasoned by air drying. The use of kiln-dried stock, however, is increasing and will probably continue to increase. The lower grades of lumber are low in monetary value so that in kiln drying them the objective is usually to get the moisture out at as low a cost as possible, considering both the expense of drying and the loss through degrade brought about by such defects as checking, warping, and loosening of knots.

It is likely to be assumed that as long as no visible damage results from kiln drying, the strength properties of the lumber are not affected. Throughout this bulletin emphasis is placed on the fact that ordinarily the strength of a box is limited by the fastening resistance of the wood, including resistance to pulling of the fastenings and to breaking at the fastenings. In the development of specifications and schedules for the kiln drying of wood for airplane construction (27), thousands of tests were made of the effect of different kiln-drying schedules on the bending strength, shock resistance, and other properties important in airplane parts. These tests demonstrated that wood can be kiln dried without loss in any strength property as compared to air drying under optimum conditions. They also demonstrated that the various strength properties and the individual species differ greatly with respect to their sensitiveness to the higher temperatures sometimes used in kiln drying and that stock may be very seriously damaged in strength properties without showing any visible evidence of this damage. The property most sensitive to kiln drying is shock resistance, which in some species is seriously reduced by comparatively low temperatures and very greatly reduced by the higher temperatures frequently used in kiln drying lumber. In every instance in which boxes made from lumber known to have been subjected to extremely high temperatures have been tested they have been found to be very low in resistance to rough handling as compared to boxes made
from air-dry lumber. This was shown by the early occurrence of the failures that resulted from the breakage of boards at and near the fastenings. Fastening resistance is reduced by any influence that renders the wood fibers brash or brittle. The low shock resistance in the airplane woods tested resulted from the high temperatures in kiln drying, which produced brashness. This fact demonstrates that care should be exercised with respect to the temperatures employed in the kiln drying of box lumber. As a result of the tests of the effect of kiln drying on airplane woods, drying schedules 10 by means of which stock can be kiln dried without material damage to any strength property have been established. Since box boards are thinner than airplane stock the time necessary for them to be exposed to the kiln temperature is shorter. Consequently higher temperatures than those allowed by the airplane schedules can no doubt be employed in drying material for use in box construction without reducing the strength and serviceability of the boxes. Unfortunately the maximum temperatures that can be safely used are not known.

![Diagram](image)

**FIGURE 25.—Effect of relative humidity and temperature on the equilibrium moisture content of wood**

It is impossible, therefore, to offer definite recommendations as to maximum permissible temperatures. It does, however, seem advisable to raise the caution that the temperatures frequently used in kiln drying such stock may result in very serious damage and to recommend that particular care be given to the drying of box lumber. If minimum thicknesses are to be used in boxes, it is essential that lumber be dried without damage to its strength properties.

Even when conditions are carefully controlled to avoid permanent damage it is undesirable that box lumber be kiln dried to too low a moisture content. Lumber that is overdried, until it has regained a normal moisture content through reabsorption, is quite brash and therefore subject to damage in handling, machining, and nailing. If lumber in the very dry condition is nailed, the nails will lose much of their holding power when reabsorption occurs under exposure to normal atmospheric conditions. Experience indicates that there is no advantage in drying box lumber below the average air-dry condition, which is usually about 12 to 15 per cent moisture content.

In the following pages are given suggestions for seasoning by both air drying and kiln drying. More detailed information on types of kilns and their control

10 These together with other schedules for the kiln drying of wood of different species are presented in *Kiln Drying Handbook (9)*. Maximum kiln temperatures permitted by the airplane schedules vary from 105° to 145° F. depending on the species to be dried and on the stage of the drying.

11 The experiments in drying airplane woods were for the most part of 3/4-inch stock.
A, Poor piling for air seasoning; B, method of marking boxes and crates for test
and operation and on air seasoning may be obtained from the Forest Products Laboratory (21).

Both the equilibrium moisture content and the rate of drying of wood are dependent upon the humidity and the temperature of the surrounding air. When wood is subjected to a constant relative humidity and temperature, it will in time come to a definite moisture content, which is called the equilibrium moisture content. The relationship between the equilibrium moisture in the wood, the temperature, and the relative humidity of the surrounding atmosphere is shown in Figure 25. From the chart it may be seen that the moisture content increases with increase in relative humidity, but decreases with increase in temperature. Since temperatures are lower and humidities are higher in winter than in summer, wood stored outside reaches a higher moisture content in winter than in summer, but when stored in a heated room wood becomes drier as a result of the lower relative humidity in the room.

GEOGRAPHIC VARIATIONS IN HUMIDITY AND TEMPERATURE

In addition to seasonal variations in humidity and temperature, there are also variations from part to part of the United States. Table 10 shows the relative humidities at different seasons of the year for a number of widely separated cities. The humidities are based on daytime readings made by the United States Weather Bureau and do not give the mean average humidity for 24-hour periods. The humidity during the night is usually much higher than that during the day, and since the equilibrium moisture content will follow the mean average humidity for the 24-hour period, it will be somewhat higher than the moisture content indicated in the table.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York City</td>
<td>73</td>
<td>70</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>Cleveland, Ohio</td>
<td>77</td>
<td>72</td>
<td>70</td>
<td>74</td>
</tr>
<tr>
<td>Spokane, Wash</td>
<td>82</td>
<td>61</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>Seattle, Wash</td>
<td>85</td>
<td>73</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>Phoenix, Ariz</td>
<td>47</td>
<td>32</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>San Diego, Calif.</td>
<td>74</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>San Francisco, Calif</td>
<td>79</td>
<td>79</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Denver, Colo.</td>
<td>54</td>
<td>51</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Washington, D. C.</td>
<td>72</td>
<td>69</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>El Paso, Tex.</td>
<td>45</td>
<td>27</td>
<td>41</td>
<td>46</td>
</tr>
<tr>
<td>Galveston, Tex.</td>
<td>84</td>
<td>82</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Jacksonville, Fla</td>
<td>80</td>
<td>74</td>
<td>80</td>
<td>83</td>
</tr>
</tbody>
</table>

AIR SEASONING

The small amount of additional work required to pile lumber properly for air seasoning (21) so as to shorten the time required for drying and to reduce deterioration is usually well worth while. Lumber thrown in a pile promiscuously, improperly stickered, or piled with loose projecting ends or on uneven foundations will warp, check, split, and otherwise depreciate in value in a comparatively short time. (Pl. 32, A). In order to be considered properly air seasoned lumber should be of a uniform moisture content of the desired percentage, straight, free from stain and decay, without undue damage to knots, and with-
out surface checks. Observance of the following suggestions will help to secure these results:

A. Foundations:
1. The foundation should be rigid and level in one direction.
2. The foundation should slope from front to rear about 1 inch to the foot.
3. The foundation should be high enough from the ground and sufficiently open to allow good circulation. The lumber should be at least 18 inches from the ground.
4. Material for foundation piers is listed in the order of durability: Concrete or masonry. Pressure cypress, redwood, or cedar. (When untreated woods are used, all points of contact should be given two coats of hot creosote.)
5. Stickers and beams should preferably be of steel or of pressure-creosoted timbers. Untreated durable woods with two costs of hot creosote at points of contact may be used.

B. Air flues:
1. Even-width stock should have lateral spaces between adjacent boards not less than 20 per cent of the width of the board. The boards in each succeeding tier should be placed directly over those below so that the lateral spaces between boards will form uninterrupted vertical flues.
2. In uneven-width material the equivalent of one tapering chimney not less than 12 inches wide at the bottom should be used for a 6-foot pile and often two such chimneys in wider piles. The space between adjacent boards should be not less than 1 inch for 4/4-inch stock and 1 1/2 inches for thicker stock.

C. Stickers:
1. All stickers should be sound, free from stain, and of even thickness. All stickers in the same course should be of the same thickness.
2. Each tier of stickers should be aligned and should be supported firmly along the entire length of the stickers.
3. Stickers for 4/4-inch lumber should be not less than seven-eighths inch thick, usually 1 1/2 inches wide for hardwood lumber, and preferably not more than 4 inches wide for any lumber. For thicker lumber, stickers should be 1 1/2 inches thick or perhaps more.
4. Stickers should slightly overlap the ends of the stock in order to reduce end checking.
5. Stickers should be of the same thickness.
6. Stickers should be not over 2 feet apart for hardwoods up to 6/4 inch in thickness. For thicker hardwoods and all softwoods three tiers of stickers should be used for 16-foot stock.

D. Placing of lumber:
1. Piles should be erected of equal length, wherever practicable.
2. Box piling should be used for mixed lengths. With this system the longest stock is piled in the outer tiers, and short lengths within the pile with one end of a board at one end of the pile and one end of the adjacent board at the opposite end of the pile. In each succeeding course, the outside end of each board should be kept immediately over the ends of those below it.
3. Each layer should be composed of boards of the same thickness.
4. The front of the pile should have a forward slope or pitch to the extent of 1 inch for each foot in height.

E. Covering:
1. All material should be under cover, either in an open shed or with roofs over individual piles.
2. A minimum front height for the pile roof of 6 inches above the lumber and a slope rearward of at least 1 inch to the foot should be used.
3. The ends and the sides of the roof should project sufficiently to prevent snow and rain from blowing into the lumber piles.

F. Site:
1. The yard should be well drained and kept free from weeds and débris.
2. The space between the sides of adjacent piles should be at least 4 feet wide and the alley between the rears of adjacent pile rows should be at least 8 feet wide.

KILN DRYING

Lumber properly kiln dried (21) should be free from surface and end checks, honeycomb, and casehardening, and the stock should be reasonably straight, and the moisture content should be as required in amount and in uniformity. Observance of the following suggestions may help to secure these results:

A. Dry kilns.
1. The construction of the kiln, the control equipment, and the arrangement of heating coils, spray lines, and ventilators must be such that the temperature and humidity may be controlled within reasonable limits.

B. Material:
1. Species of the same drying characteristics may be included in the same kiln charge.
2. Reasonable variation in thickness of stock in the same charge may be permitted if drying conditions are regulated for the wettest, thickest, and lowest drying stock.

C. Piling:
1. The method of piling must be suited to the circulation system of the kiln in which the stock is dried. Two general methods of piling are used: (1) Edge stacking where the stock stands up edgewise in the kiln truck with the edges touching, the faces of the boards separated with vertical stickers, and the circulation intended to be up or down in the open space between the faces of the boards. (2) Flat stacking, where the stock is laid flat in the loading, and spaces are provided between the faces of the boards by means of stickers laid horizontally. Circulation may be principally vertical, or principally horizontal; it always is a combination of both directions.

Some of these methods of piling are applicable to either natural circulation or forced circulation types of kilns.

In natural-circulation kilns the air movement is generally downward through the load when the stock is relatively green and upward when the stock is nearly dry. In edge stacking the plies provide the vertical flues suited to this air movement. For flat stacking vertical flues should be provided by separating the boards at least 1 1/2 inches. In piles 5 feet or over in width, a vertical flue at least 8 inches wide should also be provided in the middle of the load from the bottom of the pile up to within six layers of the top of the pile.
In forced-circulation kilns the design of the kiln usually determines the method of piling best adapted to the circulation system. The following suggestions should be observed:

1. One-inch stickers should be used for most classes of stock up to 6/4-inch in thickness and 1½-inch stickers for stock thicker than 6/4; for edge-piled stock, requirements of the stacking machine may determine both their width and their thickness. In flat piling the stickers must be in vertical alignment not over 2 feet apart for 6/4-inch stock and not over 3 feet apart for stock thicker than 6/4-inch. Except for edge stacking, all sticker lines should bear solidly on beams or crossties.

2. Each layer should consist of boards of the same thickness.

3. Piling should be done so as to avoid overhanging ends of boards. At least 18 inches should be allowed between the loads and the side walls.

4. Box piling should be used for flat-piled stock of mixed lengths. (See paragraph D2, page 82.)

D. Instruments.

1. At least one recording hygrometer should be used in each kiln. This should be checked at least once in every 30 days against a standard thermometer and set at an accuracy of 1° F.

2. The bulbs should be placed so as to measure the severest drying conditions in the load. Bulbs should be shielded from the direct radiation of hot steam coils, and the effect of cold lumber or kiln walls.

3. Occasional readings should be taken with wet-bulb and dry-bulb hygrometers to determine the accuracy of the recording hygrometers and the variations of temperature and humidity within the kiln.

4. The wet bulbs of all hygrometers should be kept covered with a film of water. If a wick is used it should be changed frequently. If a porous wet bulb is used it should be kept dripping and free from incrustation.

E. Records:

1. Temperature and humidity records should be accurately and systematically kept for each run.

F. Steaming:

1. The lumber may be heated a comparatively short time at some temperature above the drying schedule with a relative humidity that will not cause drying, the purpose of such steaming being to warm the stock, to reduce moisture gradient, or to relieve case hardening.

G. Tests during and after drying:

1. Adequate tests should be made during the drying to insure proper drying and to serve as a guide for regulating temperatures and humidities (27).

APPENDIX D. CONTAINER TESTING

Since containers in service are subjected to various and constantly changing transportation hazards, it is impractical to secure complete data for design by observing containers in service. Examinations of failures will reveal the weaknesses and suggest the principles of design to apply in overcoming them, but it is impracticable to make changes and develop balanced construction through service tests alone. For this reason, laboratory tests that closely simulate the hazards of transportation have been developed. Each test is designed to reproduce one or more of the stresses encountered in service. During these tests the sequence of failures can be observed and the weakness from which they result determined.

Since by means of such tests any number of containers can in turn be subjected to exactly the same action, the tests provide a ready means for developing the fundamental principles of design and the relationships of the various details necessary to produce a balanced construction, but, just as service tests can not be used for properly balancing the design, so laboratory tests do not show the minimum requirements of service. Each has a distinct field that can not be assumed by the other. In the following pages there are described a number of the methods that have been devised for subjecting containers to conditions and hazards similar to those encountered in service, for testing features of construction, and for testing container accessories and materials.

The methods, which for the most part have been developed by the Forest Products Laboratory, (14) have become standard and are used by container manufacturers and shippers and by commercial laboratories in this country as well as by laboratories in several foreign countries. These tests have been developed to bring out the weaknesses in the common types and designs of containers. As changes are made in container design and in methods of handling packages in shipment, the characteristic hazards and weaknesses of containers will be changed and these tests will probably need revision.

MARKING TEST BOXES AND CRATES

Numbering the faces of the box or crate makes for convenience in recording the test data. The faces are numbered as follows: The top is 1, the right side 2, the bottom 3, the left side 4, the end toward the observer 5, and the opposite end 6. The edges and corners are designated by combinations of these numbers as indicated in Plate 32, B.
DROP-CORNERWISE TEST

In the drop-cornerwise test, the box or crate with its contents is suspended with a pair of diagonally opposite corners in a vertical line and is dropped from a height of 6 inches upon a cast-iron plate or other solid surface, as illustrated in Plate 33, A. The drops are made on the corners in numerical rotation as follows:

<table>
<thead>
<tr>
<th>Faces meeting</th>
<th>Corner number</th>
<th>Faces meeting</th>
<th>Corner number</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-1-2</td>
<td>1</td>
<td>5-3-4</td>
<td>5</td>
</tr>
<tr>
<td>6-3-4</td>
<td>2</td>
<td>6-1-2</td>
<td>6</td>
</tr>
<tr>
<td>5-2-3</td>
<td>3</td>
<td>5-1-4</td>
<td>7</td>
</tr>
<tr>
<td>6-1-4</td>
<td>4</td>
<td>6-2-3</td>
<td>8</td>
</tr>
</tbody>
</table>

After the container has been dropped on each of the eight corners, the height of drop is usually increased 6 inches and the cycle repeated. Accurate records are made of the nature, the extent, and the sequence of each failure and the test is continued until complete failure occurs.

The drop cornerwise is a very severe test on the ability of the container to withstand shocks and resist distortion. It does not give satisfactory results for improvement of design if the first drops are made from a height that causes complete failure, since several failures may then occur simultaneously, thus making very difficult the determination of the weakness that first developed. Plate 33, B shows the details of the apparatus used for making this test.

DROP-EDGewise TEST

The drop-edgewise test (pl. 34, A) is similar to the drop-cornerwise test except that the container is dropped on an edge instead of a corner.

DROP-FLATWISE TEST

In the drop-flatwise test the container is dropped squarely on one of its faces. (Pl. 34, B.) The container may withstand the shock with relative ease, but it usually is a severe test of the packing of fragile articles. The test may be varied by dropping the container successively on one or more of the faces as desired.

DROP-PUNCTURE TEST

The capacity of a box to resist puncturing is often tested by dropping another box cornerwise (pl. 34, C) or by dropping some other pointed object on the face being tested. (Pl. 34, D.)

WEAVING TEST

The machine illustrated in Plate 35 is designed to simulate the side swaying or rolling of a moving freight car, or the repeated starting and stopping of a car. The swaying action of a train is reproduced on the testing machine by an oscillating table or car, which can be made to move horizontally forward and backward at different speeds through any distance up to a maximum of 8 inches. The box or crate to be tested is fastened rigidly to the table, by clamps along two of its bottom edges, and a weight equal to the average load carried by a container in the bottom tier of a loaded car is then fastened on the top. When the machine is put in operation the container is carried back and forth with the movement of the table.

This test affords a means of comparing boxes or crates with respect to their rigidity, which is indicated by their resistance to weaving or skewing. The test may be continued until complete failure occurs, but usually the box or crate is tested on the machine until the joints are loosened, and then it is taken to a drum-testing machine.

IMPACT-SHEAR TEST

The oscillating table is also used to simulate the starting and stopping action of a freight car, which produces an impact shear in the container. For this test the box is suspended freely and above the table by two metal straps. The supporting straps form a parallelogram suspension and horizontal guides, fitted with rollers to reduce the friction, allow the box to swing only in the direction of its
Drop-cornerwise test: A, (a), releasing device or trip; (b), cast-iron plate; B, details of drop-test apparatus; (a) and (b), parts of releasing device for light packages; (c) and (d), sling for light packages; (e), releasing device for heavy packages; (f), trip rope
A, Method of making drop-edgewise test; B, method of making drop-flatwise test; C, drop puncture test made by dropping another box cornerwise; D, drop puncture test made by dropping a pointed object.
A, Oscillating table of the weaving test machine adjusted for simulating the starting and stopping action of a freight car; B, box showing type of failure in this test
A, Method of making compression-on-corner test; B, method of making compression-on-edge test; C, method of making compression-on-face test
Small revolving hexagonal drum box-testing machine. Dimensions, 7 feet inside diameter and 4 feet in width.
Large revolving hexagonal drum box-testing machine. Dimensions, 14 feet inside diameter and 8 feet in width
A, Nail-pull test with static load; B, pendulum type machine arranged for determining work absorbed in pulling nails
Shear test on a nailed joint. (a) Test specimen
A, Method of making Mullen test on fiber board; B, Forest Products Laboratory score tester for solid fiber and corrugated board
length, which is parallel to the motion of the table. Two stops are fastened securely to the table and the ends of the box strike against them as the table moves forward and backward. Any desired weight may be placed on top of the box during the test. The number of complete oscillations of the table before failure of the box is indicated by an automatic counter. (Pl. 36.)

**COMPRESSION-ON-DIAGONAL-CORNERS TEST**

The rigidity of a container or its capacity to resist diagonal distortion and twisting is usually determined by measuring the force required to compress the container diagonally. (Pl. 37, A.) The load is measured at each 1/4-inch deflection of the container and the test is continued until the container has reached the maximum load that it will support, or has distorted sufficiently to cause damage to the contents. The amount that each face of the container twists out of a plane is also measured for each one-fourth inch of diagonal distortion. This test produces practically the same types of failures in the container as the drop-cornerwise test but at a rate that enables a closer study of the weaknesses.

**COMPRESSION-ON-EDGES TEST**

The compression-on-edges test is made by applying a compressive force over the whole length of two diagonally opposite edges of a box or crate as illustrated in Plate 37, B. The force required to produce each increment of distortion is measured as in the diagonal compression.

**COMPRESSION-ON-FACES TEST**

The capacity of a container to resist crushing, such as that which may be caused by heavy static loads in storage warehouses, is measured by applying direct compression over the whole surface of two parallel faces as illustrated in Plate 37, C.

**SHEAR TEST ON BOXES**

The shear test consists of shearing the box into two parts along a plane, usually parallel to the top and bottom and in the direction of the length. Ordinarily one end of the box is set on a cast-iron plate in such a position that one edge of the box overhangs the plate 2 inches. The load is applied to the opposite end of the overhanging part. Only the maximum load required to cause failure is recorded.

**DRUM TEST**

The revolving-drum type of box-testing machine (pls. 38 and 39) combines in a single test practically all of the stresses and distortions that containers encounter in service. Upon the six internal faces of the hexagonal drum, hazards and guides are arranged in such a manner that, as the drum revolves, the loaded box or crate slides and falls, striking on its ends, sides, top, bottom, edges, and corners in such ways that the stresses, shocks, and rough handling of actual transportation are simulated. On one face of the drum is a projection upon which the container falls to encounter a puncture hazard similar to that of a box upon which another has dropped cornerwise. The large drum revolves once a minute, thus enabling the observer to note the beginning of any failure and to trace the failures until the container becomes unserviceable.

**SUPPLEMENTARY TESTS**

In addition to tests on completed containers, various tests are made that give much information of value on the properties of container materials and details of construction. Among the most important of these tests are the following:

**MECHANICAL-PROPERTIES TEST**

Mechanical-properties tests are made on sawed lumber, rotary-cut lumber, and plywood. Standard methods (I) of testing small clear specimens of timber are used. Results of tests on small clear specimens of a considerable number of species are in Table 7 and Appendix F.

The holding power of nails, screws, bolts, and other fastenings or their resistance to direct pull by a static load applied in a direction parallel with the nail shank is usually determined by a special gripping device used with a testing machine as shown in Plate 40, A. In making this test only the maximum load to start is indicated. Figures representing the holding power of nails when driven into the
radial, tangential, and end surfaces of different species as determined by this test are given in Table 4.

WORK OF PULLING NAILS

The capacity of nails and other fastenings to resist withdrawal when subjected to shocks is determined by means of a pendulum type of machine, shown in Plate 40, B. The piece containing the nail to be pulled is held against two steel pins. With the pendulum in approximately a vertical position the cable is clamped to the head of the nail. The cable is then slackened as the pendulum is raised until it engages the spring catch, which in turn is adjusted to such a position that when released the pendulum will pull the nail with a single swing. The angle of rise of the pendulum after pulling the nail is read by means of a vernier, which travels on the hub of the pendulum. By computation the work absorbed in pulling the nail can be determined.

SHEAR TEST ON NAILED JOINTS

The resistance of the wood to the nails shearing out at the ends of the boards may be determined as illustrated in Plate 41.

TENSION TESTS

As shown in Plate 40, A, a testing machine intended for standard work can be equipped with special devices for making various other tests; for example, tensile-strength tests on metal strapping and wire ties, tension tests on nailed joints, shear and bending tests on joints held with corrugated fasteners, and tests on special materials and accessories, such as rope, webbing, metal corners, handles, and hinges.

DETERMINATION OF MOISTURE CONTENT

The moisture content of wood may be determined in various ways. The following method is well adapted for box lumber. A section as wide and thick as the original board and 1 inch along the grain is cut at least 2 feet from one end of each of several representative pieces. Immediately after the sample is cut all loose splinters are removed and the sample is weighed on a sensitive scale. This weight is called the "original weight."

The sample is then dried in an oven, in which a uniform temperature of about 212° F. and a free circulation of air over the end grain are maintained, until the weight becomes constant. This usually requires 48 hours. The dry sample is then weighed and the result termed the "oven-dry weight." The time required for drying may be reduced about one-half without great error in the results by using samples one-half inch long.

To calculate the moisture content, the oven-dry weight is subtracted from the original weight and the result divided by the oven-dry weight and multiplied by 100. This gives the percentage of moisture based on the oven-dry weight. The formula is:

$\frac{\text{Original weight}}{-\text{oven-dry weight}} \times 100 = \text{moisture content in per cent.}$

If an oven is not available for drying the samples reasonably accurately, moisture determinations accurate to within 1 or 2 per cent may be made by drying them on steam pipes.

BURSTING-STRENGTH TEST OF FIBER BOARD

The bursting strength (19) is the standard test used as a basis for specifications for fiber boxes. This test consists essentially in clamping the paper board between two surfaces having concentric circular apertures 1.24 inches in diameter and then applying hydraulic pressure through a noncompressible fluid to a rubber diaphragm secured to one of the circular apertures. The pressure required to burst the board is recorded by means of a pressure gauge calibrated to record pounds per square inch and is reported in points. The Mullen and the Cady tests are popular tests of the bursting type. Plate 42, A, illustrates one of the several machines used for making the bursting-strength test.

The bursting-strength tests indicate certain qualities of the board from which fiber boxes are made, but such tests do not give an accurate measure of the relative serviceability of different fiber boxes since they reflect the strength of the board in the machine direction only and do not test the scores, which are the weakest part of the box. The results from these tests are influenced by a number of conditions, such as the rate of applying pressure, the condition of the board, and the calibration of the testing machine (19).
FIBER BOARD SCORE TEST

The paper-board score tester shown in Plate 42, B, was designed by the Forest Products Laboratory to test the scores of fiber boxes. A specimen containing the scored edge is cut from the box and tested in combined bending, tearing, and tension by means of this machine.

On the machine are two clamps, one mounted on a stationary inclined ledge at the top and the other on an oscillating arm. The oscillating arm is connected with a driving mechanism by means of which it can be made to swing through various angles and at different speeds. The movable clamp is connected through a calibrated compression spring to a screw and ratchet wheel which causes a downward movement of the movable clamp when the oscillating arm moves back and forth.

The test specimen, which is 1 inch wide and about 4 1/2 inches long, has the score midway between its ends and at right angles to its length. It is first bent through an angle of 90° at the score, and is then clamped in the machine with the score resting at the sloping edge at the end of the extension of the lower jaw of the stationary clamp. Thus when the machine is in motion, the specimen is bent back and forth at the sloping edge, and the tension caused by the force applied to the movable clamp causes the specimen to tear along the sloping edge. This action simulates the conditions which are encountered by the edges or scores of a loaded fiber box when it is subjected to rough handling or to the skewing and racking caused by the swaying of a moving freight car. The test is continued until the specimen fails, and the maximum pull and the total number of bends which the specimen withstood are taken as measures of the ability of the box to withstand rough handling.

The degree or intensity of the tearing can be changed to simulate different conditions by modification of the sloping edge together with the possible variations in speed, angle of swing of the oscillating arm, and rate at which the tension is increased. A combined bending and tension action without tearing can be obtained by using an edge having a horizontal ledge over which the tension and bending is applied to the specimen instead of a ledge having a slope or inclination. Tests on the scored edges of the box are especially valuable for determining the efficiency of the method used in making the score.

APPENDIX E. FORMULAS AND RULES FOR THE DESIGN OF BOXES

As a result of years of active study of shipping containers under laboratory and service conditions, engineers at the Forest Products Laboratory have worked out formulas for determining the thicknesses of material required in sides, top, and bottom of boxes of certain types. Rules from which the dimensions of other features may be so determined as to produce well-balanced construction have also been devised.

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

As previously emphasized, 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 in this appendix is not in contradiction of, or inconsistent with, this statement. One purpose of the rules and formulas is to afford designs that can be placed in service and subjected to the improvement process. Another and perhaps more important object in presenting formulas and rules is to afford a framework to which further experience with various commodities may be related and thus determine proper values for factors that appear in the formulas and whose values are now unknown except for a loosely defined class of "average commodities." Determination of the proper values of these factors for any commodity amounts to a classification of the commodity. Such classification places considerable limitation on the use of formulas for designing boxes, since little has yet been accomplished in the classification of commodities.

The following scheme of commodity classification has been tentatively set up for use with the formulas.
TENTATIVE COMMODITY CLASSES

1. Those commodities that offer support to containers, are little damaged by local punctures, and in which the contents are of a nature to absorb considerable shock. Example—lump sugar in cartons.

2. Same as class 1 except that the commodity either does not absorb so much shock or needs greater protection. Example—ordinary canned goods.

3 and 4. Intermediate between 2 and 5.

5. Those commodities that do not offer support to the containers, absorb little of the shock, and are badly damaged by punctures.

The formulas and rules herein presented have been incorporated in certain specifications as a means of defining minimum dimensions of box parts. (See specifications for wooden boxes, nailed and locked-corner construction, and for wire-bound boxes, Appendix G.)

NAILED AND LOCKED-CORNER BOXES

THICKNESS OF SIDES, TOPS, AND BOTTOMS OF NAILED BOXES

FORMULA 1

The first formula for the thickness ($t_1$) of the side, top, or bottom of a nailed box is

$$t_1 = K \sqrt{\frac{W}{b}}$$

(1)

where $b =$ width in inches of side, top, or bottom whose thickness is to be found

$W =$ gross weight of box, that is, the weight of contents plus the estimated weight of box

$K =$ a factor whose value depends on the style of box, species of wood, class of commodity, nature of transportation and storage conditions, and number of straps with which the box is reinforced.

The value of $K$ also depends upon the internal packing. Suitable values of $K$ have been determined for only a few sets of conditions. For unstrapped boxes carrying average commodities in domestic shipment, values of one-eighth and one-tenth for Group 1 and one-eighth and one-tenth for Group 1-2 and Group 3-4 woods, respectively, have been found to give very satisfactory results.

FORMULA 2

Formula 1 does not take into consideration the length of the box. The influence of length on the thicknesses required is most important in boxes with long sides of relatively thin material in which the bending of the boards works the nails loose, and in boxes with relatively thick short sides, in which failures occur from the direct pull 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 a second formula for the thickness ($t_2$) of side, top, or bottom. This second formula is

$$t_2^{7/6} = K \sqrt[6]{\frac{W}{b} \frac{L}{60}}$$

(2)

where $L =$ length of box in inches and $K$, $W$, and $b$ have the same meaning as in formula 1.

Formula 2 may also be written as

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

(3)

where $t_1 =$ the thickness as determined by formula 1.

11 Charts by means of which any of the formulas in this appendix can be easily solved are provided (pp. 90 and 91).

12 For the purpose of determining the thicknesses of box parts the woods listed on pages 108 and 104 are divided as follows: Groups 1 and 2 are combined into a single group designated Group 1-2, and Groups 3 and 4 into a single group designated Group 3-4. The nailing requirements depend on which of the primary Groups 1, 2, 3, or 4 includes the species used for the box ends and cleats.

13 Box parts made of Group 3-4 woods may be 20 per cent less in thickness than if made of woods of Group 1-2. Hence, for any one combination of commodity class and shipping conditions the value of $K$ is 20 per cent less for Group 3-4 than for Group 1-2 woods.
If the ratio of length to thickness of side, top, or bottom as determined by formula 1 exceeds 60, formula 2 will indicate a slightly greater thickness. If this ratio is less than 60, formula 2 will indicate a slightly smaller thickness. The difference in thicknesses as determined by the two formulas will not exceed 5 per cent for ratios between the limits of 45 and 80.

These formulas give the minimum required thicknesses of lumber surfaced on one side. If any thickness as found by formula is not an available one, the next greater available thickness should be used.

CHARTS FOR THE SOLUTION OF FORMULAS

In Figure 26 and Figure 27 are provided charts for the solution of formulas 1 and 3, respectively. The thickness $t_1$ may be obtained by first finding from Figure 26 the value of $t_1$, the thickness required by formula 1, and then by using Figure 27.

### Table 11.—Values of $K$ used in Figure 26

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Species group</th>
<th>Un-strapped box</th>
<th>One-strap box</th>
<th>Two-strap box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>1-2</td>
<td>1.00</td>
<td>0.90</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>0.80</td>
<td>0.64</td>
<td>0.63</td>
</tr>
<tr>
<td>Class 2</td>
<td>1-2</td>
<td>1.25</td>
<td>1.00</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.00</td>
<td>0.80</td>
<td>0.84</td>
</tr>
<tr>
<td>Class 3</td>
<td>1-2</td>
<td>1.15</td>
<td>1.25</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.25</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>Class 4</td>
<td>1-2</td>
<td>1.15</td>
<td>1.56</td>
<td>1.25</td>
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<tr>
<td></td>
<td>3-4</td>
<td>1.56</td>
<td>1.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Class 5</td>
<td>1-2</td>
<td>2.44</td>
<td>1.95</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>3-4</td>
<td>1.95</td>
<td>1.56</td>
<td>1.25</td>
</tr>
</tbody>
</table>

### HOW TO USE THE CHARTS

**Figure 26, Formula 1**

If an unstrapped box has been selected, for Group 1 and 2 woods place 1.0, and for Group 3 and 4 woods place 0.8, on the thickness scale opposite the commodity class on the scale representing the kind of box to be used.

If a strapped box has been selected, for Group 1 and 2 woods place 0.1, and for Group 3 and 4 woods place 0.08, on the thickness scale opposite the commodity class on the scale representing a box with one or two straps, as the case may be.

Place a line, rubber band, or straight edge between the weight on the left-hand scale and the width on the right-hand scale. Read the thickness at the intersection of this line with the center line of the thickness scale.

**Figure 27, Formula 3**

1. Find $t_1$, the thickness required by formula 1 from Figure 26.
2. Connect this value of $t_1$ on the left-hand scale of Figure 27 to the length of the box on the right-hand scale by a line and at the intersection of this line with the middle scale read $t_2$, the thickness required by formula 2 or 3.

### DIMENSIONS OF OTHER BOX PARTS

The required thicknesses of sides, top, and bottom of nailed boxes having been determined, thicknesses (of ends, sides, tops, and bottoms) for locked-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 dimensions. The required thicknesses of box parts are often stated as the ratios of their thickness to the thickness of sides. These ratios are

15 Figure 26 is based on values of $K$ as listed in Table 11.
16 If the thickness scale (the strip marked "thickness of side, top, or bottom") is slit along its side and end borders it can be readily placed in the desired position. The entire chart may be removed from the bulletin and mounted for convenience in use.
to be applied to the required thickness of side as found by formula and not to the available thickness adopted for use.

**FIGURE 26.—Chart for determining thickness of sides, tops, and bottoms of nailed boxes by formula 1—length of box not taken into account:** Commodity class 1, those commodities which offer support to containers, are little damaged by local punctures, and in which the contents are of a nature to absorb considerable shock. Example—lump sugar in cartons. Commodity class 2, same as class 1 except that the commodity either does not absorb so much shock or needs greater protection. Example—ordinary canned goods. Commodity class 5, those commodities which do not offer support to the container, absorb little of the shock, and are badly damaged by punctures. Commodity classes 3 and 4, intermediate between 2 and 5.

**THICKNESSES FOR LOCKED-CORNER BOXES**

1. Tops and bottoms of locked-corner boxes: (a) Same thicknesses as required for nailed boxes.
2. Ends and sides of locked-corner boxes: (a) Ends and sides should contain not less than the total amount of lumber required for the ends and sides of uncleated-end nailed boxes, and in no case should the thickness of the ends be less than one and one-half 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 one and one-fourth times the thickness required for nailed boxes.

**THICKNESS OF ENDS AND CLEATS—NAILED BOXES**

1. Style 1 (uncleated) boxes: (a) Ends two times the thickness required for sides.

2. Styles 4 and 5 (single cleated) boxes: (a) Ends and cleats each one and one-half times the thickness required for sides—sides nailed to both ends and cleats. (b) Ends one and three-fourths times the thickness required for sides—cleats not thinner than sides—sides nailed to ends only.
3. Styles 2 and 2½ (double cleated) boxes: (a) Ends and cleats each one and one-fourth times the thickness required for sides—sides, top, and bottom nailed to both ends and cleats. Applies also to style 3. (b) Cleats one and one-half times the thickness and cleats not less in thickness than required for sides—sides, top, and bottom nailed only to the cleats. Does not apply to style 3.

4. Ends and cleats of Group 3-4 woods may be 20 per cent less in thickness than if Group 1-2 woods are used.

**Width of Cleats**

The cleats for ordinary boxes should be not less in width than three times their thickness. Very long cleats, however, should exceed this width in order to prevent breaking across the grain. Triangular or square cleats used for style 5 boxes may be not less in cross sectional area than the requirements for ordinary rectangular cleats.

**Nailing of Sides, Tops, and Bottoms to Ends and Cleats**

If the nails are driven in a single row as in the top and bottom of a style 4 box and the piece holding the points of the nails is of the Groups 2 or 3 woods of thickness one and one-half times the thickness required for the sides, top, and bottom, the size of the nail in pennies should not be greater than the thickness of the piece holding the points, expressed in eighths of an inch. For Group 1 woods, the nails may be one size larger and sometimes even two sizes for the very soft coniferous woods, but for Group 4 woods the nails should be one size smaller. If 6d nails are required, they should not be spaced over 2 inches when held in the side grain and not over 1½ inches when held in the end grain. The spacing should be correspondingly decreased one-fourth inch for each size below 6d and increased one-fourth inch for each size above 6d. Where the two pieces fastened together are of equal thickness, the nails may be one size larger than required by the foregoing rule with no increase in spacing. Where the thickness of the piece under the nail head is less than two-thirds the thickness of the piece holding the nail point, nails one or two sizes smaller should be used than is required where the piece under the nail head has a greater thickness, and the spacing should be correspondingly reduced one-half inch for each reduction in size of nail.

Where the nails are driven in two rows as in the style 2 box and the thickness of the ends and cleats are each one and one-fourth times the thickness of the sides, the nails should be spaced about one-fourth inch closer than required for a style 4 box having the same thickness of ends and cleats.

**Fastening Cleats to Ends**

In fastening cleats to the ends of boxes, the nails should not only be clinched but should also be driven in two rows near the edges of the cleats and spaced approximately the same as in the ends of the adjacent side, top, or bottom. See Figure 28 for details of nailing cleats to the box ends. If the box ends are thinner than the cleats, the nail heads should bear against the end pieces to resist more effectively pulling away of the ends from the cleats.

**Corrugated Fasteners**

Two pieces one-half inch or more in thickness joined with corrugated fasteners approximate the strength of a single piece where the corrugated fasteners are spaced approximately 8 inches along the joint and are driven alternately from both sides to a depth slightly less than the thickness of the pieces into which they are driven. Fasteners 1½ inches in length across the joint usually do not pull out of the material. Corrugated fasteners are much less effective when driven from one side than when driven alternately from both sides. Corrugated fasteners placed in a glued joint hold the joint while the glue is setting and produce a more rigid joint than corrugated fasteners alone.

**Thicknesses of Sides, Top, and Bottom of Strapped Boxes**

If nailed or locked-corner boxes of any style are strapped as defined under metal straps in the following paragraph, the thicknesses of the sides, top, and bottom may be reduced 20 per cent where one strap is used or 36 per cent where two straps are used. The use of straps 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
For all styles when the end and cleats are 
$\frac{1}{4}$ inch or less, $d + \frac{1}{8}$ inch. For all thicker stock, 
$\frac{d}{2}$ inch.
When $W + 2$ inches or less, $r = \frac{1}{8}$ inch. For larger values of $W$, $r = \frac{3}{8}$ inch.
In style 1, $L$ = length of nails holding sides.
In style $2\frac{1}{2}$, $n = \frac{1}{4}$ to $\frac{1}{8}$ of an inch.
Nails through cleats and ends should be long enough to clinch well, and spaced approximately
the same as in the adjacent side, top, or bottom
as shown.
Good construction is obtained with 6d nails by
making $S + \frac{1}{2}$ inches for sides and $S + 2$ inches for
tops and bottoms. With larger nails $S$ may be
increased $\frac{1}{4}$ inch for each penny in excess of six.
These values of $S$ may be varied enough to allow an
odd number of nails to be used in edges where the
nails are staggered in two rows, also to prevent
nails being driven in cracks, and to give addition-
al nails when conditions demand. Every board
should have at least two nails in each nailing edge.

FIGURE 28.—Details for nailing standard styles of boxes for domestic shipment
without straps should be used as the basis for the ratio of end to side thickness. The reduction in the thicknesses of sides, top, and bottom by the addition of straps makes advisable some changes in the nailing of the sides, top, and bottom to ends and cleats. (See nailing of strapped boxes, p. 108.)

**Metal Straps**

When two or more nailless straps (flat steel straps or steel wires) are used, the two outer straps should be applied approximately one-sixth the length of the box from the ends, and the other straps spaced evenly between them. Nailed steel straps should be applied around the ends of the box or may be spaced the same as nailless straps if they are fastened to battens.

---

**Figure 29.**—Recommended sizes of flat metal straps for nailed boxes

The total cross-sectional area of the strapping, in square inches, should equal approximately one one-thousand-four-hundredths of the square root of twice the gross weight of the box and contents in pounds for one strap, and one eight-hundred-and-fortieths of the same quantity for two or more straps; thus, for two straps each one will be one one-thousand-six-hundred-and-eightieths of the quantity, and for three straps each one will be one two-thousand-five-hundred-and-twentieths of the quantity. Larger straps apparently do not add a proportional increase to the strength of the box, while smaller straps reduce the serviceability of the box more than in proportion to the reduction in size of the strap. This relation of strap sizes applies to wires as well as to both nailed and nailless flat metal straps. The seals fastening the ends of nailless strapping should develop at least 60 per cent of the tensile strength of the strapping. The size of strapping required for boxes carrying different loads is shown in Figure 29.
To find the required size for one, two, or three straps, use the chart as follows: Starting with the weight of the box and contents, move directly upward to the curve for the number of straps decided upon, then move horizontally to the left to the line representing the thickness of the strap to be used. The first vertical line at or beyond this point represents the width of strap required. Or, move from the curve to the left, to the vertical line representing the width of the strap decided upon, and the first diagonal line at or above this point represents the thickness of strap required.

**Thickness of Single-Piece Sides**

When the sides of nailed and locked-corner boxes are made of single-piece stock they may be 12½ per cent less in thickness than that required by the preceding formulas and rules.

**Thickness of Parts Surfaced on Two Sides**

When the material is surfaced on two sides, the parts may be one thirty-second inch less in thickness than that required by the preceding formulas and rules.

**Wire-Bound Boxes**

**Thickness of Sheet Material**

Three formulas for the thickness of sheet material required in a wire-bound box have been devised and charts for their easy solution are presented on pages 97 to 100. Which of these should be used depends on certain relations between the weight of the contents and the average of the width and depth of the box. In the following formulas—

\[ t = \text{thickness of sheet material in inches}. \]
\[ W = \text{weight of contents in pounds}. \]
\[ b = \text{average of width and depth of box in inches}. \]

\( K_1, K_2, \) and \( K_3 \) are factors in the formulas for thickness. Their values depend on the nature of the commodity, the species of wood used, and the transportation conditions. For the same class of commodity and for the same transportation conditions the values of \( K_1, K_2, \) and \( K_3 \) should be 20 per cent greater for Group 1 woods and 10 per cent greater for Group 2 woods than for Group 3 woods, but may be 10 per cent less for Group 4 woods.

\( C_1 \) and \( C_2 \) are experimental values in supplementary equations defining the limits within which the three formulas apply.

1. For boxes with heavy contents and with narrow faces, a minimum cross-sectional area (thickness multiplied by width) is required to prevent the breaking of the sheet material near the corners of the box and near the end wires. This cross-sectional area varies with the weight of contents according to the formula

\[ tb = K_1 W^{2/5} \]  

from which is derived the formula

\[ t = K_1 \left( \frac{W^{3/5}}{b} \right) \]  

Formula (5) applies where \( b \) does not exceed \( C_1 \sqrt[3]{W} \)

2. For boxes where \( b \) is greater than \( C_1 \sqrt[3]{W} \) and does not exceed \( C_2 \sqrt[3]{W} \) the thickness required for a given value of \( b \) varies directly as the square root of the weight, and the thickness for a given weight varies inversely as the square root of \( b \). This relation is expressed as

\[ t = K_2 \left( \frac{\sqrt{W}}{b} \right) \]  

\(^17\) The thickness actually needed in the narrow faces is sometimes greater than that needed in the wide faces. However, since it is not practicable to use different thicknesses in the wide and narrow faces of the same box, the average of the width and depth of the boxes is used in the design formulas.
3. The thickness of material for boxes the average width of whose narrow faces \( b \) exceeds \( C_1 \sqrt{W} \) is that required to prevent mashing at the box corners and is given by

\[
t = K_3 \sqrt{W}
\]  

(7)

The following values of the factors used in defining the limits of formulas 5, 6, and 7 have been found to give satisfactory results in designing boxes of rotary-cut lumber of Group 3 woods that carry commodities requiring average protection:

\[
\begin{align*}
K_1 &= 0.105, \\
K_2 &= 0.057, \\
K_3 &= 0.034, \\
C_1 &= 3.33, \\
C_2 &= 2.85.
\end{align*}
\]

**SIZE OF WIRE**

The size of wire required depends upon the weight of the box contents and may be expressed by the formula

\[
a = \frac{\sqrt{W}}{504}
\]  

(8)

where \( a \) equals the sum of the cross-sectional area of all the binding wires, and \( W \) equals weight of box contents. The cross-sectional area of each wire equals \( a \) divided by the number of wires used. This is the same general equation as that developed for determining the size of straps for nailed boxes, but requires slightly greater total cross-sectional area of wire for wire-bound boxes than for nailed boxes.

**SPACING OF WIRES**

Experience has shown that usually the end wires and adjacent intermediate wires (p. 25) need to be spaced closer than the other wires. The following is the maximum distance the wires not adjacent the end wires should be spaced to prevent excessive springing of the sheet material under the weight and wedging action of the contents and to produce a well-balanced box:

With \( \frac{1}{4} \)-inch sides, top, and bottom, the maximum spacing of wires should not exceed 5 inches; with \( \frac{1}{6} \)-inch or \( \frac{1}{8} \)-inch material the maximum spacing should not exceed 6 inches; with \( \frac{1}{12} \)-inch or \( \frac{1}{4} \)-inch material the maximum spacing should not exceed 7 inches; with \( \frac{1}{16} \)-inch material the maximum spacing should not exceed 8 inches; and with \( \frac{1}{8} \)-inch material the maximum spacing should not exceed 9 inches.

**BOX END REINFORCEMENT**

With the standard cleat used in the ordinary wire-bound box construction the reinforcement required for the box ends depends upon the weight and nature of the contents and upon the size and shape of the box. The required thickness for the sides, top, and bottom is likewise dependent upon these same factors and in much the same way. The end reinforcements, therefore, can be approximately associated with the thickness required of the sides, tops, and bottoms.

With the standard cleat, the ends and cleats without reinforcements are stronger than necessary to balance the strength of \( \frac{1}{6} \)-inch sides, top, and bottom, but produce a good balanced construction without additional reinforcements if used in combination with \( \frac{1}{4} \)-inch sides, top, and bottom.

In boxes with \( \frac{1}{4} \)-inch sides, top, and bottom the end cleats and stapling are weaker than the sides, top, and bottom. Reinforcing end battens (styles D, E, and X) nailed in place increase the strength of the box but do not add so much strength as a wire or strap placed lengthwise around the box and over the widest faces.

In boxes made of \( \frac{1}{6} \)-inch sheet material the ends need to be reinforced with battens (styles M, N, O, or P) nailed in place or with two reinforcing wires or straps, one over the ends, top, and bottom, and one over the ends and sides.

The ends and cleats of boxes with \( \frac{3}{4} \)-inch sides, top, and bottom should be reinforced with battens in addition to two wires or straps in order to balance the strength of the sides, top, and bottom.

While the laboratory has made no tests on wire-bound boxes with \( \frac{3}{4} \)-inch and \( \frac{1}{2} \)-inch cleats as against standard \( \frac{1}{16} \)-inch cleats, general deductions would lead to the expectation that the \( \frac{3}{4} \)-inch and the \( \frac{1}{2} \)-inch cleats would be in approximate balance, respectively, with the \( \frac{3}{4} \)-inch and with \( \frac{1}{16} \)-inch sheet material.
The sum of the cross-sectional areas of the reinforcing wires or straps should be about one-fourth the total cross-sectional area of the binding wires as found from formula 8.

**SPACING OF STAPLES IN WIRE-BOUND BOXES AND CRATES**

It is common practice to space the staples in wire-bound boxes 1½ to 2 inches. The strength of boxes for carrying very heavy loads may be increased by nailing the sheet material to the cleats and battens or by spacing the staples as close as 1 inch, in which event the box must be run through the fabricating machine a second time. In boxes with relatively wide faces and carrying light loads the staple spacing may often exceed 2 inches without detriment. In wire-bound crates at least two staples should be driven in each end of each slat and near the edges.

**CHARTS FOR DESIGNING WIRE-BOUND BOXES**

Figures 30 to 33 are charts to facilitate solution of the formulas for determining sizes of parts and reinforcements for wire-bound boxes.

**HOW TO USE THE CHARTS**

**THICKNESS OF MATERIAL**

To determine the thickness of sheet material to be used, first select the chart pertaining to the species of wood under consideration. Starting with the weight of contents, follow the horizontal weight line from the scale at the left border of the chart to its intersection with the vertical line from the scale at the lower border representing the average of width and depth of box. At or above this intersection is the line representing the thickness of material.

**NUMBER AND SIZE OF WIRES**

To determine the number and size of wires to be used, start with the weight of the contents. Follow the horizontal weight line to its intersection with the curve representing the gauge of wire chosen. At or to the right of this intersection is the vertical line representing the number of wires.
For many weights there is a choice of gages and number of wires that may be used. The dimensions of the box and the fact that the wires should not be spaced closer than 4 inches to each other should be kept in mind, however, and the rules regarding maximum spacing of wires should be observed. These points may prove the determining factors in cases where a greater range of selection is otherwise indicated by the chart.

**APPENDIX F. DESCRIPTION OF TABLE 7**

(See p. 56)

**COLUMN 1, COMMON AND BOTANICAL NAMES OF SPECIES**

Column 1 gives the common and botanical names of the various species of wood as adopted by the United States Forest Service (18).

**COLUMN 2, NUMBER OF TREES TESTED**

The number of trees tested shows the extent of work done on each species, and is an aid in estimating the reliability of the average figures. The greater the number of trees tested, the closer may the averages given be expected to approach the true average of the species.
COLUMN 3, SPECIFIC GRAVITY

Specific gravity is defined as the relation of the weight of a substance to that of an equal volume of water. The specific gravity values given in column 3 are based on the weight of wood when oven dry and its volume when green.

COLUMNS 4 AND 5, WEIGHT PER CUBIC FOOT

Ordinarily, wood is spoken of as "dry," or as "green" or "wet." In order to be correct, various stages of drying or dryness must be recognized in establishing the weight, not only because of the effect of the moisture content on weight, but because of change in volume with moisture changes.

When wood is green, or freshly cut, it contains a considerable quantity of water. After wood has dried by exposure to the air until its weight is practically constant, it is said to be "air-dry." If dried in an oven at 212° F. until all moisture is driven off, wood is "oven-dry."

Green wood usually contains "absorbed" water within the cell walls and "free" water in the cell cavities. In drying, the free water from the cell cavities is the first to be evaporated. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber but at which the cell walls are still saturated with moisture. The fiber-saturation point varies with the species. The ordinary proportion of moisture—based on the weight of the dry wood—at the fiber-saturation point is from 22 to 30 per cent. As a rule, the strength properties of wood begin to increase and shrinkage begins to occur when the fiber-saturation point is reached in seasoning. See p. 86 for method of determining moisture content of wood.
The weights of wood at two important stages are given in columns 4 and 5. The weight when green as given in column 4 includes the moisture present at the time the trees were cut. The moisture content of green timber varies greatly among different species. It also varies among different trees of the same species and different parts of the same tree. In most softwood species the sapwood has more moisture than the heartwood. For instance, the sapwood of southern yellow pine usually contains moisture in excess of 100 per cent, whereas the heartwood has only about 30 or 40 per cent moisture. Large variations in green weight, depending on the proportion of sapwood, may occur in species having a high moisture content in the sapwood. Softwood lumber in the green condition that is obtained from young trees averages heavier than that obtained from old trees because the young trees contain a larger proportion of sapwood.

The amount of moisture in air-dried wood depends on the size and form of the pieces, and the climate. The species vary widely in the rate at which they give off moisture in drying, and also in the rate at which they take up moisture during periods of wet or damp weather. The average air-dry condition reached in the North Central States by material 2 inches and less in thickness, when sheltered from rain and snow and without artificial heating, is a moisture content of about 12 per cent. The figures given in column 5 are for this moisture content. The moisture content of wood is commonly expressed as a percentage of the weight of the oven-dry or moisture-free wood. If a specimen from a board weighed 112 grams immediately after cut, and after oven drying was found to weigh 100 grams, it is said to have contained 12 per cent moisture.

Figure 33.—Minimum thicknesses of sheet material and number and size of binding wires for wire-bound boxes made of Group 4 woods
moisture content of thoroughly air-dry material may be 3 to 5 per cent higher in humid regions, and in very dry climates, as much lower. Large timbers will have a higher average moisture content when thoroughly air-dry than boards or small dimension stock.

When the moisture content in comparatively dry wood changes, two actions which counteract one another take place and the weight per cubic foot changes but little. Thus, if the wood dries further, the weight per cubic foot becomes lower because of loss in moisture, while at the same time it increases because shrinkage causes the same wood substance to occupy less space. Conversely, if it absorbs moisture, both weight and volume are increased.

The weight of wood at any moisture content near 12 per cent may be estimated by assuming that a \( \frac{1}{2} \) per cent change in weight per cubic foot accompanies a 1 per cent change in moisture content. For example, wood at 8 per cent moisture content would weigh about 2 per cent less per cubic foot than at 12 per cent, whereas the weight at 14 per cent moisture would be about 1 per cent greater than at 12 per cent.

**COLUMNS 6, 7, AND 8, SHRINKAGE**

Shrinkage across the grain, that is, shrinkage in the width and thickness of boards, results when the wood loses some of the absorbed moisture. Likewise, swelling occurs when dry wood is soaked or when it takes up moisture from the air; much as a sponge gets larger when wet. Shrinkage of wood in the direction of the grain (length of boards or timbers) is usually too small to be of practical importance.

The figures in columns 6 and 7 are average values of the measured radial and tangential shrinkages which took place in drying small clear specimens from the green state to an oven-dry condition. Radial shrinkage is that across the annual growth rings in a cross section, such as in the width of a quarter-sawed board; tangential shrinkage that parallel to the curves of the annual growth rings in a cross section, such as in the width of a flat-sawed board.

Column 8 lists figures on the relative shrinkage in volume from the green to the oven-dry condition for the various species. These figures are computed from actual volume measurements of small clear specimens, combined with actual radial and tangential shrinkage measurements, the results of which are recorded in columns 6 and 7. Volumetric shrinkage values that are comparable with those of columns 6 and 7 may be obtained from column 8 by dividing the figures listed by 10.

The shrinkage which will take place in any piece of wood depends on a great many factors, some of which have not been thoroughly studied. In all species the tangential shrinkage is more than the radial, the average ratio being about 9 to 5. Hence, flat-sawed boards shrink less in width but more in the thickness than quarter-sawed or edge-grain boards. Ordinarily the less the difference between radial and tangential shrinkage, the less is the tendency to check in drying.

Air-drying wood is continually taking on or giving off moisture with changing weather or heating conditions. Time is required for these moisture changes, however, so there is always a lag between changes in air conditions and their full effect on the moisture condition of the wood. The lag is greater in some species than in others. As a result some species, whose shrinkage from the green to the oven-dry condition is large, do not cause as much inconvenience in use as woods with lower shrinkage, because the changes in dimensions do not follow atmospheric changes so closely. The shrinkage figures given do not take into account the readiness with which the species take on and give off moisture. Consequently they should be considered as the relative shrinkage between woods after long exposure to fairly uniform atmospheric conditions or to the same change in moisture content.

**COLUMN 9, BENDING STRENGTH**

Column 9 gives figures on bending strength. Bending strength is a measure of the load-carrying capacity of beams, which are usually horizontal members resting on two or more supports. Examples of beams are crate skids and box sides. The figures for bending strength afford a direct comparison of the breaking strength of clear beams of the various species.

If a species is low in bending strength, it does not necessarily follow that it is not suitable for use in boxes and crates. It does indicate, however, that larger sizes may be necessary than if species which rank higher in this property are used.

Box and crate parts are subjected to bending action and, while bending strength is of some importance, it is, particularly in sides, tops, and bottoms of boxes, of
less importance than fastening resistance. As pointed out elsewhere, it is seldom possible to fasten box parts together securely enough to utilize the full bending strength of clear lumber.

**COLUMN 10, COMpressive STRENGTH (ENDWISE)**

The figures of column 10, compressive strength, apply to comparatively short compression members. Compression members in boxes and crates are usually rectangular in cross section, and support end loads which act in the direction of the length. Endwise compressive strength of short members is seldom a controlling factor in the selection of box and crate woods except where they are used for blocking the commodity in place.

When the length of a compression member becomes more than about 11 times its least dimension, it is classed as either an intermediate or a long column, and the values in column 10 do not apply.

When compression members are of a length more than about 11 times the least dimension, stiffness begins to be a factor in the strength, and at a length of 20 to 30 times the least dimension, as in diagonal braces and edge members of crates, it is the controlling property and the member is classed as a long column. The values in column 10 are not applicable to long columns.

If one species is lower in compressive strength than another, the difference may be compensated by using a member of correspondingly larger cross-sectional area.

**COLUMN 11, STIFFNESS**

When any weight or load is placed on a member, a deflection is produced. Stiffness is a measure of the resistance to deflection and relates particularly to beams. It is one of the properties required in diagonal braces for crates. The figures in column 11 give the average stiffness of the different species. Difference in stiffness between species may be compensated by changing the size of members.

**COLUMN 12, HARDNESS**

Hardness is the property which makes a surface difficult to dent or scratch. The harder the wood, other things being equal, the better it resists wear, the less it crushes or mashes under loads, and the better it can be polished; on the other hand, the more difficult it is to cut with tools, the harder it is to nail, and the more it splits in nailing. The greater the figure given in the table, the greater the hardness of the wood.

There is a pronounced difference in hardness between the spring wood and the summer wood of some species, such as southern yellow pine and Douglas fir. Where this is true, differences in surface hardness occur at close intervals, depending on whether spring wood or summer wood is encountered. In woods like maple, which do not have pronounced spring wood and summer wood, the hardness of the surface is more nearly uniform.

**COLUMN 13, SHOCK RESISTANCE**

Shock resistance is the capacity to withstand suddenly applied loads. Hence, woods high in shock resistance are resistant to repeated shock, jars, jolts, and blows. The greater the figure in the table, the greater is the shock resistance of the species.

**PERCENTAGE ESTIMATED PROBABLE VARIATION**

The percentage figures in the bottom two lines of Table 7 exclusive of footnotes offer a means of estimating the variability, a detailed discussion of which is given in the Comparative Strength Properties of Woods Grown in the United States (12).

The percentage figures in the last line of Table 7 indicate the variation, above and below the average, which may be expected to include half of all the material of a species. For example, consider the hardness of red alder in Table 7. The hardness (column 12) is 48, and the variation of an individual piece is 16 per cent. From these figures, it may be estimated that the hardness of one-half of the red alder would fall within the limits 40 and 56. The approximate proportion of material of a species falling within certain other percentages of the Table 7 values may be estimated on the basis of the following relations:

- 75 per cent is within 1.71 times the percentage probable variation.
- 82 per cent is within 2.00 times the percentage probable variation.
- 90 per cent is within 2.44 times the percentage probable variation.
- 99 per cent is within 3.00 times the percentage probable variation.
The percentage figures in the next to last line indicate that there is an even chance that the true average is within these percentages of the figures in Table 7. The percentages given applying to species represented by various numbers of trees from 1 to 50 are presented in Comparative Strength Properties of Woods Grown in United States (12). Mortality statistics upon which insurance rates are based tell very closely how many men of any large group will live to be a certain age, but they do not enable one to say whether John Doe at that age will be included among the living. In a similar manner, the variability figures given in the next to the last line of Table 7 permit one to estimate how many of the species of wood will have their averages raised or lowered by a specified amount by additional tests, but one cannot say that red alder or any other designated species will be raised by this amount. Such calculations are of most value when applied to groups, but are less definite when applied to individual species.

APPENDIX G. SPECIFICATIONS

The following specifications are given as examples of the application of the principles, formulas, and rules presented in this bulletin and as a guide for obtaining containers of balanced construction. These specifications have been prepared by the container committee of the Federal Specifications Board. This specification for nailed and locked-corner boxes is a revision of the specification which was adopted by the American Society for Testing Materials as tentative standard in 1920. It retains the salient features of the older specification but new information which has been approved by leading manufacturers, shippers, and carriers has been added.

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, WOODEN, NAILED AND LOCKED-CORNER CONSTRUCTION

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

This specification covers two forms of construction, nailed, styles 1, 2, 2½, 3, 4, and 5, and locked-corner, style 6. (Pl. 1.)

III. MATERIALS AND WORKMANSHIP

1. Material:
   (a) Lumber—
      (1) Seasoning.—All pieces shall be made of well-seasoned lumber.
      (2) Defects.—The pieces shall show no defects that materially weaken them, expose the contents of the box to damage, or interfere with the prescribed nailing.
      No knot or knot hole shall have a diameter exceeding one-third of the width of the piece.
      (3) Species of wood.—The principal woods used for boxes are classified as follows:

<table>
<thead>
<tr>
<th>Group 1</th>
<th>COMMON NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen.</td>
<td>Fir, alpine.</td>
</tr>
<tr>
<td>Aspen, largetooth.</td>
<td>Fir, balsam.</td>
</tr>
<tr>
<td>Basswood.</td>
<td>Fir, California red.</td>
</tr>
<tr>
<td>Butternut.</td>
<td>Fir, lowland white.</td>
</tr>
<tr>
<td>Buckeye, yellow.</td>
<td>Fir, noble.</td>
</tr>
<tr>
<td>Cedar, northern white.</td>
<td>Fir, silver.</td>
</tr>
<tr>
<td>Cedar, Port Orford.</td>
<td>Fir, white.</td>
</tr>
<tr>
<td>Cedar, western red.</td>
<td>Magnolia, cucumber.</td>
</tr>
<tr>
<td>Chestnut.</td>
<td>Magnolia, evergreen.</td>
</tr>
<tr>
<td>Cottonwood, black.</td>
<td>Pine, jack.</td>
</tr>
<tr>
<td>Cottonwood, eastern.</td>
<td>Pine, lodgepole.</td>
</tr>
<tr>
<td>Cypress, southern.</td>
<td>Pine, northern white.</td>
</tr>
<tr>
<td>Fir.</td>
<td>Pine, sugar.</td>
</tr>
<tr>
<td>Magnolia.</td>
<td>Pine, western white.</td>
</tr>
<tr>
<td>Magnolia, cucumber.</td>
<td>Pine, western yellow.</td>
</tr>
<tr>
<td>Magnolia, evergreen.</td>
<td>Poplar, yellow.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Redwood.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Spruce, Engelmann.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Spruce, red.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Spruce, Sitka.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Spruce, white.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Willow, black.</td>
</tr>
<tr>
<td>Magnolia, Sitka.</td>
<td>Willow, western black.</td>
</tr>
</tbody>
</table>

20 The Federal Specifications Board was organized under the Bureau of the Budget in 1921. It was composed of representatives of each of the purchasing units of the United States Government, the director of the Bureau of Standards being chairman of the board ex-officio. Its purpose is to unify Government specifications and to bring them into harmony with the best commercial practice wherever the conditions permit. The Government specifications are submitted before adoption for criticism by industry.
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GROUP 2  

COMMON NAME

Fir, Douglas.
Hemlock, eastern.
Hemlock, western.
Larch, western.

Pine, loblolly.
Pine, longleaf.
Pine, mountain.
Pine, pitch.

Pine, pond.
Pine, shortleaf.
Pine, slash.
Tamarack.

GROUP 3  

COMMON NAME

Ash, black.
Ash, pumpkin.
Elm, American.

Gum, black.
Gum, red.
Gum, tupelo.

Maple, silver.
Sycamore.

GROUP 4  

COMMON NAME

Ash, green.
Ash, white.
Beech.
Birch, sweet.
Birch, yellow.

Elm, rock.
Elm, slippery.
Hackberry.
Hickory.
Maple, black.

Maple, sugar.
Oaks, red.
Oaks, white.

(b) Nails—Cement-coated nails of the dimensions given in Table 12 shall be used. Uncoated nails may be used in accordance with Section IV. (a) and IV. 7 (b) (2).

TABLE 12.—Dimensions of cement-coated steel wire nails

<table>
<thead>
<tr>
<th>Size of nails</th>
<th>Length</th>
<th>Cooler and sinker nails</th>
<th>Standard box nails</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gage No.</td>
<td>Gage No.</td>
<td></td>
</tr>
<tr>
<td>Inches</td>
<td></td>
<td>(Washburn &amp; Moen)</td>
<td>(Washburn &amp; Moen)</td>
</tr>
<tr>
<td>Two penny</td>
<td>1</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Three penny</td>
<td>1½</td>
<td>15½</td>
<td>15</td>
</tr>
<tr>
<td>Four penny</td>
<td>1¾</td>
<td>14</td>
<td>13½</td>
</tr>
<tr>
<td>Five penny</td>
<td>1½</td>
<td>13½</td>
<td>13</td>
</tr>
<tr>
<td>Six penny</td>
<td>1½</td>
<td>13</td>
<td>13½</td>
</tr>
<tr>
<td>Seven penny</td>
<td>2½</td>
<td>12½</td>
<td>12½</td>
</tr>
<tr>
<td>Eight penny</td>
<td>2¾</td>
<td>11½</td>
<td>11½</td>
</tr>
<tr>
<td>Nine penny</td>
<td>2½</td>
<td>11½</td>
<td>11½</td>
</tr>
<tr>
<td>Ten penny</td>
<td>2½</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

1 Cooler nails and sinker nails are identical except for their heads. The head of the cooler nail is flat on the underside, while the head of the sinker nail is cone shaped on the underside and slightly smaller. Either can be used in a nailing machine. Standard box nails are the same length as cooler nails and sinker nails, but are smaller in diameter.

(c) Strapping—

(1) Either round or flat metal straps may be used. When used without nails, flat strapping shall have a tensile strength of approximately 84,000 pounds per square inch, and round strapping shall have a tensile strength of not less than 60,000 pounds per square inch. When used with nails, round or flat strapping shall have a tensile strength of not less than 60,000 nor more than 84,000 pounds per square inch.

(2) Seals used to hold together the ends of nailless straps shall have not less than 60 per cent of the tensile strength of the strap.

2. Workmanship:

(a) Fabrication—All parts of the box shall be cut to size and the box shall be fabricated in accordance with good commercial practice.

(b) Variation in thickness—The wooden parts shall average not less than the required thickness. Occasional variations in thickness due to mis-manufacture will be permitted in not over 10 per cent of the pieces but no part of any piece shall be less than seven-eighths the required thickness.

(c) Driving of nails: Nails shall be driven so as not to project above the surface of the wood. Occasional overdriving of nails will be permitted but no nail shall be overdriven more than one-eighth the thickness of the piece.
IV. GENERAL REQUIREMENTS

1. Thickness of parts of unstrapped boxes:

(a) Thickness by formula—The thickness of the sides and of the top and bottom shall not be less than the thickness computed by the following formula:

\[ t = \frac{1}{3}\sqrt{\frac{w}{b}} \]

in which \( t \) = thickness of sides, or of top or bottom— inches
\( w \) = gross weight of the box and its contents—pounds
\( b \) = width of a side or width of top or bottom— inches

Example.—What is the thickness of ends, cleats, sides, top, and bottom of a \( \text{style 2} \) box, 36 inches long, 22\( \frac{1}{8} \) inches wide, and 12\( \frac{1}{2} \) inches deep, for carrying a net load of 190 pounds? Estimated gross weight of box and contents, 200 pounds.

\[
t (\text{of side}) = \frac{1}{3}\sqrt{\frac{200}{12.5}} = \frac{1}{2} \text{ inch}
\]

\[
t (\text{of top or bottom}) = \frac{1}{4}\sqrt{\frac{200}{22.25}} = \frac{3}{8} \text{ inch}
\]

From Section V. 2 \( b \), the ends and cleats may each be one and one-fourth times the thickness of the sides, which could be five-eighth inch; or from Section V. 2 \( c \), the ends may be equal to the sides, thickness if the thickness of the cleats is one and one-half times the thickness of the sides, which would be three-quarters inch.

(b) Thickness by chart—The thickness of the sides, top, and bottom may also be determined from the chart designated as Figure 34. This is done as follows: Place a straight edge on the chart so that it crosses

<table>
<thead>
<tr>
<th>Weight - box and contents (pounds)</th>
<th>Thickness of side, top, or bottom (inches)</th>
<th>Width of side, top, or bottom (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>( \frac{3}{8} )</td>
<td>10</td>
</tr>
<tr>
<td>90</td>
<td>( \frac{3}{8} )</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>( \frac{1}{4} )</td>
<td>10</td>
</tr>
<tr>
<td>70</td>
<td>( \frac{1}{4} )</td>
<td>9</td>
</tr>
<tr>
<td>60</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>50</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>40</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>30</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>25</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>20</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>( \frac{1}{8} )</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 34.—Chart for determining the thickness of side, top, or bottom of unstrapped boxes.
the vertical left-hand scale at the point corresponding to the gross weight; pivot the straight edge on this point so that it crosses the vertical right-hand scale at the point corresponding to the width of the side, top, or bottom; the straight edge will then cross the middle scale at a point which will be the proper thickness for the part in question.

(c) Thickness of parts of various species of wood—The thickness of parts determined as indicated in Section IV. 1 (a) and (b) applies to parts made of the woods in Groups 1 and 2, Section III. 1 (a) (3). If the parts are made from woods in Groups 3 and 4, the thickness may be less than the specified value by the amount given in Table 13.

**Table 13.—Reduction in thickness of part if made of woods in Groups 3 and 4**

<table>
<thead>
<tr>
<th>Specified thickness (woods in Groups 1 and 2)</th>
<th>Allowable reduction for woods in Groups 3 and 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ to ½ inch, inclusive</td>
<td>⅜</td>
</tr>
<tr>
<td>Over ½ to 1 inch, inclusive</td>
<td>⅜</td>
</tr>
<tr>
<td>Over 1 to 2 inches, inclusive</td>
<td>⅜</td>
</tr>
</tbody>
</table>

(d) One-piece sides—

1. Sides made from one piece of wood may be not less than seven-eighths of the thickness determined as indicated in Section IV. 1 (a) and (b).

2. Two or more pieces, which are Linderman jointed and glued, shall be considered one piece.

3. Two or more pieces one-half inch or more in thickness and not less than 1½ inch in width at either end which are either butt-jointed or matched and which are fastened with corrugated fasteners shall be considered one piece. The corrugated fasteners shall be 1½ inches in length and shall penetrate about three-quarters the thickness of the material. They shall be spaced not more than 4 inches from the ends of the boards and not more than 8 inches apart. If three or more corrugated fasteners are used in a joint, they shall be driven alternately from opposite sides of the part.

2. Number of pieces in any part: The number of pieces in any part (namely, side, top, bottom, or end) shall not exceed the number given in Table 14.

**Table 14.—Number of pieces in any part**

<table>
<thead>
<tr>
<th>Width of part</th>
<th>Maximum number of pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 4 inches</td>
<td>1</td>
</tr>
<tr>
<td>4 to 7 inches</td>
<td>2</td>
</tr>
<tr>
<td>7 to 10 inches</td>
<td>3</td>
</tr>
<tr>
<td>10 inches and over</td>
<td>1 piece for each 3 inches of width. No piece shall be less than 2½ inches in width.</td>
</tr>
</tbody>
</table>

3. Thickness of parts of strapped boxes: The thicknesses of the sides, tops, and bottoms of strapped boxes may be less than those given for unstrapped boxes by the amounts given in Table 15.

**Table 15.—Thickness of sides, tops, and bottoms**

<table>
<thead>
<tr>
<th>Unstrapped boxes</th>
<th>Strapped boxes with—</th>
<th>Unstrapped boxes</th>
<th>Strapped boxes with—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One strap</td>
<td>Two or more straps</td>
<td>One strap</td>
</tr>
<tr>
<td>7½</td>
<td>Inch</td>
<td>Inch</td>
<td>7½</td>
</tr>
<tr>
<td>1¾</td>
<td>⅜</td>
<td>⅜</td>
<td>1¾</td>
</tr>
<tr>
<td>5½</td>
<td>⅜</td>
<td>⅜</td>
<td>5½</td>
</tr>
<tr>
<td>9½</td>
<td>⅜</td>
<td>⅜</td>
<td>9½</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
4. Uncleated ends:
   (a) Thickness—The ends shall not be less than twice the thickness required for sides, but no end shall be less than three-eighth inch thick.
   (b) Joining—
      (1) Ends made of two or more pieces seven-eighth inch or less in thickness shall be either, first, cleated; or second, butt jointed, or matched and fastened with corrugated fasteners, in accordance with Tables 16 and 17.

<table>
<thead>
<tr>
<th>Thickness of box end</th>
<th>Size of fasteners</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4 inch</td>
<td>1/4 by 1 1/2</td>
</tr>
<tr>
<td>5/8, 1/2, and 3/4 inch</td>
<td>5/8 by 1 1/2</td>
</tr>
<tr>
<td>1 1/4 and 3/4 inch</td>
<td>7/8 by 1 1/2</td>
</tr>
</tbody>
</table>

**Table 16.—Size of corrugated fasteners**

<table>
<thead>
<tr>
<th>Length of box end</th>
<th>Fasteners</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 inches and under</td>
<td>2</td>
</tr>
<tr>
<td>16 to 24 inches</td>
<td>3</td>
</tr>
<tr>
<td>24 to 36 inches</td>
<td>4</td>
</tr>
</tbody>
</table>

(2) Two or more pieces Linderman jointed shall be considered one piece.

5. Surfacing:
   (a) Smoothness—The outside surface of the box shall be sufficiently smooth to permit legible marking.

   (b) Allowance for surfacing—If the boards are surfaced on both sides (to protect the contents), the thickness may be one-thirty-second inch less than the thickness required for boards surfaced on one side.

6. Nailing:
   (a) Uncoated nails—If nails which are not cement coated are used (except for cleats), the number of nails required shall be increased by 25 per cent.

   (b) Size of nails for unstrapped boxes—Cement-coated nails shall be of the size given in Table 18, depending upon the species of the wood and the thickness of the piece holding the points of the nails.

**Table 18.—Sizes of cement-coated cooler, sinker, and box nails for unstrapped boxes**

<table>
<thead>
<tr>
<th>Species of wood</th>
<th>Size of nail used for nailing—</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sides, tops, and bottoms to ends or cleats of the thickness stated in parts of an inch</td>
<td>Top and bottom to side of the thickness stated in parts of an inch</td>
</tr>
<tr>
<td>% or less</td>
<td>3/4</td>
</tr>
<tr>
<td>Group 1. . . . . . .</td>
<td>Penny</td>
</tr>
<tr>
<td>Group 2. . . . . . .</td>
<td>4</td>
</tr>
<tr>
<td>Group 3. . . . . . .</td>
<td>3</td>
</tr>
<tr>
<td>Group 4. . . . . . .</td>
<td>3</td>
</tr>
</tbody>
</table>

(c) Spacing of nails—
   (1) Nails holding the side, top, or bottom to the ends shall be spaced about as given in Table 19.
TABLE 19.—Spacing of cement-coated nails for unstrapped boxes

<table>
<thead>
<tr>
<th>Size of nail</th>
<th>Spacing when driven into—</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Side grain of end</td>
<td>End grain of end</td>
</tr>
<tr>
<td>Inches</td>
<td>Inches</td>
<td></td>
</tr>
<tr>
<td>Sixpenny or smaller</td>
<td>2</td>
<td>1 1/4</td>
</tr>
<tr>
<td>Sevenpenny</td>
<td>2 1/4</td>
<td>2</td>
</tr>
<tr>
<td>Eightpenny</td>
<td>2 1/2</td>
<td>2 1/4</td>
</tr>
<tr>
<td>Ninepenny</td>
<td>2 3/4</td>
<td>2 3/4</td>
</tr>
<tr>
<td>Tenpenny</td>
<td>3</td>
<td>2 3/4</td>
</tr>
</tbody>
</table>

(2) The next smaller nails than the size required by Table 18 may be used for unstrapped boxes, but they shall be spaced one-fourth inch closer than required by Table 19 for the size of nail used.

(3) Each board in the side, top, or bottom shall have at least two nails at each nailing end, except that boards less than 2 1/4 inches in width which are, (1), Linderman jointed, or (2), either butt jointed or matched and are fastened with corrugated fasteners as required by Section IV. 1 (d) (3) may have only one nail.

(4) If the sides are less than one-half inch in thickness, neither the top nor the bottom shall be nailed to the sides unless the order requires side nailing.

(5) When ends and cleats are the same thickness, approximately half of the nails in the ends of the sides, top, and bottom shall be driven into the ends and the remainder into the cleats.

(6) If the top or bottom is nailed to the side, the nails shall be spaced between 6 and 8 inches.

(7) When the sides, top, and bottom of strapped boxes are reduced in accordance with the thicknesses given in Table 15 the boxes shall be fastened with the next smaller nail than the size required by Table 18 and they shall be spaced one-fourth inch closer than required by Table 19 for the size of nails used.

7. Cleats:
   (a) Widths—The width of cleats shall not be less than three times the required thickness.
   (b) Nailing—
      (1) Each piece of the end shall be nailed to each cleat with not less than two nails, except that boards less than 2 1/4 inches in width which are joined in accordance with either Section IV. 1 (d) (2) or (3) may have only one nail.
      (2) The nails shall pass through both the cleat and the end and be clinched. Either cement-coated or uncoated nails may be used. If the cleats are thicker than the ends, the nails shall be driven through the ends into the cleats and clinched.
      (3) The nails in each cleat shall be driven in two rows spaced as given in Table 19.

8. Strapping:
   (a) Size—Straps shall be of the size required by Figure 29, depending on the gross weight (box and contents).
      (1) To find the size of flat straps from this diagram, start with the gross weight and move upward to the curve for the number of straps, then move horizontally toward the left to the line for the thickness of the strap. The width of the strap is given directly below this point. For example, weight 260 pounds, 2 straps, thickness 0.020 inch; the required width of strap is eleven-sixteenths inch and the next wider strap is three-fourths inch.
(2) To find the size of wire straps start with the gross weight and move upward to the curve for the number of straps, then move horizontally to the left to scale showing cross-sectional area of one strap. Determine from Table 20 the gage of wire having the required cross-sectional area. For example, weight 260 pounds, two wire straps. Required cross-sectional area is 0.014 square inch. From Table 20 it is found that 0.0143 square inch is the cross-sectional area of a 10-gage wire.

Table 20.—Conversion of cross-sectional area of one strap to gage of wire

<table>
<thead>
<tr>
<th>Cross-sectional area of one wire</th>
<th>Washburn &amp; Moen Gage number</th>
<th>Cross-sectional area of one wire</th>
<th>Washburn &amp; Moen Gage number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square inch</td>
<td></td>
<td>Square inch</td>
<td></td>
</tr>
<tr>
<td>0.0041</td>
<td>15</td>
<td>0.0127</td>
<td>10</td>
</tr>
<tr>
<td>0.0050</td>
<td>14</td>
<td>0.0143</td>
<td>9.5</td>
</tr>
<tr>
<td>0.0065</td>
<td>13</td>
<td>0.0156</td>
<td>9</td>
</tr>
<tr>
<td>0.0075</td>
<td>12½</td>
<td>0.0172</td>
<td>8</td>
</tr>
<tr>
<td>0.0087</td>
<td>12</td>
<td>0.0206</td>
<td>7</td>
</tr>
<tr>
<td>0.0098</td>
<td>11½</td>
<td>0.0246</td>
<td>6</td>
</tr>
<tr>
<td>0.0114</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) Tightness—All straps shall be drawn tight so as to sink into the edges of the box.

c) Distance between straps—If two or more nailless straps are used, the distance between any strap and either end of the box shall not be less than one-sixth the length of the box.

d) Nailing straps—If the straps are nailed, one shall be placed around each end of the box and secured by nails of the size required by Table 18 spaced twice the distance required by Table 19.

V. DETAIL REQUIREMENTS

1. Style 1. Nailed construction, no cleats:
   (a) Construction—The box shall be made substantially as shown for style 1, Plate 1.
   (b) Grain in ends—In the ends the grain of the wood shall run the long way.
   (c) Allowable weight of box and contents—Several pieces in sides, style 1 boxes, having sides made from two or more pieces, may be used if the weight of the contents does not exceed 60 pounds.
   (d) Allowable weight of box and contents—One-piece sides style 1 boxes, having single-piece sides of sawed lumber or veneer, may be used if the gross weight (box and contents) does not exceed 100 pounds.

2. Style 2. Nailed construction, having four cleats (plain) at each end:
   (a) Construction—The box shall be made substantially as shown for style 2, Plate 1.
   (b) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths or more in thickness. The thickness of the ends and cleats may be the same provided this thickness is not less than one and one-quarter times the required thickness of the sides.
   (c) Thickness of ends and sides—The thickness of the ends and sides may be the same provided the thickness of the cleats is not less than one and one-half times the required thickness of the sides.
   (d) Length of cleats—The ends of the cleats which run across the grain of the end boards shall be one-eighth inch from the inside surface of the top and bottom.
   (e) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   (f) Allowable weight of box and contents—Boxes of style 2 may be used for any gross weight.
3. Style 2½. Nailed construction having four cleats (two notched) at each end:
   (a) Construction—The box shall be made substantially as shown for style 2½, Plate 1.
   (b) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths inch or more in thickness. The thickness of the ends and cleats may be the same provided this thickness is not less than one and one-quarter times the required thickness of the sides.
   (c) Thickness of ends and sides—The thickness of the ends and sides may be the same provided the thickness of the cleats is not less than one and one-half times the required thickness of the sides.
   (d) Length of cleats—The ends of the cleats which run across the grain of the end boards shall be one-eighth inch from the inside surface of the top and bottom.
   (e) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   (f) Allowable weight of box and contents—Boxes of style 2½ may be used for any gross weight.

4. Style 3. Nailed construction having four cleats (beveled ends) at each end:
   (a) Construction—The box shall be made substantially as shown for style 3, Plate 1.
   (b) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths inch or more in thickness. The ends and cleats must each have a thickness at least one and one-fourth times the thickness required for the sides.
   (c) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   (d) Allowable weight of box and contents—Boxes of style 3 may be used for any gross weight up to 250 pounds.

5. Style 4. Nailed construction having two cleats at each end:
   (a) Construction—The box shall be made substantially as shown for style 4, Plate 1.
   (b) Thickness of ends—The thickness of the ends shall not be less than three-eighths inch.
   (c) Thickness of ends and cleats—The ends and cleats may be of the same thickness provided this thickness is not less than one and one-half times the required thickness of the sides.
   (d) Thickness of cleats and sides—The cleats may be the same thickness as the sides, provided the thickness of the ends is not less than one and three-quarters times the required thickness of the sides.
   (e) Direction of grain in cleats and ends—The cleats shall run across the grain of the end boards and shall extend within one-eighth inch of the outside surface of the top and bottom.
   (f) Cleats overlapped—The sides shall extend over the cleats.
   (g) Allowable weight of box and contents—Boxes of style 4 may be used for any gross weight up to 250 pounds.

6. Style 5. Nailed construction having two inside cleats at each end:
   (a) Construction—The box shall be made substantially as shown for style 5, Plate 1.
   (b) Thickness of ends—The thickness of the ends shall not be less than three-eighths inch.
   (c) Thickness of ends and cleats—The ends and cleats may be of the same thickness provided this thickness is not less than one and one-half times the required thickness of the sides.
   (d) Thickness of cleats and sides—The cleats may be the same thickness as the sides, provided the thickness of the ends is not less than one and three-quarters times the required thickness of the sides.
   (e) Shape of cleats—The cleats may be either triangular or square in section, provided the cross-sectional area is not less than the cross-sectional area of the required rectangular cleats.
   (f) Direction of grain in cleats and ends—The cleats shall run across the grain of the end boards and shall extend within one-eighth inch of the inside surface of the top and bottom.
   (g) Ends overlapped—The sides shall extend over the ends and be flush with the outside face of the ends.
   (h) Allowable weight of box and contents—Boxes of style 5 may be used for any gross weight up to 250 pounds.
7. **Style 6. Locked-corner construction:**

   (a) **Construction**—The box shall be made substantially as shown for style 6, Plate 1.

   (b) **Thickness of ends and sides**—The ends and sides may be of the same thickness, provided they are not less than one and one-half times the thickness required in Section IV. 1 or 3.

   (c) **Thickness of sides**—The thickness of the sides may be not less than one and one-quarter times the thickness required in Section IV. 1 or 3, provided the thickness of the ends is not less than one and three-quarters times the thickness required in Section IV. 1 or 3.

   (d) **Allowable weight of box and contents**—Style 6 boxes, having sides made from two or more pieces, may be used if the gross weight does not exceed 60 pounds.

   (e) **Allowable weight of box and contents**—Style 6 boxes, having single-piece sides of sawed lumber, may be used if the gross weight does not exceed 100 pounds.

---

**VI. METHOD OF INSPECTION AND TEST**

1. **Visual and manual inspection:** The boxes shall be inspected visually and manually for compliance with this specification, particularly that the lumber is well seasoned and that the construction is that shown in Plate 1 for the style of box stated in the order.

2. **Measuring instruments:** Suitable measuring instruments, such as a micrometer caliper, a graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts including nails and strapping.

3. **Moisture content:** The moisture content of the wood need not be determined by laboratory methods.

4. **Strength of seals:** The strength of the seals, Section III. 1 (c) (2), for flat nailless straps, shall be computed from the average tensile strengths of three specimens of sealed straps and three specimens of the strapping. These specimens may be any convenient length (say 18 inches). Each sealed specimen shall be prepared by fastening together the ends of two pieces of strapping with the seal applied in the usual way. The seal shall be near the middle of the specimen. A testing machine or other apparatus, such as weights, spring balance, etc., approved by the inspector shall be used to determine the strength.

---

**VII. PACKING AND MARKING OF SHIPMENTS**

1. (See Section VIII, 3.)

---

**VIII. NOTES**

1. **Scope of specification:** This specification applies to all empty wooden boxes, nailed and locked-corner construction, purchased by the Government for the domestic shipment of Government property by common carrier.

2. **Exceptions to specifications:** This specification applies to the majority of domestic shipments in wooden boxes. Exceptional commodities may require less protection, while other commodities, especially dangerous articles, may require better boxes than are specified here. In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (25) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. **Requirements for packing:** Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

4. **Well-seasoned lumber:** For box construction, well-seasoned lumber has a moisture content of 12 to 18 per cent of the weight of the wood after oven drying at 212° F. to a constant weight.

5. **Applying strapping:** All strapping shall be applied immediately before the box is shipped and should be drawn sufficiently tight to sink into the edges of the box. Nailless straps should be applied at right angles to the edges of the box; otherwise they are likely to become loose.
6. Orders for boxes: Orders for nailed or locked-corner boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)—and the weight of the contents (in pounds).

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, WOODEN, CLEATED PLYWOOD CONSTRUCTION

I. GENERAL SPECIFICATIONS
There are no general specifications applicable to this specification.

II. STYLES
1. The wooden boxes covered by this specification are of styles A, B, C, D, E, F, G, H, I, J, and K. The construction of these styles is shown in Figure 4.
2. Boxes furnished under this specification shall be of style B, D, E, or G (having 3-way corners), unless there is some special reason for using one of the other styles.

III. MATERIAL AND WORKMANSHIP
1. Material.
(a) Species of wood—The principal woods used for boxes are classified as shown in Table 21.

<table>
<thead>
<tr>
<th>Group</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Same as Group 1, p. 103.)</td>
</tr>
<tr>
<td>2</td>
<td>(Same as Group 2, p. 104.)</td>
</tr>
<tr>
<td>3</td>
<td>(Same as Group 3, p. 104.)</td>
</tr>
<tr>
<td>4</td>
<td>(Same as Group 4, p. 104.)</td>
</tr>
</tbody>
</table>

(b) Seasoning—The parts shall be made from thoroughly seasoned lumber.
(c) Defects—No defects shall show in the parts that will materially weaken the boxes, expose their contents to damage, or interfere with the prescribed nailing.

2. Workmanship:
Plywood—
(a) The plies shall be firmly glued together throughout the entire area in contact.
(b) If a ply is made of two or more pieces, the edges shall be butted and the space between the edges shall not exceed one-fourth inch.

IV. GENERAL REQUIREMENTS
1. Plywood construction:
(a) Each face of the box shall be covered with a single piece of plywood.
(b) The plywood shall be made of three plies or of five plies, and the grain of each ply shall cross the grain of the adjacent ply or plies at an angle of approximately 90°.
(c) The thickness of each ply shall not exceed one-twelfth inch.
(d) The thickness of the plywood shall comply with the requirements given in Table 22. Occasional pieces shall not be more than 6 per cent less than the thickness specified.

Table 22.—Minimum thickness of plywood for boxes of various gross weights

<table>
<thead>
<tr>
<th>Gross weight of box and contents</th>
<th>Thickness of plywood in—</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groups 1 and 2</td>
</tr>
<tr>
<td>Not over 150 pounds</td>
<td>⁷⁄₈&quot;</td>
</tr>
<tr>
<td>150 to 450 pounds</td>
<td>⁷⁄₈&quot;</td>
</tr>
<tr>
<td>450 to 800 pounds</td>
<td>⁷⁄₈&quot;</td>
</tr>
<tr>
<td>Over 800 pounds</td>
<td>⁷⁄₈&quot;</td>
</tr>
</tbody>
</table>
2. Cleat construction:
   (a) Number of cleats—
      (1) Two cleats shall be used along each edge of the box, styles A and B, when the gross weight (box and contents) exceeds 150 pounds.
      (2) One cleat may be used along each edge of the box, styles C to K, inclusive, when the gross weight does not exceed 150 pounds.
   (b) Size of cleats—
      (1) The thickness and width of the cleats for boxes of styles A and B shall comply with the requirements given in Table 23.
      (2) Cleats on boxes of styles C to K, inclusive, shall be not less than three-fourths inch thick and of the width given in Table 23.
      (3) The cleats shall average not less than the required thickness. Occasional variations in thickness due to mismanufacture will be permitted in not over 10 per cent of the pieces, but no part of any cleat shall be less than seven-eighths the required thickness. The variation of the occasional cleat below the width specified shall not exceed one-eighth inch.

   **Table 23.—Minimum size of cleats for boxes of styles A and B**

<table>
<thead>
<tr>
<th>Gross weight of box and contents</th>
<th>Minimum thickness of cleats for woods in—</th>
<th>Minimum width of cleats for all woods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groups 1 and 2</td>
<td>Groups 3 and 4</td>
</tr>
<tr>
<td>Not over 75 pounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 to 150 pounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 to 450 pounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>450 to 800 pounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 800 pounds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Actual, not nominal.

3. Nailing requirements:
   (a) The plywood panels shall be nailed or stapled to the cleats. (See fig. 4.) The nails or staples shall be driven through the plywood into and through the cleats and clinched. The nails or staples shall be staggered and spaced not more than 3 inches apart.
   (b) If a panel has an edge which is not cleated, the plywood along that edge shall be fastened to the cleats on an adjacent face by cement-coated nails driven through the plywood into the cleats. The nails shall be not less than 1 inch in length, and have heads not less than three-eighths inch in diameter, and be spaced not over 3 inches apart.
   (c) The plywood and cleats of a face shall be fastened to the cleats on the adjacent face by cement-coated nails. The size of the nails and their spacing shall comply with the requirements given in Tables 24 and 25.

   **Table 24.—Sizes of cement-coated nails for fastening together adjacent faces**

<table>
<thead>
<tr>
<th>Thickness of cleat</th>
<th>Cooler and sinker Standard box</th>
<th>Cooler and sinker Standard box</th>
<th>Cooler and sinker Standard box</th>
<th>Cooler and sinker Standard box</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% inch</td>
<td>Penny</td>
<td>Penny</td>
<td>Penny</td>
<td>Penny</td>
</tr>
<tr>
<td>7% inch</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>8% inch</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9% inch</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>13% inches</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

1 Table 12 gives the length and gage of the three kinds of nails.
Table 25.—Spacing of cement-coated cooler and sinker nails for fastening together adjacent faces

<table>
<thead>
<tr>
<th>Gross weight of box and contents</th>
<th>Spacing (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not over 75 pounds</td>
<td>6</td>
</tr>
<tr>
<td>75 to 150 pounds</td>
<td>5</td>
</tr>
<tr>
<td>150 to 450 pounds</td>
<td>4</td>
</tr>
<tr>
<td>450 to 800 pounds</td>
<td>3</td>
</tr>
<tr>
<td>Over 800 pounds</td>
<td>2</td>
</tr>
</tbody>
</table>

Boxes nailed with standard cement-coated box nails shall have approximately 10 per cent more nails than boxes nailed with cooler and sinker cement-coated nails.

Two nails shall be driven through each end of a cleat into the cleat on the adjacent face, except that when the gross weight does not exceed 150 pounds one nail may be used.

V. DETAIL REQUIREMENTS

Plywood boxes shall be constructed as illustrated in Figure 4 for the style ordered.

In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (25) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.).

VI. METHOD OF INSPECTION AND TEST

1. Visual and manual inspection.—The boxes shall be inspected visually and manually for compliance with these specifications, particularly that the lumber is well seasoned and that the construction is that shown in Figure 4 for the style of box ordered.

2. Measuring instruments.—Suitable measuring instruments, such as a micrometer caliper, graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts, including nails.

3. Moisture content.—The moisture content of the wood need not be determined by laboratory methods.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 3.)

VIII. NOTES

1. Scope of specification.—This specification applies to all empty wooden boxes, cleated plywood construction, purchased by the Government for the domestic shipment of Government property by common carrier.

2. Exceptions to specifications.—This specification applies to the majority of shipments in wood boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require better boxes than are specified here.

3. Requirements for packing.—Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

4. Well-seasoned lumber.—For box construction, well-seasoned lumber has a moisture content of from 12 to 18 per cent of the weight of the wood after oven drying at 212° F. to constant weight.

5. Three-way corners.—In a box having 3-way corners, the sides overlap the ends, the ends overlap the top and bottom, and the top and bottom overlap the sides.

6. Orders for boxes.—Orders for plywood boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)— and the weight of the contents (pounds).
7. Selection of style.—The selection of the style of box depends largely on the nature and weight of the commodity and how the commodity is to be supported. Types B, D, E, and G (having 3-way corners) are all satisfactory if the boxes are not to be opened for inspection. If the boxes are to be opened and reclosed, types A and K would, in general, be preferable. The full-cleated types A and B are the strongest and most suitable for heavy commodities if the weight may be applied over the entire area of any of the faces.

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, FIBER, CORRUGATED

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

1. This specification covers the usual styles of corrugated fiber boxes without wooden frames, as follows:
   (a) One piece—
       Style 1—1-piece box.
   (b) Two piece—
       Style 2—half-slotted box.
       Style 3—design box.
       Style 4—telescope box (design style).
       Style 5—telescope box (taped-corner style).
   (c) Three piece—
       Style 6—triple-slide box.

2. The construction of these boxes is shown in Figure 8.

III. MATERIAL AND WORKMANSHIP

1. Material:
   (a) The box shall be made of either double-faced corrugated board of or double-wall board.
   (b) Double-faced corrugated board shall have one corrugated sheet between two flat facings. The corrugations shall be securely glued to the facing over all of the surfaces in contact.
   (c) Double-wall board shall have one flat filler between two corrugated sheets and one flat facing on each outer surface. The corrugations shall be securely glued to the filler sheet and to the facings over all of the surfaces in contact.
   (d) Facings and liners shall comply with the requirements in Table 26.
   (e) Corrugated sheets may be strawboard, chestnut fiber board, pine wood fiber board, or other material which has been demonstrated to give equal service. The sheet before corrugating shall be calendared to a uniform thickness of not less than 0.009 inch. The sheet shall neither crack nor break when corrugated. There shall be not less than 32 corrugations per foot. There are no bursting strength requirements for corrugated sheets.
   (f) The outer facing of each board shall be waterproofed except the board for the inner slide of style 6 boxes.
   (g) Metal fasteners (rivets, staples, and stitching wire) shall be steel, treated to resist rust, and when subjected to conditions of use shall not show cracks or other evidence of weakness.
   (h) Pads, when required by transportation rules for filling the space between the ends of inner flaps of style 1 and style 2 boxes, shall be made of the same board that is used in the box.
   (i) Gummed tape—
       (1) Gummed tape for boxes made of board, items 1 and 2, Table 26, may be either paper or cloth. The tape shall be not less than 2 inches wide, shall have a bursting strength of not less than 60 points, and shall be uniformly coated with glue.
       (2) Gummed tape for boxes made of board, items 3, 4, and 5, Table 26, shall be cloth. The tape shall be not less than 3 inches wide, shall have a bursting strength of not less than 80 points, and shall be uniformly coated with glue.
2. Workmanship: All corrugated board parts shall be cut square and shall be the required size. They shall be creased and slotted so that in the assembled box the parts fit closely without undue binding. Further, all creasing shall be performed so as not to cause surface breaks in the board, either at the time of creasing or when filling and sealing the box, nor any separation of the facings or fillers from the corrugated sheet. No nap shall project beyond the edge of the box.

IV. GENERAL REQUIREMENTS

1. Corrugated fiber board: The corrugated board of the box shall comply with Table 26.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Gross weight of box and contents not over</th>
<th>Size of box (length, breadth, and depth added not over)</th>
<th>Minimum thickness of board</th>
<th>Minimum bursting strength of board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>60 Double-faced</td>
<td>0.016</td>
<td>85 175</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>65 do</td>
<td>0.016</td>
<td>85 200</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>70 do</td>
<td>0.016</td>
<td>135 275</td>
</tr>
<tr>
<td>4</td>
<td>65</td>
<td>65 Double-wall</td>
<td>0.016</td>
<td>85 200</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>70 do</td>
<td>0.016</td>
<td>185 275</td>
</tr>
</tbody>
</table>

1 Bursting strength requirement also applies to filler in item No. 5.

2. Metal fastenings:
   (a) Metal fastenings may be rivets, staples, or stitching wire.
   (b) Staples or stitches shall be not less than one-half inch wide, shall pass through all the pieces to be fastened, and shall be clinched.
   (c) Rivets of an equivalent strength and holding power may be substituted for wire staples or stitches.

3. Body joints:
   (a) Body joints shall be butt, spliced, or lapped.
   (b) Butt joints shall have the edges of the board meet and shall be fastened with tape glued along the entire length of the joint.
   (c) Spliced joints shall have the corrugated portion of one edge (and the filler, if any) removed and the inner and outer facings spliced over the adjoining edge. The overlap shall not be less than 1 inch and both facings shall be securely glued.
   (d) Lapped joints shall have the edges overlap not less than 1½ inches and shall be secured with metal fasteners spaced not more than 2½ inches.

4. Body piece: For styles 1, 2, and 6, the body piece shall be made from one piece and shall have the joint along one of the four edges perpendicular to the opening.

5. Covers: Separate covers shall be made from one piece of corrugated board. Corner joints may be butt, spliced, or lapped as defined for body joints except that if lapped joints are used, each joint shall have not less than two metal fasteners.

V. DETAIL REQUIREMENTS

1. Style 1, 1-piece box:
   (a) This box shall be made from one piece, slotted and scored to form a body piece having four flaps for closing each of two opposite faces.
   (b) The width of each of the inner flaps shall be not less than one-half its length measured along its creased edge.
   (c) The two outer flaps when in the closed position shall either meet at the middle of the face or shall overlap not less than 1 inch.
   (d) The body joint shall be butt, spliced, or lapped.

2. Style 2, half-slotted box:
   (a) The body of this box shall have four flaps which close one face as in style 1, and a separate cover shall fit over the opposite face.
   (b) All joints shall be butt, spliced, or lapped.
3. Style 3, design box:
   (a) The body of this box shall have a continuous (undivided) bottom and sides. The depth of the cover shall be less than the depth of the body.
   (b) All body joints shall be lapped.
   (c) All cover joints shall be butt, spliced, or lapped.
4. Style 4, telescope box (design style): This box shall be similar to style 3, except that the body and cover shall have the same depth.
5. Style 5, telescope box (taped-corner style): This box shall be similar to style 4, except that the joints in the body and cover shall be butt joints.
6. Style 6, triple-slide box: This box shall be made of three rectangular body pieces each having four faces. All joints shall be butt or spliced joints. The pieces shall slide together snugly and there shall be two thicknesses of corrugated board on each of the six faces of the box.

VI. METHOD OF TESTING

1. Bursting-strength apparatus: The bursting-strength test consists essentially in clamping the fiber board between two surfaces having concentric circular apertures 1.24 inches in diameter and then applying hydraulic pressure through a fluid to a rubber diaphragm secured to one of the circular apertures. The pressure required to burst the board is recorded by means of a pressure gauge calibrated to record pounds per square inch and is reported in “points.” For detailed information, see Official Paper Testing Methods of the Technical Association of the Pulp and Paper Industries (19, v. 88, p. 51-55).

2. Bursting-strength method: The bursting strength of corrugated fiber board or gummed tape shall be determined as follows:
   (a) In testing, the board or tape shall be clamped firmly in the machine to prevent slipping; the wheel of the testing machine shall be turned at a uniform speed of approximately two revolutions per second. The corrugations of the corrugated board must not be crushed when clamped in the testing machine.
   (b) Six punctures shall be made, three from each side of the board. For the board to comply with this specification, not more than one puncture shall fall below the strength specified in Table 26.
   (c) If the board fails to pass the test as specified in VI.2 (b), then a retest may be made consisting of 24 punctures, 12 from each side of the board. If not more than four punctures fall below the strength requirements, the board complies with this specification.
   (d) The punctures should preferably be made on the specimen after it has come to moisture equilibrium with an atmosphere of 65 per cent relative humidity at a temperature of 70° F.
   (e) When testing double-faced corrugated board, if a puncture gives two “pops,” the result shall be disregarded and another puncture made.

3. Strength of joints: The strength of the joints shall be observed by grasping a body or a cover in the hands, one each side of the joint, and pulling until the joint ruptures. Failure shall occur in the board, not in the fastenings nor by separation of the glued surfaces.

4. (a) Visual and manual inspection: The boxes shall be inspected visually for compliance with this specification, particularly that the construction is that shown in Figure 8, for the style of box stated in the order.
   (b) The fit of the flaps, slides, and cover shall be determined by assembling and disassembling the box.

5. Measuring instruments: Suitable measuring instruments such as a graduated scale or rule shall be used to determine the dimensions.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 4.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty corrugated fiber boxes purchased by the Government for the domestic shipment of Government property by common carrier.

2. Exceptions to specifications: This specification applies to the majority of shipments in fiber boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require better boxes than are here specified. In no case should the quality of the
container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (25) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammmable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. Variations within styles: It is not intended to prevent the use of ordinary variations within styles, such as different lengths of closing flaps. Such variations are subject to the discretion of the department ordering the boxes. The design of special styles of corrugated fiber containers is not covered by this specification.

4. Requirements for packing: Since these shipping containers are packed, closed, and marked by the shipper and not by the manufacturer of the container, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

5. Selection of style: The following information dealing with the six styles of corrugated fiber boxes included in this specification may be helpful in making a satisfactory selection:

(a) Style 1, 1-piece box.—This style of box is often called a “slotted carton.” It is probably in more general use than any other style considered in this specification, and is used for shipping a wide variety of materials. It is shipped flat, takes up but little room in storage, and is set up and sealed by the shipper. For freight and express shipments, the flaps must be sealed according to rules of the transportation companies. Express rules require tying with specified materials, while freight rules offer several optional methods of sealing.

(b) Style 2, half-slotted box.—This box differs from style 1 in the fact that it has a separate cover which makes it a convenient shelf package as well as shipping container. It is also convenient to cut down its depth to change the size of the box. The flaps must be sealed in the same manner as provided for style 1. Express rules require tying with specified materials, while freight rules offer several optional methods of sealing.

(c) Style 3, design box.—The body part of this box is ordinarily folded flat for shipment and is set up by the shipper with a hand stapling device. The covers are usually finished with tape on the corners ready for use and are shipped either set up or nested. The cover may also be made the same as the body if it is desired to have it fold flat. This box was originally intended for express shipments where something stronger than the ordinary cardboard carton was desired, but it is also used for freight. For express shipments, it must be closed by tying in a prescribed manner. Freight rules provide several optional methods of closing, some of which involve gluing or sealing with tape.

(d) Style 4, telescope box (design style).—Both top and bottom of this box may be shipped and stored flat to be set up by the user. It is usually used when a shallow container is desired, as for books, pictures, and lithographic cutouts. Because of the added thicknesses of material, the sides and ends provide more cushioning protection than the top and bottom. For freight shipments, this box must be tied and sealed in a prescribed manner. For express, the rules are somewhat similar except that seals are not required.

(e) Style 5, telescope box (taped-corner style).—This box is shipped to the user set up and ready for use. It is used for the same materials as style 4 and the same closing requirements apply.

(f) Style 6, triple-slide box.—This style has two thicknesses of material on all faces, thus offering the same cushioning protection on all sides. It is used for freight, express, and parcel post shipments and is used in a large number of sizes. The closing requirements for this style of box are fairly simple and easy to comply with.

6. Orders for boxes: Orders for corrugated fiber boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, depth (in inches)—and the weight of the contents (pounds).
PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION
FOR BOXES, FIBER, SOLID

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

1. This specification covers the usual styles of solid fiber boxes without wooden frames as follows:
   (a) One piece—
       Style A, 1-piece box.
   (b) Two piece—
       Style B, half-slotted box.
       Style C, design box.
       Style D, telescope box.

2. The construction of these boxes is shown in Figure 9.

3. The style of box shall be stated in the invitation for bids.

III. MATERIAL AND WORKMANSHIP

1. Material:
   (a) The box shall be made of fiber board consisting of three or more plies of either fiber or pulp board firmly glued together.
   (b) No ply shall be less than 0.016 inch thick.
   (c) The outer ply shall be waterproofed.
   (d) Pads, when required by transportation rules for filling the space between the ends of inner flaps of style A and style B boxes, shall be made of the same board as the box.
   (e) Metal fasteners (rivets, staples, and stitching wire) shall be of steel, treated to resist rust, and when subjected to conditions of use shall not show cracks or other evidence of weakness.

2. Workmanship:
   (a) All fiber board parts shall be cut square and shall be of the required size. They shall be creased and slotted so that in the assembled box the parts fit closely without undue binding. All creasing shall be performed so as not to cause surface breaks in the board, either at the time of creasing, or when filling and sealing the box. No flap shall project beyond an edge of the box.

IV. GENERAL REQUIREMENTS

1. Fiber board: The fiber board in the box shall comply with Table 27.

   Table 27.—Thickness and bursting strength of solid fiber board

<table>
<thead>
<tr>
<th>Maximum weight of box and contents</th>
<th>Maximum size of box, length, breadth, and depth added</th>
<th>Minimum thickness of board</th>
<th>Minimum bursting strength of board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pounds</td>
<td>Inches</td>
<td>Inch</td>
<td>Pounds</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>0.060</td>
<td>175</td>
</tr>
<tr>
<td>65</td>
<td>65</td>
<td>0.080</td>
<td>200</td>
</tr>
<tr>
<td>90</td>
<td>70</td>
<td>0.100</td>
<td>275</td>
</tr>
</tbody>
</table>

2. Metal fastenings:
   (a) Metal fastenings may be rivets, staples, or stitching wire.
   (b) Staples, or stitches shall be not less than one-half inch wide, shall pass through all the pieces to be fastened, and shall be clinched.
   (c) Rivets of an equivalent strength and holding power may be substituted for wire staples or stitches.
3. Body joints:
   (a) The joint is that part of the box where the box manufacturer joins the
       body of the box together.
   (b) For styles A and B the body piece shall be made from one piece and shall
       have the joint along one of the four edges except that, if the grain
       (machine direction) of the fiber board is parallel to the joint, the body
       piece may have two joints, one at each of two diagonally opposite
       edges.
   (c) At each joint in the body piece the fiber board shall overlap not less
       than 1½ inches and be secured either by metal fasteners or by glue.
   (d) If metal fasteners are used, they shall be spaced not over 2½ inches and
       the distance between the outer fasteners and the end of the joint shall
       not exceed 1 inch. If the length of the joint exceeds 18 inches, an
       additional fastener shall be used about 1 inch from each end.
   (e) If glue is used, it shall secure firmly the entire surface of the joint. If
       the length of the joint exceeds 18 inches, a metal fastener shall be
       used about 1 inch from each end.

4. Covers: Separate covers shall be made from one piece of fiber board, and each
   corner joint shall be fastened with not less than two metal fasteners.

V. DETAIL REQUIREMENTS

1. Style A, 1-piece box:
   (a) This box shall be made from one piece, slotted and scored to form a
       body piece having four flaps for closing each of two opposite faces.
   (b) The width of each of the inner flaps shall not be less than one-half its
       length measured along its creased edge.
   (c) The two outer flaps when in the closed position shall either meet at the
       middle of the face or shall overlap not less than 1 inch.

2. Style B, half-slotted box: The body of this box shall have four flaps which
   close one face as in type A. A separate cover shall fit over the opposite
   face.

3. Style C, design box: The body of this box shall have a continuous (undivided)
   bottom and sides. The depth of the separate cover shall be less than
   the depth of the body.

4. Style D, telescope box: This box shall be similar to style C except that the
   body and the cover shall have the same depth.

VI. METHODS OF TESTING

1. Bursting-strength apparatus: The bursting-strength test consists essentially
   in clamping the fiber board between two surfaces having concentric cir-
   cular apertures 1.24 inches in diameter and then applying hydraulic
   pressure through a fluid to a rubber diaphragm secured to one of the cir-
   cular apertures. The pressure required to burst the board is recorded
   by means of a pressure gauge calibrated to record pounds per square inch
   and is reported in "points." For detailed information see Official Paper
   Testing Methods of the Technical Association of Pulp and Paper Industries

2. Bursting-strength method: The bursting strength of fiber board shall be de-
   termined as follows:
   (a) In testing, the board shall be clamped firmly in the machine to prevent
       slipping, the wheel of the testing machine shall be turned at a uniform
       speed of approximately two revolutions per second.
   (b) Six punctures shall be made, three from each side of the board. For
       the board to comply with this specification not more than one punc-
       ture shall fall below the strength requirements.
   (c) If the board fails to pass the test as specified in VI. 2 (b), then a retest
       may be made consisting of 24 punctures, 12 from each side of the
       board. If not more than four punctures fall below the strength
       requirements, the board complies with this specification.
   (d) The punctures should preferably be made on the board after it has come
       to moisture equilibrium in an atmosphere of 65 per cent relative
       humidity at a temperature of 70° F.

3. Waterproofing: The waterproofing of the board shall be determined by the
   decrease in bursting strength after the board has been exposed at ordinary
   room temperature to a column of water 3 inches high and not less than
   4 inches in diameter for three hours. When making the test the clamp
   shall be centered so as not to cover any portion of the board which has
not been exposed to the column of water. The bursting strength shall be determined in accordance with VI. 1 and 2. Boards when subjected to this test shall have at least 50 per cent of the bursting strength determined by VI. 2.

4. Strength of joints: The strength of the joints shall be observed by grasping a body or a cover in the hands on each side of the joint and pulling until the joint ruptures. Failure shall occur in the fiber board, not in the fasteners nor by separation of the glued surfaces.

5. (a) Visual and manual inspection: The boxes shall be inspected visually and manually for compliance with this specification, particularly that the construction is that shown in Figure 9 for the style of box stated in the order.

(b) The fit of the flaps, slides, and cover shall be determined by assembling and disassembling the box.

6. Measuring instruments: Suitable measuring instruments such as a graduated scale or rule shall be used to determine the dimensions.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 4.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty solid fiber boxes purchased by the Government for the domestic shipment of Government property by common carrier.

2. Exceptions to specifications: This specification applies to the majority of shipments in fiber boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require stronger boxes than are here specified. In no case should the quality of the container fall below the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (25) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. Variations within styles: It is not intended to prevent the use of ordinary variations within styles, such as different lengths of closing flaps. Such variations are subject to the discretion of the department ordering the boxes. The design of special styles of solid fiber boxes is not covered by this specification.

4. Requirements for packing: Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the boxes, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

5. Selection of style: The following information dealing with the four styles of solid fiber boxes included in this specification may be helpful in making a satisfactory selection.

(a) Style A, 1-piece box—This style box is often called a "slotted carton." It is probably in more general use than any of the styles considered in this specification and is used for shipping a wide variety of materials. It is shipped flat, takes up but little room in storage, and is set up and sealed by the shipper. For freight and express shipments, the flaps must be sealed according to rules of the transportation companies.

(b) Style B, half-slotted box, 2-piece—This box differs from style A in that it has a separate cover which makes it a convenient shelf package as well as a shipping container. The body may be cut down decreasing the depth which is a convenient way to change the size of the box. The flaps must be sealed in the same manner as provided for style A. Express rules require tying with specified materials, while freight rules offer several optional methods of sealing.

(c) Style C, design box—The body part of this box is ordinarily folded flat for shipment and is set up by the shipper with a hand stapling device. The covers may also be shipped flat and be made up by the shipper. This box is used for both express and freight shipments. Freight rules offer optional methods of sealing, depending on the cover construction. Express rules are somewhat different from freight rules for methods of sealing this box.
(d) Style D, telescope box—This style of box is often used when a shallow container is desired, such as for books, pictures, and lithographic cut-outs. For freight shipments, this box must be tied and sealed in a prescribed manner. For express, the rules are somewhat similar except that seals are not required.

6. Orders for boxes: Orders for solid fiber boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)—and the weight of the contents (pounds).

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR WIRE-BOUND BOXES

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

This specification covers all common styles of wire-bound boxes.

(Definitions of the wire-bound box and its parts are given under "Notes," paragraph 1 (a).)

III. MATERIAL AND WORKMANSHIP

1. Material:
   (a) Lumber—
   (1) Seasoning—All pieces shall be made of well-seasoned lumber.
   (2) Defects—The pieces shall show no defects that materially weaken them, expose the contents of the box to damage, or interfere with the prescribed stapling or nailing. Each cleat and batten shall be free from knots and from cross grain which runs across it within a distance equal to one-half its length.
   In the thin boards of the sides, top, bottom, and ends large knots at the ends of the pieces, slanting shakes, and decayed wood are especially objectionable.
   (3) Species of wood—The principal woods used for boxes are classified as follows:
   
<table>
<thead>
<tr>
<th>Group</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Same as Group 1, p. 103.</td>
</tr>
<tr>
<td>2</td>
<td>Same as Group 2, p. 104.</td>
</tr>
<tr>
<td>3</td>
<td>Same as Group 3, p. 104.</td>
</tr>
<tr>
<td>4</td>
<td>Same as Group 4, p. 104.</td>
</tr>
</tbody>
</table>

   (b) Binding wire—The binding wire shall be of a quality that will make an efficient closure which can not easily be opened and reclosed without giving evidence of the operation.
   (c) Staple wire—The staple wire shall be of such a quality and hardness as to produce well-formed staples that will drive properly.
   (d) Nails—Cement-coated cooler or sinker nails of the dimensions given in Table 28 shall be standard for wire-bound boxes.

   Table 28.—Dimensions of standard cement-coated cooler and sinker nails

<table>
<thead>
<tr>
<th>Size</th>
<th>Length</th>
<th>Diameter</th>
<th></th>
<th>Size</th>
<th>Length</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches</td>
<td>Gage No.1</td>
<td>Inch</td>
<td></td>
<td>Inches</td>
<td>Gage No.1</td>
</tr>
<tr>
<td>Two-penny</td>
<td></td>
<td>16</td>
<td>0.0625</td>
<td>Six-penny</td>
<td>2%</td>
<td>13</td>
</tr>
<tr>
<td>Three-penny</td>
<td>1½</td>
<td>15½</td>
<td>0.0672</td>
<td>Seven-penny</td>
<td>2%</td>
<td>12½</td>
</tr>
<tr>
<td>Four-penny</td>
<td></td>
<td>14</td>
<td>0.0800</td>
<td>Eight-penny</td>
<td>2%</td>
<td>11½</td>
</tr>
<tr>
<td>Five-penny</td>
<td></td>
<td>13½</td>
<td>0.0857</td>
<td>Nine-penny</td>
<td>2%</td>
<td>11½</td>
</tr>
</tbody>
</table>

1 Washburn & Moen.

If nails less than 1 inch long are required, standard cement-coated barrel nails of the following sizes are suggested: Three-fourths inch by 15½ gage, and seven-eighths inch by 14½ gage.

21 Prepared by the Forest Products Laboratory in cooperation with the Wirebound Box Manufacturer's Association. The specification is tentative and subject to revision before being adopted as standard.
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(e) Reinforcing wires—
(1) Either wires, having a tensile strength of not less than 60,000 pounds per square inch, or "special annealed" flat metal straps may be used. (Special annealed strapping has an average tensile strength of approximately 84,000 pounds per square inch.)
(2) Closures or seals used to hold together the ends of the reinforcing wires or straps shall have not less than 60 per cent of the tensile strength of the wire or strap.

2. Workmanship:
(a) Fabrication—All parts of the box shall be cut to size and the box shall be fabricated in accordance with good commercial practice. The separate sections of the mat shall be spaced such a distance from each other that, when assembled, the thin boards and wires shall fold in such a manner as to give enough tension to the wires to make a tight corner.

(b) Variation in thickness of thin boards—
(1) The thin boards in each box shall average not less than the specified thickness. No part of any piece shall be less than seven-eighths the specified thickness.
(2) An allowance not greater than 5 per cent below the thickness of veneer specified shall be made for shrinkage, it being assumed that the material was cut full thickness when green.
(3) Thicknesses of resawn lumber are specified for material S1S or S2S. If neither side is surfaced, one sixty-fourth inch thicker material must be used.

(c) Variations in dimensions of cleats—
(1) A variation of not more than one-sixteenth inch in one or one-thirty-second inch in each dimension below the specified cross-sectional dimensions of the cleat will be permitted.

(d) Driving of staples—
(1) The staples on the wires which are coincidental with cleats shall be driven home astride the binding wires, through the thin boards into the cleats. The points of the staples may go through the cleats and clinch but must not protrude from the cleats.
(2) The staples on intermediate wires shall be driven astride the binding wires, through the thin boards, and shall be firmly clinched.
(3) The staples or nails securing the end boards to the inside of the cleats and battens shall be driven flush with the surface of the wood. Occasional overdriving of staples or nails will be permitted, but the head of no staple or nail shall protrude or be overdriven more than one-eighth the thickness of the piece.

(e) Application of binding wires—Each binding wire shall be continuous once around the box with the ends of sufficient length to be securely twisted at one side; provided, that wires not less than No. 12 gage may be in sections, if there are loops at the connection end of each section one of which may be passed through the other and bent back securely against the box.

IV. GENERAL REQUIREMENTS

See detail requirements.

V. DETAIL REQUIREMENTS

1. Sides, top, and bottom:
(a) Thickness—The thin boards of the sides, top, and bottom shall be not less than the thicknesses indicated by the appropriate design chart, Figures 30, 31, 32, and 33.

(b) Method of determining thickness of thin boards—To determine the thickness of thin boards, proceed as follows: First, select the chart pertaining to the species of material under consideration. Start with the weight of contents. Follow the horizontal weight line from the scale at the left border of the chart to its intersection with the vertical
line from the scale at the lower border representing the average of width and depth of box. At or above this intersection is the line representing the thickness of material required.

(c) Minimum width of thin boards—Thin boards less than 2 inches wide at either end shall not be used.

2. Ends:
   (a) Thickness—The thickness of the thin boards (if any) in the ends shall be not less than that of the sides, top, and bottom.

3. Cleats:
   (a) Dimensions—Cleats shall be designated as light (thirteen-sixteenth inch thick by nine-sixteenth inch wide), standard (thirteen-sixteenth inch thick by seven-eighth inch wide), and heavy (1 1/4 inch thick by thirteen-sixteenth inch wide). The thickness of a cleat is defined as the dimension parallel to the grain direction of the thin boards in the sides, top, and bottom.

4. Battens:
   (a) Thickness—Battens shall be the same thickness, measured in the same direction, as the cleats.
   (b) Arrangement—Most of the common arrangements of battens are shown in Figure 7, page 27.
   (c) Purpose of battens—Battens may be required for one or both of two principal purposes; (1) to reinforce the thin boards of the ends, and (2) to reinforce the cleats.

   (1) End reinforcement—When the thin boards of the ends are of the same thickness as the sides, top, and bottom, they shall be reinforced with battens across the grain so spaced that the distance between battens or between cleats and battens is not greater than as follows: (These battens shall be not less than thirteen-sixteenth inch in width.)

   For 1/4-inch ends, 10 inches.
   For 3/8 or 5/16-inch ends, 12 inches.
   For 1/2 or 3/4-inch ends, 14 inches.
   For 7/16-inch ends, 16 inches.
   For 5/8-inch ends, 18 inches.

   Liners not thinner than the ends may be substituted for battens on ends 3/4 inch or less in thickness. The liners adjacent to the side cleats shall be not less in width than the cleats. Intermediate liners shall be not less than 3 inches wide. If liners inside the end interfere with the contents of the box they may be positioned between the end and cleats (on the outside of the end but inside the cleats).

   (2) Cleat reinforcement—No reinforcement is required for cleats of the species and sizes indicated below if the weight of contents is not greater than that shown in Table 29.

### Table 29.—Weight of contents permitted in boxes without cleat reinforcement

<table>
<thead>
<tr>
<th>Wood in cleats</th>
<th>For light cleats (13/16 by 9/16 inch)</th>
<th>For standard cleats (13/16 by 3/8 inch)</th>
<th>For heavy cleats (1 1/4 by 13/16 inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds</td>
<td>Pounds</td>
<td>Pounds</td>
</tr>
<tr>
<td>Group 1</td>
<td>29</td>
<td>98</td>
<td>231</td>
</tr>
<tr>
<td>Group 2</td>
<td>38</td>
<td>126</td>
<td>300</td>
</tr>
<tr>
<td>Group 3</td>
<td>50</td>
<td>169</td>
<td>400</td>
</tr>
<tr>
<td>Group 4</td>
<td>69</td>
<td>234</td>
<td>547</td>
</tr>
</tbody>
</table>

Reinforcement for standard cleats of the species and for the weights of contents indicated shall be not less than given in Table 30. (The battens shall be not less than 1 1/4 inches in width.)
TABLE 30.—Reinforcements required for standard cleats of boxes carrying various weights of contents

<table>
<thead>
<tr>
<th>Wood in cleats</th>
<th>Weight of contents, pounds</th>
<th>Cleat reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1...</td>
<td>98 to 231...</td>
<td>(1) Battens adjacent to and parallel with the short cleats, or (2) one reinforcing wire over faces of widest dimension.</td>
</tr>
<tr>
<td>Group 2...</td>
<td>126 to 300...</td>
<td>(1) Battens adjacent to and parallel with all cleats, or (2) battens adjacent to and parallel with the short cleats and one reinforcing wire over faces of widest dimension, or (3) two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 3...</td>
<td>169 to 400...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 4...</td>
<td>254 to 547...</td>
<td>Battens adjacent to and parallel with the short cleats, or (2) one reinforcing wire over faces of widest dimension.</td>
</tr>
<tr>
<td>Group 1...</td>
<td>231 to 450...</td>
<td>(1) Battens adjacent to and parallel with all cleats, or (2) battens adjacent to and parallel with the short cleats and one reinforcing wire over faces of widest dimension, or (3) two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 2...</td>
<td>300 to 585...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 3...</td>
<td>400 to 780...</td>
<td>Battens adjacent to and parallel with the short cleats, or (2) one reinforcing wire over faces of widest dimension.</td>
</tr>
<tr>
<td>Group 4...</td>
<td>547 to 1,068...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 1...</td>
<td>Over 450...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 2...</td>
<td>Over 585...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 3...</td>
<td>Over 780...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
<tr>
<td>Group 4...</td>
<td>Over 1,068...</td>
<td>Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).</td>
</tr>
</tbody>
</table>

5. Stapling of sides, top, and bottom:
   (a) The spacing of staples is defined as the average distance between centers of staples.
   (b) Staples on wires which are coincidental with cleats made of Groups 3 and 4 woods shall be of not less than the gauge and length shown below and shall be spaced not farther apart than as indicated below:
      For thin boards one-eighth inch in thickness—
      \[
      \begin{array}{ccc}
      \text{Length (inches)} & \text{Spacing (inches)} \\
      \frac{3}{8} & 2 \\
      \end{array}
      \]
      For thin boards more than one-eighth inch to and including one-fourth inch in thickness—
      \[
      \begin{array}{ccc}
      \text{Length (inches)} & \text{Spacing (inches)} \\
      1 \frac{1}{2} & 2 \\
      1 & 1 \frac{1}{4} \\
      \frac{3}{8} & 1 \frac{1}{2} \\
      1 & 2 \\
      \end{array}
      \]
      For thin boards more than one-fourth inch to and including three-eighths inch in thickness—
      \[
      \begin{array}{ccc}
      \text{Length (inches)} & \text{Spacing (inches)} \\
      1 \frac{1}{2} & 2 \\
      1 \frac{1}{8} & 1 \frac{1}{4} \\
      1 \frac{1}{4} & 1 \frac{1}{4} \\
      1 & 1 \frac{1}{4} \\
      \end{array}
      \]
   (c) At least two staples must be placed in each end of each thin board.
   (d) When cleats are made of woods of Groups 1 and 2, the staples shall be spaced at least one-fourth inch closer than as specified for cleats of Groups 3 and 4 woods.
   (e) The staples on intermediate wires shall be not smaller than as follows:
      For thin boards one-eighth inch in thickness—18 gage by three-eighths inch long.
      For thin boards more than one-eighth inch to and including seven-thirty-seconds inch in thickness—18 gage by seven-sixteenths inch long.
      For thin boards more than seven thirty-seconds of an inch, to and including three-eighths of an inch in thickness—18 gage by nine-sixteenths of an inch long.
   (f) The staple nearest each corner of the box shall be not more than 1\frac{1}{2} inches from the end of the cleat.

6. Fastenings of ends:
   (a) Staples or cement-coated nails used to fasten the ends to the cleats and battens shall be not smaller than 16 gage, and shall be long enough to penetrate at least three-fourths the thickness of the cleats or battens. If these nails or staples extend through the cleat or batten they shall be clinched.
(b) The average space between staples or nails in cleats or battens extending across the grain of the ends shall be not more than 2\(\frac{1}{2}\) inches beginning not more than 1\(\frac{3}{4}\) inches from the open face of the box, and in battens extending along the grain of the ends the space between nails or staples shall be not more than 6 inches.

(c) Staples used to fasten the liners to the ends shall be long enough to clinch securely. In the intermediate liners the staples shall be staggered so as to have two rows, and the distance between staples in each row shall be not more than 3 inches.

7. Auxiliary fastenings:
   (a) One sixpenny nail for light cleats and one or more sevenpenny nails for standard and heavy cleats shall be driven through the thin board and cleat into each end of each batten that comes in end contact with a cleat.
   (b) Battens required adjacent to and parallel with the standard cleats shall not only be secured to the thin boards of the ends, as indicated in paragraph 6, but shall have sevenpenny nails, spaced not more than 5 inches apart, driven through the thin boards and cleats into the battens.
   Longer nails than those specified in paragraph 7 (a) and (b) may be used provided they are not of larger gage.

8. Thick ends:
   (a) As indicated by paragraph 4 (c) (1) thicker ends without battens may be used in some cases in place of the thinner ends with battens. For example, if the ends are 18 inches long between the cross cleats and the thin boards are less than three-eighths of an inch in thickness one batten (style A) is required, whereas three-eighths-inch ends without battens (style T) could be used.
   (b) If the sides, top, and bottom of the box are fastened to ends having thicknesses of not less than that shown in Table 31, with nails of the sizes indicated and spaced not more than 2\(\frac{1}{2}\) inches apart, battens may be dispensed with.

<table>
<thead>
<tr>
<th>Required thickness of thin boards</th>
<th>Thickness of ends without battens</th>
<th>Size of nailing of ends without battens</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\frac{1}{2})-inch or less</td>
<td>Inch (\frac{1}{2})</td>
<td>Penny None required.</td>
</tr>
<tr>
<td>Over (\frac{1}{4}) to (\frac{1}{2}) inch</td>
<td>(\frac{1}{4})</td>
<td>4</td>
</tr>
<tr>
<td>Over (\frac{1}{2}) to (\frac{3}{4}) inch</td>
<td>(\frac{1}{4}) to (\frac{3}{8})</td>
<td>5</td>
</tr>
</tbody>
</table>

1 For fastening of ends to cleats see par. 6 (a) and (b).

9. Binding wires:
   (a) Number and gage—The binding wires shall be of not less than the number and gage (Washburn & Moen) indicated by the design charts, Figures 30, 31, 32, and 33.
   (b) Method of determining number and gage of binding wires. The wire curves are the same on all four of the charts. To determine the number and size of wires to use, start with the weight of the contents. Follow the horizontal weight line to its intersection with the curve representing the gage of wire chosen. At or to the right of this intersection is the vertical line representing the number of wires required.
   For many weights there is a choice of gages and number of wires that may be used. The dimensions of the box must be kept in mind, however, and also the fact that the wires can not be spaced closer than 4 inches to each other, and the notes in paragraph 9 (c) regarding maximum spacing of wires should be observed. These points may prove the determining factors in a given case where a greater range of selection is otherwise indicated by the chart.
(c) Maximum spacing of binding wires—Unless otherwise specified, the binding wires must be uniformly spaced, and the distance between the wires shall be not greater than as follows:

- For ¼-inch material, 5 inches.
- For ⅜ and ⅝ inch material, 6 inches.
- For ⅞ inch material, 7 inches.
- For 7⁄₆-inch material, 8 inches.
- For 9⁄₆-inch material, 9 inches.

It is often advantageous to use closer spacing between the first and second wires from the ends of the box than between the other wires.

(d) Binding wires of gages other than those shown in Figures 30, 31, 32, and 33 may be used provided the aggregate cross-sectional area is equal to that required by the figures.

10. Reinforcing wires:

(a) The size of reinforcing wires of flat metal straps around the box (ends and sides, or ends, top, and bottom) when required shall be not less than as indicated in Table 32.

<table>
<thead>
<tr>
<th>Weight of contents</th>
<th>One wire</th>
<th>Two wires</th>
<th>One flat metal strap</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gage 1</td>
<td>Gage 2</td>
<td>Inch</td>
</tr>
<tr>
<td>150 to 200 pounds</td>
<td>13</td>
<td>14</td>
<td>½ by 0.018</td>
</tr>
<tr>
<td>250 to 400 pounds</td>
<td>12</td>
<td>13</td>
<td>⅜ by 0.018</td>
</tr>
<tr>
<td>400 to 570 pounds</td>
<td>11</td>
<td>12</td>
<td>⅞ by 0.023</td>
</tr>
<tr>
<td>570 to 800 pounds</td>
<td>10</td>
<td>11</td>
<td>⅛ by 0.025</td>
</tr>
</tbody>
</table>

1 Flat metal straps of other widths and thicknesses but of equivalent cross-sectional area may be substituted for the sizes indicated.

2 Washburn & Moen gage.

11. Use of heavier material: Nothing herein contained shall be construed as prohibiting the use of boxes constructed of thicker thin boards, additional or heavier wires, heavier cleats, longer staples, or with closer spacing of staples.

VI. METHOD OF INSPECTION AND TEST

1. Visual and manual inspection: The boxes shall be inspected visually and manually for compliance with the specifications, particularly that the lumber is well seasoned and that the construction is that of the style of box stated in the order.

2. Measuring instruments: Suitable measuring instruments, such as a micrometer caliper, a graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts including wires, nails, and staples.

3. Moisture content: The moisture content of the wood need not be determined by laboratory methods.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 3.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty wire-bound boxes purchased by the Government for the domestic shipment of Government property by common carrier.

(a) Definition of the wire-bound box and its parts—

(1) The wire-bound box is a container, the sides, top, and bottom of which are stapled to several steel binding wires, and fastened to a framework of cleats at each end by staples driven astride the end binding wires, the ends being nailed or stapled to the end cleats. The box is closed by looping the wires, or by twisting together or otherwise joining securely the ends of each binding wire, the method used depending upon whether the binding wire is sectional or continuous.
(2) By mat is meant that part of the box consisting of the faces which are attached to the binding wires; a knocked-down wire-bound box exclusive of the end pieces.

(3) By cleats is meant those strips of lumber used to form the framework of the wire-bound box and to which the sides, top, and bottom are stapled.

(4) By battens is meant those reinforcing strips of lumber attached to the end faces of the box.

(5) By liners is meant thin strips of wood fastened inside or outside across the grain of the end.

(6) By reinforcing wires is meant those wires which are in addition to, and usually to be applied at right angles to the regular binding wires, after the box has been packed and closed, their principal purpose being to reinforce the end construction.

2. Exceptions to specifications: This specification applies to most domestic shipments in wire-bound boxes. Exceptional commodities may require less protection, while other commodities, especially dangerous articles, may require better boxes than are specified here. In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. Requirements for packing: Since these boxes are packed, closed, and marked by the shipper, and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

4. Well-seasoned lumber: For box construction, well-seasoned lumber has a moisture content of 12 to 18 per cent of the weight of the wood after even drying at 212° F. to a constant weight.

5. Heavy cleats:
   (a) Reinforcement for the heavy cleats is not covered in these specifications.
   (b) Relatively few wire-bound box manufacturers are prepared at present to furnish the heavy cleats. Bids should, therefore, be made to cover alternate construction, heavy cleats, or standard cleats with appropriate reinforcement.
### APPENDIX H. WOOD CONSUMED IN THE MANUFACTURE OF BOXES AND CRATES, 1928

#### TABLE 33.—Wood consumed in the manufacture of boxes and crates, 1928 ¹ by kinds of wood and forms

[Quantities in thousand feet, board measure]

#### SOFTWOODS

<table>
<thead>
<tr>
<th>Kinds of wood</th>
<th>Lumber</th>
<th>Veneer</th>
<th>Bolts</th>
<th>All forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar, eastern red</td>
<td>333</td>
<td>-</td>
<td>85</td>
<td>418</td>
</tr>
<tr>
<td>Cedar, eastern white</td>
<td>-</td>
<td>5</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Cedar, western</td>
<td>21,039</td>
<td>-</td>
<td>2,869</td>
<td>23,908</td>
</tr>
<tr>
<td>Cypress</td>
<td>22,164</td>
<td>25</td>
<td>3,659</td>
<td>25,848</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>74,804</td>
<td>197</td>
<td>300</td>
<td>75,301</td>
</tr>
<tr>
<td>Fir other than Douglas</td>
<td>46,039</td>
<td>-</td>
<td>6,036</td>
<td>52,075</td>
</tr>
<tr>
<td>Hemlock</td>
<td>321,368</td>
<td>-</td>
<td>722</td>
<td>322,090</td>
</tr>
<tr>
<td>Larch</td>
<td>5,271</td>
<td>-</td>
<td>64</td>
<td>5,335</td>
</tr>
<tr>
<td>Pine, southern yellow</td>
<td>1,150,998</td>
<td>35,976</td>
<td>39,355</td>
<td>1,226,333</td>
</tr>
<tr>
<td>Pine, western yellow</td>
<td>1,003,588</td>
<td>1,282</td>
<td>657</td>
<td>1,005,377</td>
</tr>
<tr>
<td>Pine, white</td>
<td>708,762</td>
<td>40</td>
<td>1,121</td>
<td>719,923</td>
</tr>
<tr>
<td>Redwood</td>
<td>209</td>
<td>1</td>
<td>1,401</td>
<td>210</td>
</tr>
<tr>
<td>Spruce</td>
<td>278,666</td>
<td>243</td>
<td>-</td>
<td>280,310</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,633,266</td>
<td>37,758</td>
<td>61,633</td>
<td>3,732,354</td>
</tr>
</tbody>
</table>

#### HARDWOODS

<table>
<thead>
<tr>
<th>Kinds of wood</th>
<th>Lumber</th>
<th>Veneer</th>
<th>Bolts</th>
<th>All forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alder</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Apple wood</td>
<td>-</td>
<td>-</td>
<td>126</td>
<td>126</td>
</tr>
<tr>
<td>Ash</td>
<td>11,863</td>
<td>154</td>
<td>1,837</td>
<td>13,854</td>
</tr>
<tr>
<td>Basswood</td>
<td>42,421</td>
<td>1,181</td>
<td>13,700</td>
<td>57,401</td>
</tr>
<tr>
<td>Beech</td>
<td>20,237</td>
<td>2,198</td>
<td>13,384</td>
<td>44,819</td>
</tr>
<tr>
<td>Birch</td>
<td>86,968</td>
<td>13,857</td>
<td>4,977</td>
<td>105,792</td>
</tr>
<tr>
<td>Buckeye</td>
<td>1,462</td>
<td>-</td>
<td>1,462</td>
<td>1,462</td>
</tr>
<tr>
<td>Butternut</td>
<td>35</td>
<td>-</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Cherry</td>
<td>32</td>
<td>-</td>
<td>126</td>
<td>126</td>
</tr>
<tr>
<td>Chestnut</td>
<td>10,367</td>
<td>64</td>
<td>103</td>
<td>10,434</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>110,741</td>
<td>8,284</td>
<td>28,927</td>
<td>148,027</td>
</tr>
<tr>
<td>Elm</td>
<td>33,312</td>
<td>2,726</td>
<td>11,976</td>
<td>48,014</td>
</tr>
<tr>
<td>Hackberry</td>
<td>21</td>
<td>-</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Hickory</td>
<td>154</td>
<td>42</td>
<td>750</td>
<td>1,247</td>
</tr>
<tr>
<td>Hornbeam</td>
<td>35</td>
<td>-</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Maple</td>
<td>72,268</td>
<td>9,575</td>
<td>12,689</td>
<td>94,533</td>
</tr>
<tr>
<td>Oak</td>
<td>66,100</td>
<td>30</td>
<td>2,088</td>
<td>68,288</td>
</tr>
<tr>
<td>Red gum</td>
<td>251,603</td>
<td>90,560</td>
<td>78,857</td>
<td>421,020</td>
</tr>
<tr>
<td>Sycamore</td>
<td>5,196</td>
<td>353</td>
<td>5,431</td>
<td>11,220</td>
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<tr>
<td>Tupelo</td>
<td>97,488</td>
<td>10,529</td>
<td>12,541</td>
<td>120,558</td>
</tr>
<tr>
<td>Willow</td>
<td>4,263</td>
<td>-</td>
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<td>9,361</td>
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<tr>
<td>Yellow poplar</td>
<td>88,905</td>
<td>1,939</td>
<td>5,775</td>
<td>96,619</td>
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<tr>
<td>Miscellaneous</td>
<td>89</td>
<td>3</td>
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<td>142</td>
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<tr>
<td><strong>Total</strong></td>
<td>912,660</td>
<td>141,739</td>
<td>194,355</td>
<td>1,248,784</td>
</tr>
</tbody>
</table>

| Foreign woods          | 82     | -      | -     | 82        |
| **Total**              | 4,546,048| 179,497| 255,685| 4,981,320|

¹ This table includes wood used in the manufacture of boxes and crates for sale, and also material for boxes and crates manufactured and used by firms that make other wooden products. It does not include material used for boxes and crates by firms that manufacture products of materials other than wood, except in cases where such firms have separate establishments for making boxes and crates. A small percentage of the quantities included in this table was used for baskets.

In some cases the names of woods given in the table include several species; also, some of the woods are commonly known by various trade names, as follows:

- Western yellow pine covers not only this species, often known in the trade as "western white pine," "California white pine," "pondosa pine," and "western soft pine," but also includes lodgepole pine.
- White pine includes northern white pine (also called "eastern white pine"), western white pine (often called "Idaho white pine"), sugar pine, and Norway pine.
- Cottonwood includes also aspen.
- Red gum includes "sap gum," which is the trade name for the sapwood of the red gum tree.
- Tupelo (known as "tupelo gum," "cotton gum," and "bay poplar") includes also black gum.
- Yellow poplar includes also cucumber and magnolia.

Forest Service: The Bureau of the Census cooperating in the canvass. These data form a part of the Forest Survey of the United States.

83899°—30—9

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TABLE 34.—Wood consumed in the manufacture of boxes and crates, 1928, by States and forms of raw material

<table>
<thead>
<tr>
<th>State</th>
<th>Lumber</th>
<th>Veneer</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Softwoods</td>
<td>Hardwoods</td>
</tr>
<tr>
<td>Alabama</td>
<td>16,826</td>
<td>15,742</td>
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<tr>
<td>Arizona</td>
<td>29,784</td>
<td>3,746</td>
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<td>Arkansas</td>
<td>17,571</td>
<td>3,230</td>
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<td>California</td>
<td>652,119</td>
<td>3,746</td>
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<td>10,304</td>
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<td>9,842</td>
<td>887</td>
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<td>7,192</td>
<td>600</td>
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<tr>
<td>Florida</td>
<td>39,422</td>
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<td>74,987</td>
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<td>48,591</td>
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<td>65,265</td>
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<td>244,857</td>
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<td>130,518</td>
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<tr>
<td>Texas</td>
<td>6,425</td>
<td>27,870</td>
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<td>Vermont</td>
<td>10,015</td>
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<td>Virginia</td>
<td>153,745</td>
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<td>Washington</td>
<td>449,635</td>
<td>6,402</td>
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<td>1,616</td>
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<td>Wisconsin</td>
<td>92,413</td>
<td>77,728</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>3,633,266</strong></td>
<td><strong>912,690</strong></td>
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</table>

1 This table includes wood used in the manufacture of boxes and crates for sale, and also material for boxes and crates manufactured and used by firms who make other wooden products. It does not include material used for boxes and crates by firms that manufacture products of materials other than wood, except in cases where such firms have separate establishments for making boxes and crates. A small percentage of the wood included in this table was used for baskets.
<table>
<thead>
<tr>
<th>State</th>
<th>Bolts Softwoods (num-ber)</th>
<th>Hardwoods</th>
<th>Total</th>
<th>Softwoods</th>
<th>Hardwoods</th>
<th>Total</th>
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</table>

Forest Service: The Bureau of the Census cooperating in the canvass. These data form a part of the Forest Survey of the United States.
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(4) ELMENDORF, A.

(5) ———

(6) FISHER, D. F.

(7) GRAYATT, G. F., and MARSHALL, R. P.

(8) HATT, W. K.

(9) HUMPHREY, C. J.

(10) KOEHLER, A.

(11) ———

(12) MARKWARDT, L. J.

(13) NELLIS, J. C.


(15) ——— and WILSON, T. R. C.

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ORGANIZATION OF THE
UNITED STATES DEPARTMENT OF AGRICULTURE

March 26, 1930

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Director of Extension Work: C. W. Warburton.
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