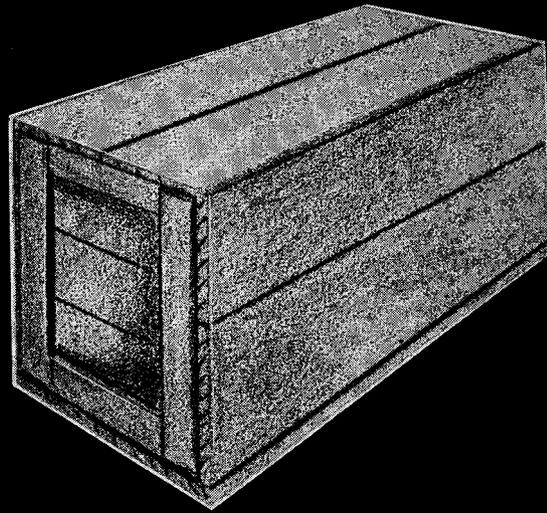


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# NAILING BETTER WOOD BOXES AND CRATES



by L. O. Anderson

FOREST SERVICE  
U.S. DEPARTMENT OF AGRICULTURE

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# Nailing Better Wood Boxes and Crates

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## INTRODUCTION

The strength and stability of wood containers depend primarily on adequate methods of fastening. This has been shown by extensive packaging research conducted at the Forest Products Laboratory as a part of its program to improve the serviceability and utility of wood products.

Containers made of wood can be assembled with a variety of fastenings, including nails, staples, screws, lag screws, bolts, and adhesives. Because nails are the most commonly used fasteners in box and crate construction, their proper use is stressed in this handbook.

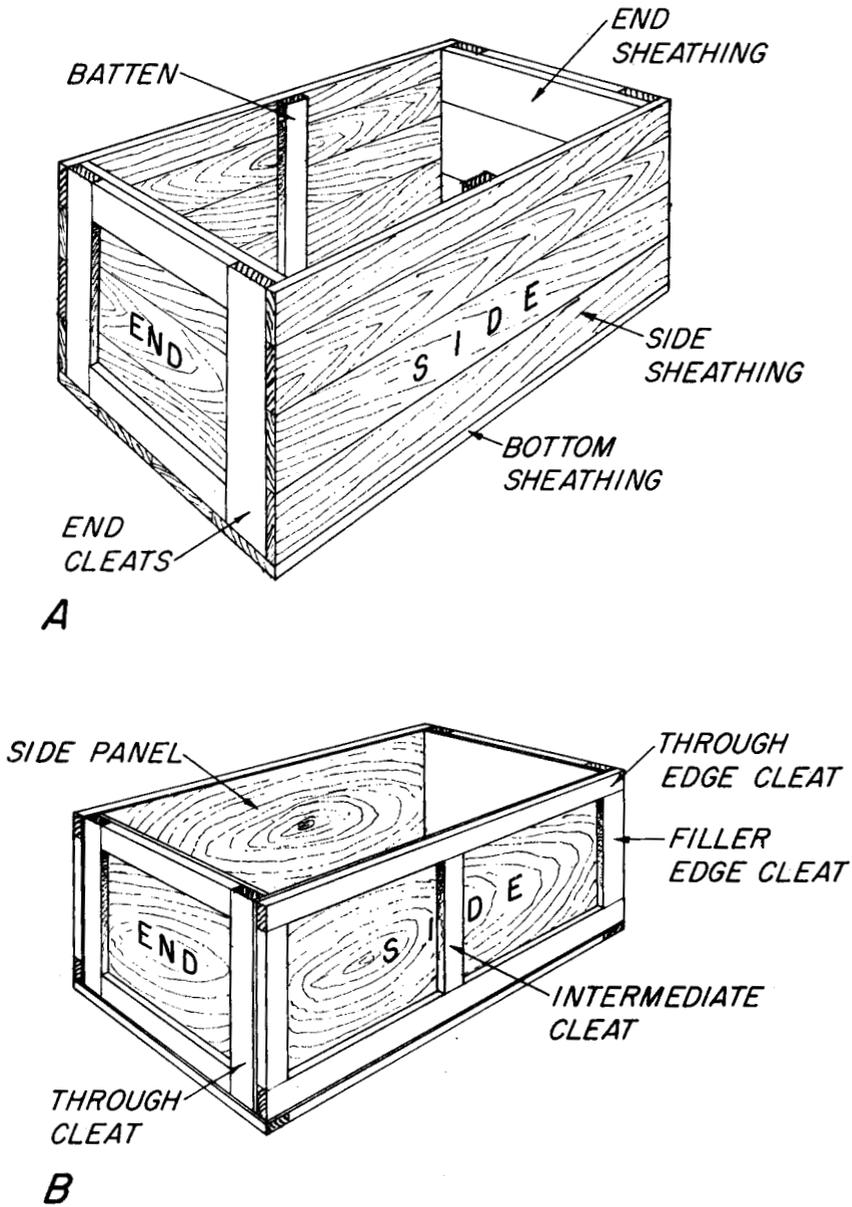
Nails are used to fabricate and assemble many styles of boxes and crates. Two typical box styles and two styles of crates are cited in this handbook to illustrate the principles of fabrication with nails. These are the nailed wood box commonly called style 2 in specifications, and the cleated plywood box (fig. 1), the sheathed crate (fig. 2), and the open crate (fig. 3). The nailing methods used to make these containers are adaptable to many other styles, since good nailing principles vary little.

The two basic procedures in box and crate construction are fabrication nailing and assembly nailing. Fabrication nailing means the nailing of box or crate parts. Examples are the nailing of cleats to the end boards of boxes, or sheathing to the frame members of a sheathed crate panel. Normally in fabrication, the nails are driven through both members and clinched, unless the total thickness of the members is too great. Assembly nailing means the assembly of the sides, top, bottom, and ends of a nailed wood box, or the various panels of a crate, to form the finished container.

Containers properly nailed with the right kinds and sizes of nails will be dependably strong and rigid. Containers improperly nailed may fail even though wood members of adequate size and high qual-

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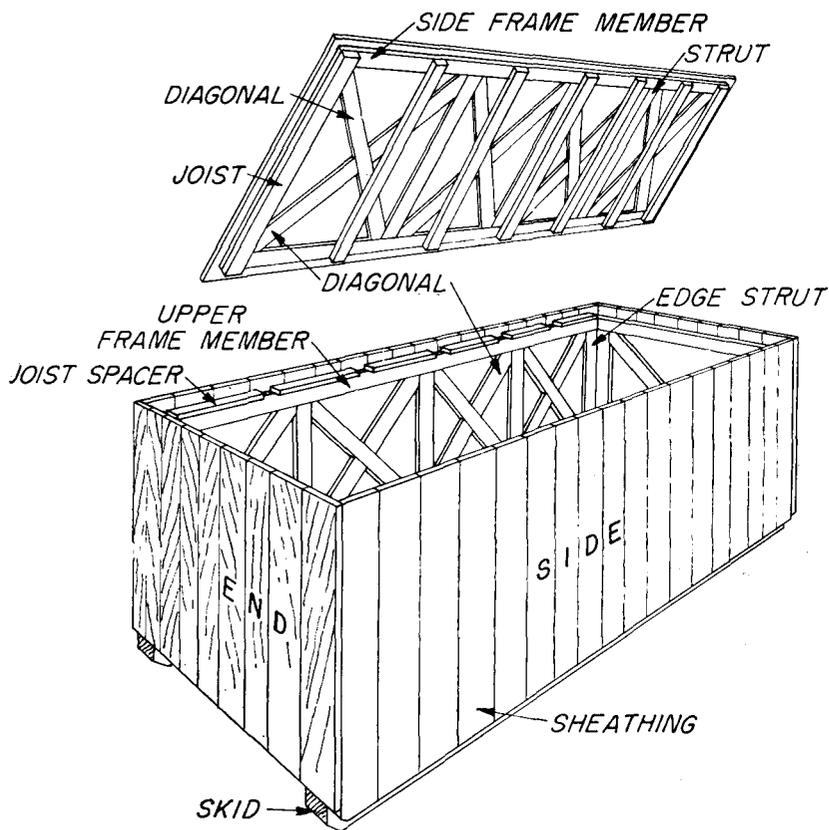
<sup>1</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.



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FIGURE 1.—Typical wood boxes: A, Style 2 nailed wood box; B, cleated panel box.

ity are used. Adequate nailing means not the use of a large number of nails but rather the use of the correct sizes, numbers, and types of nails at the right places. The purpose of this publication is to describe the most important aspects of good nailing for wood boxes and crates.



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FIGURE 2.—Typical lumber-sheathed crate.

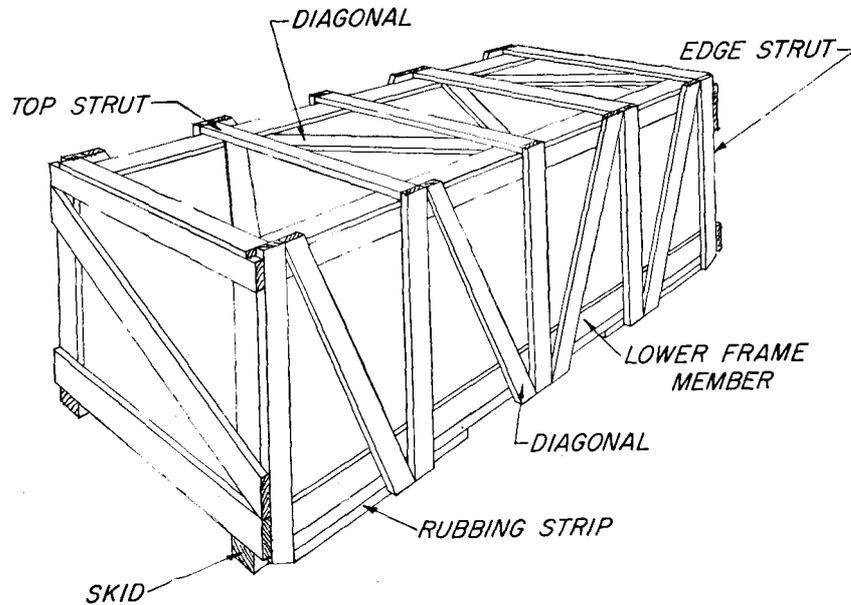
## TYPES AND SIZES OF NAILS

### Types of Nails

Nails are available in such great variety that they can be used for almost any purpose requiring fasteners. These nails are made in many sizes and shapes, from steel, aluminum, copper, and other metals. Not all types, however, are satisfactory for boxes and crates. Some of the more common types used in containers are shown in figure 4.

### *Common and Box Nails*

Common nails and smooth box nails are most often used in fabrication nailing where clinching is required. A nail that is to be clinched need not be coated nor given any other treatment to increase its withdrawal resistance. Common and box nails have the same length, but the box nail is smaller in diameter (table 1).



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FIGURE 3.—Typical open crate.

Clout nails are commonly used to fasten plywood or other sheet materials to cleats of boxes or to thinner frame members of crates. These nails, available in lengths from  $\frac{3}{4}$  to  $1\frac{1}{2}$  inches, have long, tapered, duckbill points that clinch easily (fig. 4), and larger heads than other container nails of comparable length.

### *Cement-Coated Nails*

Cement-coated nails are steel nails with a resin or similar coating that increases their withdrawal resistance. These nails are the most common type used in the assembly of boxes and crates. Cement-coated nails can be obtained in a variety of sizes and diameters; the most common types are sinkers, coolers, and box nails (fig. 4). Corker nails are also available with cement coating, although not often used for box and crate construction.

### *Etched Nails*

Etched nails are bright steel nails (fig. 4) that have been treated in a chemical solution developed at the Forest Products Laboratory to roughen the surface and thereby increase withdrawal resistance. The surface does not deteriorate as much as the coating on cement-coated nails. Any steel nail may be treated with this solution.

Clean, bright nails can be effectively etched. Remove any lubricant on the nails before treatment.

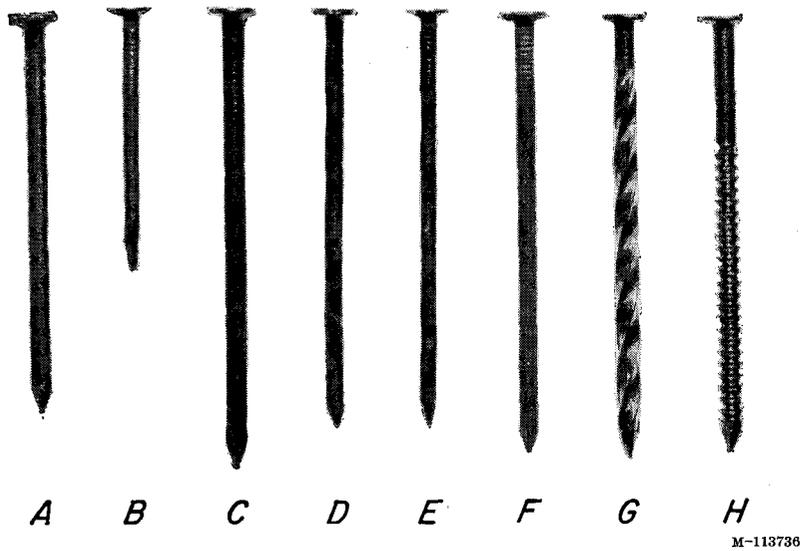


FIGURE 4.—Nail types: A, Common; B, clout; C, sinker (cement-coated); D, cooler (cement-coated); E, box (cement-coated); F, etched; G, spirally grooved; H, annular-grooved.

Etching is done as follows:

(1) Prepare a 10 percent solution (by weight) of commercial monoammonium phosphate in water. Do not use a metal container to prepare or store the solution. Keep the solution at room temperature, approximately 70° F. Five gallons of solution are sufficient to etch 100 pounds of nails.

(2) Immerse the nails in the solution for about 7 hours and stir occasionally to change the position of the nails for more uniform treatment.

(3) At the end of the etching period, remove the nails from the solution, rinse them thoroughly in water, and dry them to prevent rusting.

Other roughened-shank nails with somewhat increased withdrawal resistance include sandblasted, parkerized, and galvanized nails. Galvanized, stainless steel, aluminum, copper, and brass nails are used in special containers intended for service under severe shipping and storage conditions where rust must be avoided.

### *Deformed-Shank Nails*

Deformed-shank nails retain a great percentage of their withdrawal resistance even after the wood has undergone many changes in moisture content. The two most common varieties of deformed-shank nails are the spirally grooved nail, which has a series of spirals around its shank, and the annular-grooved nail, which has

TABLE 1.—Dimensions and number per pound of standard sizes and kinds of nails commonly used for boxes and crates

LENGTH IN INCHES

Size of nail <sup>1</sup>	Bright		Cement-coated			
	Common	Box	Corkers	Sinkers	Coolers	Box
2d.....	1	1			1	
3d.....	1¼	1¼		1¼	1⅛	1⅛
4d.....	1½	1½		1¾	1¾	1¾
5d.....	1¾	1¾		1⅝	1⅝	1⅝
6d.....	2	2	1⅞	1⅞	1⅞	1⅞
7d.....	2¼	2¼		2⅞	2⅞	2⅞
8d.....	2½	2½	2¾	2¾	2¾	2¾
9d.....	2¾	2¾	2⅝	2⅝		2⅝
10d.....	3	3	2⅞	2⅞	2⅞	2⅞
12d.....	3¼	3¼		3⅞		
16d.....	3½	3½		3¾		
20d.....	4	4	3¾	3¾		

GAGE <sup>2</sup>

2d.....	15	15½			16	
3d.....	14	14½		15½	15½	16
4d.....	12½	14		14	14	15½
5d.....	12½	14		13½	13½	15
6d.....	11½	12½	12½	13	13	13½
7d.....	11½	12½		12½	12½	13½
8d.....	10¼	11½	11	11½	11½	12½
9d.....	10¼	11½	11	11½		12½
10d.....	9	10½	10	11	11	11½
12d.....	9	10½		10		
16d.....	8	10		9		
20d.....	6	9	7	7		

APPROXIMATE NUMBER OF NAILS PER POUND

2d.....	830	1,010			1,094	
3d.....	528	635		850	848	988
4d.....	316	473		495	488	710
5d.....	271	406		364	364	522
6d.....	168	236	232	275	275	310
7d.....	150	210		212	212	283
8d.....	106	145	129	142	142	191
9d.....	96	132	114	130		172
10d.....	69	94	84	104	104	118
12d.....	63	88		77		
16d.....	49	71		61		
20d.....	31	52	36	37		

<sup>1</sup> Nails are available in sizes up to sixty penny. Bolts are usually preferred in boxes and crates, however, where nails larger than twenty penny would be required.

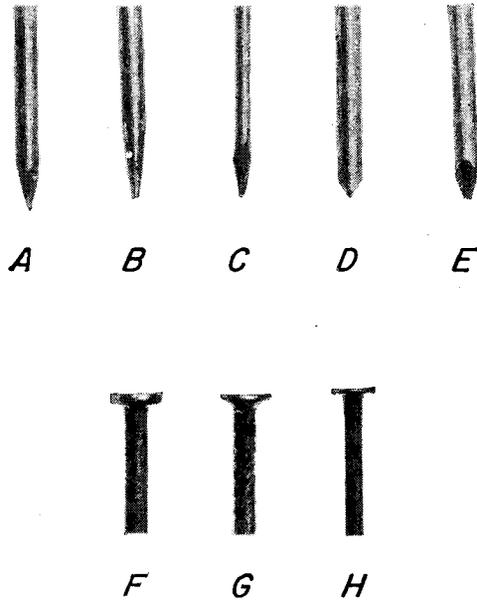
<sup>2</sup> Conformed to the American Steel and Wire Company steel wire gage.

small grooves around its perimeter (fig. 4). In general, annular-grooved nails sustain larger static-withdrawal loads and spirally grooved nails sustain greater impact-withdrawal loads than do other nails.

### Nail Points and Heads

Diamond-pointed nails are perhaps most commonly used in container construction. The clout nail has a duckbill point that is easily clinched because of its taper. Some special nails have a needle point or a chisel point. A sharply pointed nail will cause splits in denser woods. To minimize these splits, slightly blunt the point of the nail before it is used. When only a few nails are needed, blunt them with a hammer. Blunting on an emery wheel is more practical when a large number are needed.

Nailheads vary somewhat in diameter and thickness (fig. 5). The fiat head is used for the common nail, the cement-coated cooler, and other similar nails. The countersunk head, used for the sinker nail, provides additional strength and does not break off easily. The cement-coated box nail has a broad, flat head. Do not use this type of nail in dense hardwood, or where an uneven blow may shear off the head.



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FIGURE 5.—Nail points and heads: A, Diamond; B, needle; C, duckbill; D, chisel; E, blunted; F, flat; G, countersunk; H, broad flat.

## Nail Sizes

The size of most nails, particularly those used for containers, is based on their length; the diameter or gage varies with length and nail type. The usual designation for these nail sizes is expressed by the "penny" system, abbreviated as "d." Thus, a sixpenny nail is expressed as 6d, and an eightpenny as 8d. The penny system originated in England, where it is said to have been based on the weight of a thousand nails; that is, 1,000 tenpenny nails weighed 10 pounds and 1,000 eightpenny nails 8 pounds.

Bright common nails and box nails are of the same length, but box nails are smaller in diameter for a given penny size (table 1). Among cement-coated nails, sinker nails are available in the greatest range of sizes. In sizes less than tenpenny, the four types of cement-coated nails are of the same length for each penny size. These nails are  $\frac{1}{8}$  inch shorter than bright common nails and box nails of equivalent penny size (table 1). Bright box nails are larger in diameter than cement-coated box nails of equivalent penny size.

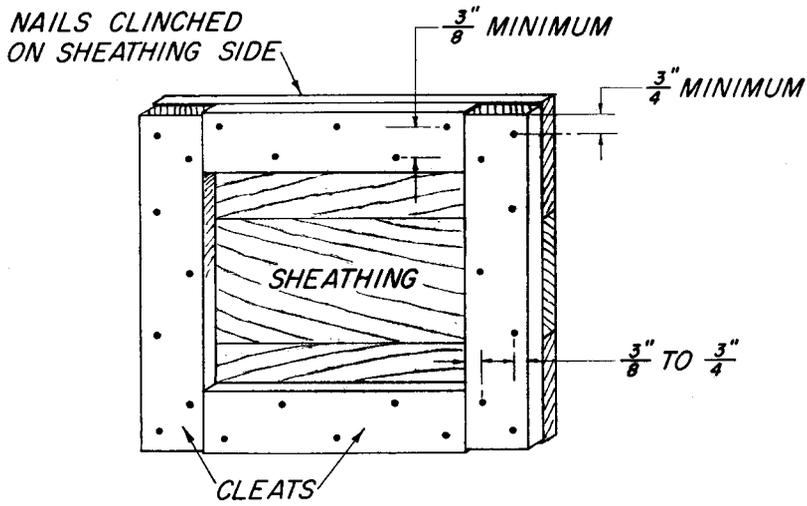
## HOW TO NAIL A WOOD BOX

Generally speaking, box manufacturers use automatic nailing machines as much as possible. These machines drive and clinch a number of nails at one time and can be readily adjusted for the fabrication of box parts of various sizes. They are also used to fasten the sides and bottom of the box to the ends; the top is often nailed on by hand after the contents are packed. The fabricated box parts that form complete units are called "box shook" and are shipped to the user in knocked-down form. The nailing principles discussed here for the fabrication and assembly of two common styles of boxes may be adapted to almost any similar container.

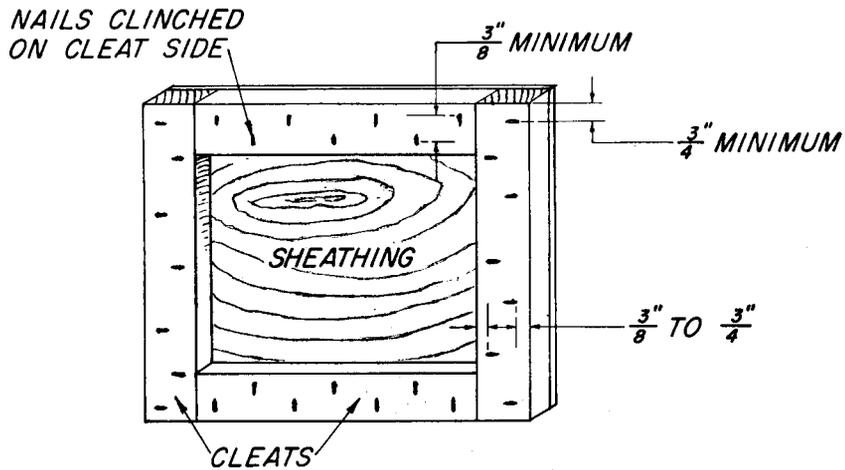
### Nailing of Cleats and Battens

Ends of nailed wood boxes and panels of cleated panel boxes are usually fabricated with nails that are driven through both the cleat, or batten, and the sheathing and then clinched (fig. 6). Nails should be long enough to allow for proper clinching. This extra length should be at least  $\frac{1}{8}$  inch for fourpenny and smaller nails,  $\frac{1}{4}$  inch for fivepenny, sixpenny, and sevenpenny nails, and  $\frac{3}{8}$  inch for eightpenny nails. Longer nails require a longer clinch because of their greater diameter. Clout nails, however, should be clinched at least  $\frac{1}{4}$  inch because of their thin, tapered, duckbill point.

These recommendations are based on the strength advantage of an adequate clinch. Too long a clinch is undesirable because of the difficulty of burying the nail point and the end of the shank into



A



B

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FIGURE 6.—Nailing patterns and spacings for box ends of A, a nailed wood box, and B, a cleated panel box.

the wood. Clinching across rather than parallel to the grain of the wood is recommended because it gives 20 percent greater withdrawal resistance.

Nails are usually clinched against the sheathing. However, in cleated panel boxes made with plywood or some other sheathing material that is too thin, it is best to clinch against the cleats for greater strength. Clinching makes it especially important to select nails with heads that will not shear off when they are driven. Such nails include sinkers, coolers, corkers, and common nails. Common nails and sinker-type nails are often used and are a good choice because they are available in many lengths. Sinker nails have strong countersunk heads that prevent their breaking off when used in hardwoods.

In nailing plywood, fiberboard, or other sheathing material to the cleats, use nails with heads large enough in diameter to prevent their being pulled through the sheathing. These nailheads should also be thick enough so that they will not shear off. In box construction, use a nail with a head not less than  $\frac{7}{32}$  inch in diameter, especially in fiberboard, paper-overlaid veneers, and the thinner plywoods. Various types of nails, in the sizes and shank gages commonly used to make cleated panel boxes, are shown in table 2.

TABLE 2.—Types of nails often used to fasten sheathing to cleats of cleated panel boxes

Nail type	Size	Length	Gage	Head diameter
	<i>Penny</i>	<i>Inches</i>		<i>Inches</i>
Box (smooth).....	3	1¼	14½	$\frac{7}{32}$
	4	1½	14	$\frac{7}{32}$
	5	1¾	14	$\frac{7}{32}$
Clout.....		$\frac{3}{4}$	15	$\frac{7}{32}$
		$\frac{7}{8}$	14	$\frac{1}{4}$ —
		1	14	$\frac{1}{4}$ —
		1¼	14	$\frac{1}{4}$ —
		1½	13	$\frac{1}{4}$ +
		1¾	13	$\frac{1}{4}$ +
		1½	13	$\frac{1}{4}$ +
Sinkers.....	5	1¾	13½	$\frac{7}{32}$
Coolers.....	4	1¾	14	$\frac{7}{32}$
	5	1¾	13½	$\frac{15}{64}$
Common.....	4	1½	12½	$\frac{1}{4}$
	5	1¾	12½	$\frac{1}{4}$

The nails used to fasten the sheathing of nailed wood boxes and cleated panel boxes are driven in a two-row staggered pattern (fig. 6). For nailed wood boxes, the recommended spacing of nails in each row is as follows:

Nail size (penny):	Average spacing (inches)	Nail size (penny):	Average spacing (inches)
6 or smaller.....	2	10.....	3
7.....	2¼	12.....	3½
8.....	2½	16.....	4
9.....	2¾		

Space rows of nails not less than  $\frac{3}{8}$  inch apart;  $\frac{3}{4}$  inch or more is better if the cleat is wide enough, particularly with the larger nails, in order to avoid cleat splitting. In wide cleats, each row should be about  $\frac{3}{4}$  inch from the nearest edge. Space nails evenly along the length of the cleat. The first nail at either end of the cleats should not be closer than  $\frac{3}{4}$  inch nor farther than  $1\frac{1}{2}$  inches from the cleat end (fig. 6). Nail each board in an end panel to each vertical cleat with at least two nails.

Nail interior battens for the sides, reinforcing cleats, diagonals, and similar members of wood boxes as described for end cleats.

The cleats in cleated panel boxes should be nailed as described for the ends of the nailed wood box, but space the nails in each row not more than 6 inches apart.

### **Assembly Nailing of Boxes**

Assembly nailing of a box requires the use of coated nails or nails with roughened or deformed shanks to increase withdrawal resistance. The nails should have strong heads of sufficient size to prevent them from pulling through the wood or breaking off. The types used for box part fabrication—such as sinkers, coolers, and corkers—are satisfactory.

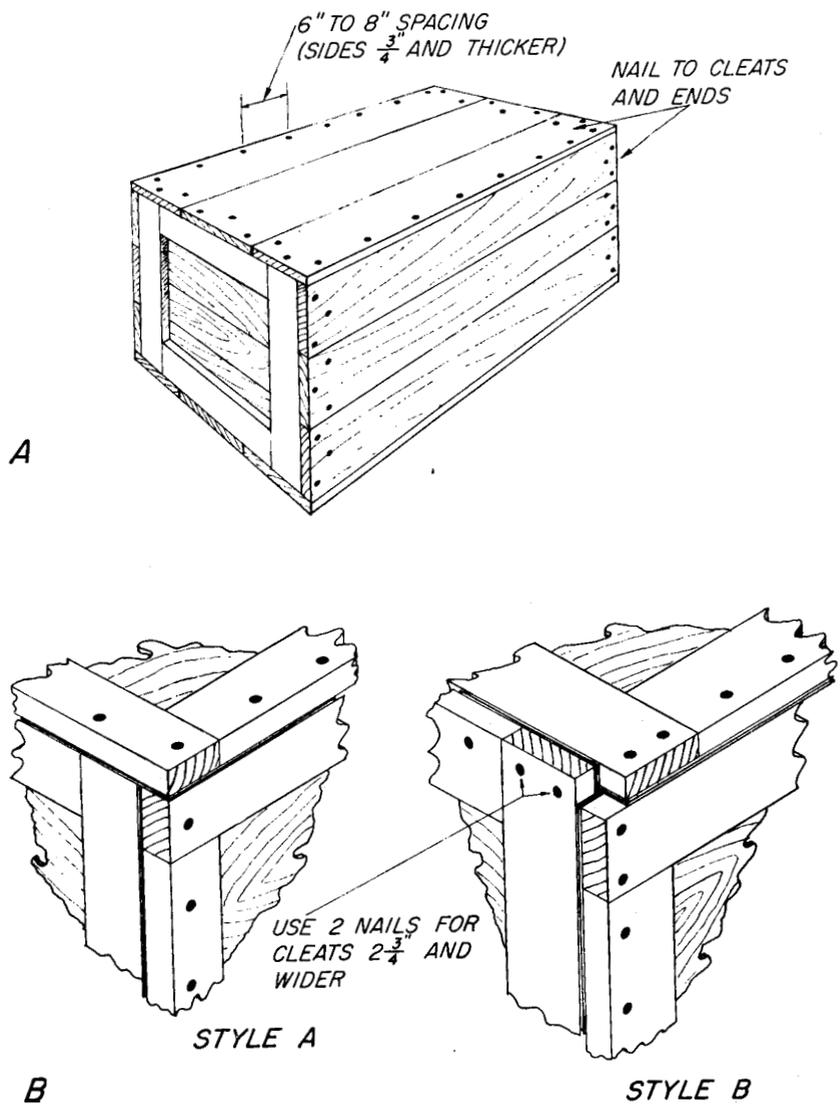
### ***Nailed Wood Boxes***

Although no definite assembly procedure need be followed, the logical first step is to nail the sides of a box to the ends. Nail the side sheathing of nailed wood boxes to the ends (fig. 7). The nails are placed in a staggered pattern by alternately nailing into the end cleat and the end sheathing.

A good rule to follow in selecting nails of proper size is that the nail be long enough to penetrate at least 2 to  $2\frac{1}{2}$  times the thickness of the sheathing or the fastening members. Table 3, which lists nail sizes for box assembly purposes, gives data of value in selecting the proper nails for low- and high-density woods according to the grouping by species shown on page 39.

Place the first nails in the top and bottom boards of the side sheathing at about one-half the spacing distance (designated on page 10) from the edges (fig. 7). This distance may vary a little because of knots, checks, or the location of fabrication nails. Drive at least two nails at each end of each board of the sides.

For nailed wood boxes, space the nails as shown on page 10. If the sheathing frequently splits, nails one penny smaller can be used and spaced one-fourth inch closer than is specified on page 10 for nails of the size actually used.



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FIGURE 7.—Assemblynailing patterns for A, nailed wood box, and B, cleated panel boxes.

The bottom and top sheathing boards are nailed to the end sheathing and end cleats in the same general manner described for the sides.

Top and bottom boards are sometimes nailed to the side sheathing when the thickness of the side sheathing is at least three-fourths of an inch. Sevenpenny nails are used for side sheathing less than  $\frac{7}{8}$  inch thick and eightpenny nails for thicker side sheathing. Space nails about 6 to 8 inches apart (fig. 7).

TABLE 3.—Nail sizes recommended for assembly of nailed wood boxes made of woods grouped for density <sup>1</sup>

Thickness of sheathing (inches)	Size of nails			
	Group I woods	Group II woods	Group III woods	Group IV woods
	<i>Penny</i>	<i>Penny</i>	<i>Penny</i>	<i>Penny</i>
3/8	6	5	5	4
1/2	7	6	5	5
5/8	8	7	6	6
3/4	9	8	7	6
7/8	10	9	8	7
1 to 1 1/8	12	10	9	8

<sup>1</sup> Group I, soft woods; II, hard coniferous woods; III, medium density hardwoods; IV, heavy hardwoods.

### Cleated Panel Boxes

Assembly nails used to attach the ends of cleated panel boxes cannot be placed in a staggered pattern; all must be driven into the edge cleats (fig. 7). This type of nailing may cause the cleat to split if the nails are too large or the nail spacing is too close. The choice of nail length should be based on the combined thickness of the panel material and the cleat. The penetration of the nail into the edge of the cleat should be about twice this combined thickness. Table 4 gives nail sizes and spacings recommended for nailing side, top, and bottom panels to the ends, and the top and bottom panels to the sides. However, nails should not be so long that they penetrate the opposite edge of the cleat.

Space assembly nails evenly, and use at least one nail in the end of each cleat that is less than 2 3/4 inches wide; in wider cleats, use 2 nails (fig. 7).

TABLE 4.—Nail size and spacing for assembly of cleated panel boxes

Combined thickness of panel and cleat (inches)	Size of nails		Spacing of nails (all wood groups)
	Group I and II woods	Group III and IV woods	
	<i>Penny</i>	<i>Penny</i>	<i>Inches</i>
3/4	8	7	5
7/8	9	8	5
1	9	8	4 1/2
1 1/8	10	9	4 1/2
1 1/4	10	9	4
1 3/8	12	10	4

Most boxes are reinforced with wire or flat metal tension straps. These straps are placed around the perimeter of a nailed wood box and stapled in place. On cleated panel boxes the straps are placed on the cleat around the top, bottom, and ends. Under most conditions, strapping has some value for nailed wood and cleated panel boxes when properly placed and stapled. However, it presents a snagging hazard when it becomes loose.

### Rules for Nailing Boxes

1. Bright nails may be used to fasten sheathing to cleats if the nails are clinched. Use coated, etched, or other types of roughened- or deformed-shank nails, however, if clinching is not done. For lumber sheathing, use common, sinker, cooler, corker, or similar types of nails. For plywood sheathing, use clout nails.

2. Clinch nails across the grain of the wood. Allow a length of clinch of not less than  $\frac{1}{8}$  inch for fourpenny and smaller nails,  $\frac{1}{4}$  inch for fivepenny, sixpenny, and sevenpenny nails and clout nails, and  $\frac{3}{8}$  inch for eightpenny nails. Longer nails may require a  $\frac{1}{2}$ -inch clinch.

3. Fasten cleats or battens of box parts to sheathing with two rows of nails whenever possible. Likewise, place assembly nails in a two-row or staggered pattern when practical.

4. In the fabrication of nailed wood box parts, nail the ends of each end-sheathing board to each vertical cleat with at least two nails.

5. Drive nails so that neither the head nor the point projects above the surface.

6. When nailing sides, top, and bottom to the ends of nailed wood boxes, put at least two nails in each end of each sheathing board.

7. For assembly of sides, top, and bottom to the ends, use nails long enough to penetrate into the ends 2 to  $2\frac{1}{2}$  times the thickness of the sheathing.

8. If the desired nail is not available or wood splitting cannot be avoided by slightly blunting the nail point, use the next smaller nail and decrease nail spacing slightly.

9. When two rows of nails are required in the assembly of boxes, drive the nails alternately into the cleat and the sheathing.

10. If the sides are at least  $\frac{3}{4}$  inch thick, fasten the top and bottom sheathing to the sides with nails spaced 6 to 8 inches apart.

11. When nailing thin plywood, fiberboard, and paper-overlaid veneer to the cleats, use nails with heads at least  $\frac{7}{32}$  inch in diameter: this will prevent them from pulling through the sheathing.

## HOW TO NAIL A WOOD CRATE

Proper fabrication nailing of panels of both open and sheathed crates develops the full strength of the crate and its members. In open crates especially, fabrication nailing of panels is critically important. In sheathed crates, the fabrication nailing joins adjacent members by means of sheathing that is securely nailed to all frame members.

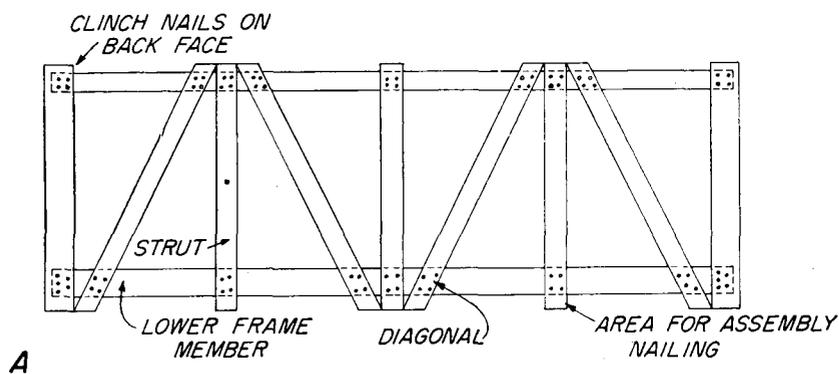
The construction and appearance of a crate are quite different from that of a wood box, but the principles of nailing are similar. Fabrication of the parts consists of nailing various framing pieces together, with or without sheathing, to form panels. Assembly consists of fastening these panels together to form the container. The sizes of nails recommended in this handbook for assembly of crates are those generally used for group I and II woods (see page 19). When woods of groups III and IV are used, use nails one penny smaller for assembly nailing.

### Fabrication Nailing of Open Crates

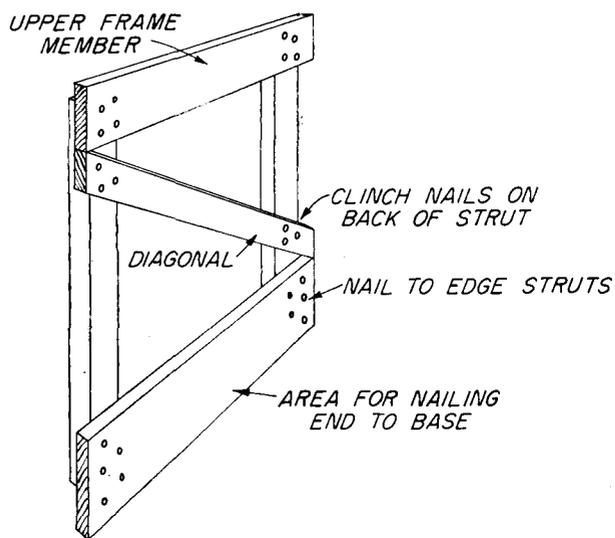
One of the simplest crates to build is the open crate. The key to good fabrication nailing of its panels is effective nail clinching. Because the sides, ends, and tops of open crates are much alike, the same nailing methods are employed for all. The parts of each panel are laid on one another and nailed together at the proper places; the nails are clinched on the inner face (fig. 8).

The nailing patterns and the number and placement of the nails should be such that the full strength of the members is approached. However, don't use too many nails, for they may split the wood. The nailing patterns recommended for woods of groups I and II are shown in figure 9 for crate members crossing at right angles. Use at least two nails for each joint. For woods of groups III and IV, the number of nails per joint may be decreased by one if the wood splits when the designated number of nails is used. For members crossing at angles other than 90 degrees, patterns similar to those in figure 9 should be used. A detailed nailing pattern for the base is shown in figure 10.

Clinch all nails used in the fabrication of open crates, unless the member containing the nail point is more than 2 inches thick or the total thickness of all members exceeds 3 inches. A  $\frac{1}{4}$ -inch minimum clinch is recommended for sevenpenny and smaller nails; a  $\frac{3}{8}$ -inch clinch for eightpenny through twelvepenny nails; and a  $\frac{1}{2}$ -inch clinch for larger nails.



A



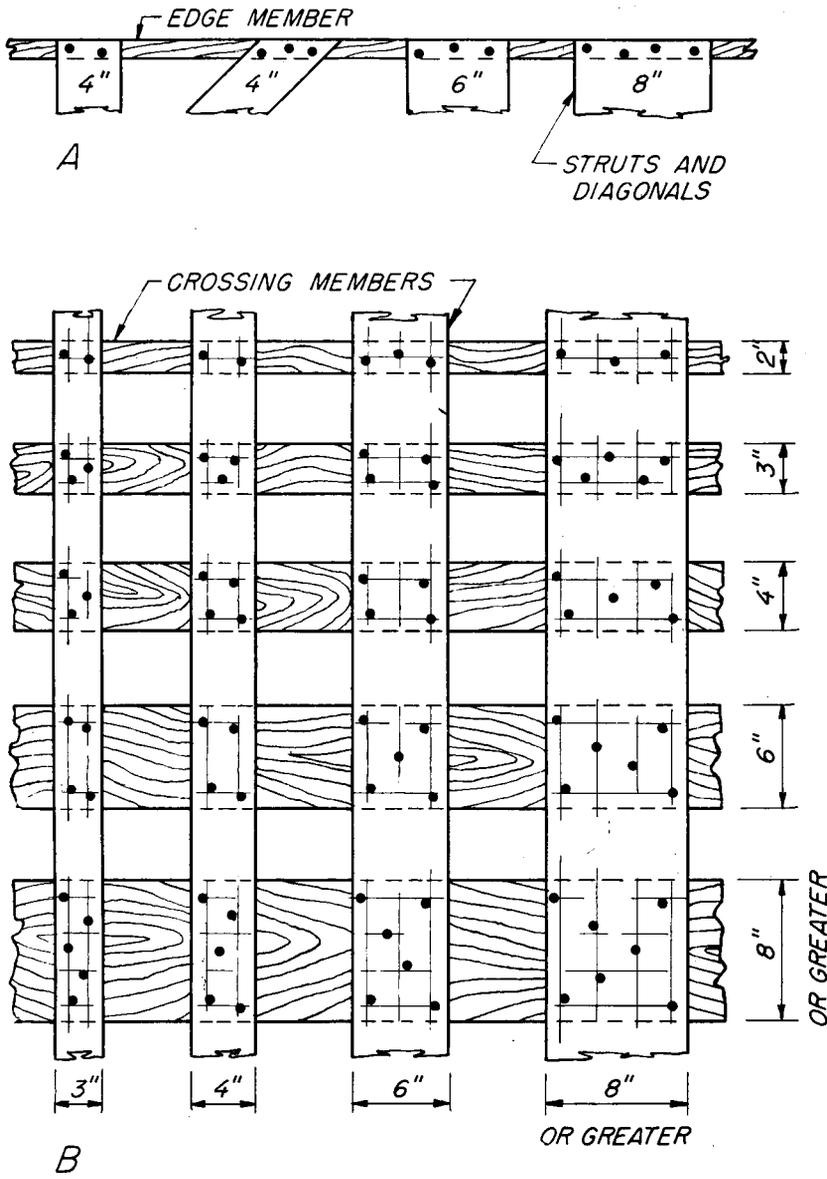
B

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FIGURE 8.—Typical construction for open crates: A, Fabrication of sides or top; B, fabrication of ends.

### Fabrication Nailing of Crate Base

The framing of bases for sheathed and open crates is similar. The cross members, including the end headers and the larger load-bearing floorboards, are usually bolted to the skids (fig. 10). The diagonals, cross members, and lumber and plywood flooring are nailed to the skids. The nailing patterns shown in figure 9 are used to fasten members, except plywood flooring, to the skids. Ply-

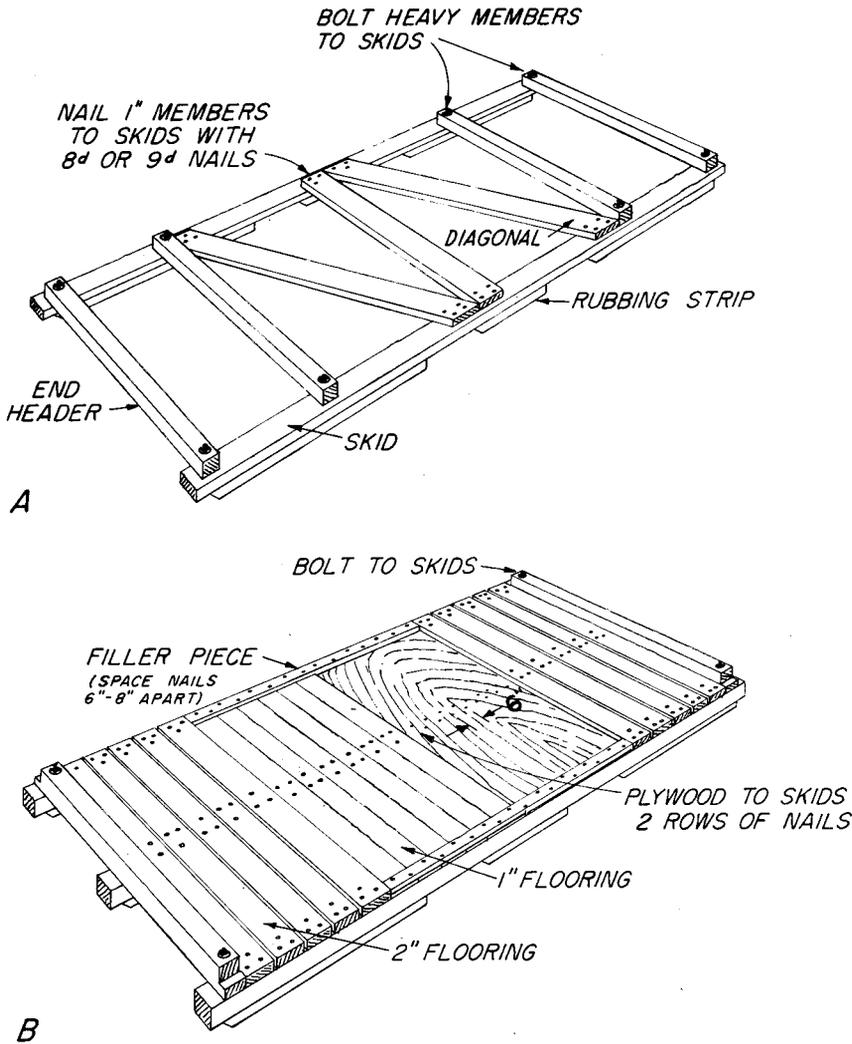


M-111519

FIGURE 9.—Typical nailing patterns for open crates: A, Nailing for assembly of panels to each other ; B, nailing for fabrication of panels, as used to nail floorboards to skids and lumber sheathing to frame members.

wood flooring is nailed in a two-row staggered pattern, with the nails in each row spaced about 6 inches apart.

The nails should be long enough to penetrate the skid for a distance 2 to 2½ times the thickness of the member holding the head without, projecting through, but not less than 1½ inches. Thus, to



M-111520

FIGURE 10.—Typical constructions for crate bases: *A*, Base for open crates; *B*, for sheathed crate.

nail a  $\frac{3}{4}$ -inch-thick board to a large skid requires a nail about  $2\frac{1}{4}$  to  $2\frac{5}{8}$  inches long; for example, an eightpenny or ninepenny cement-coated sinker nail, or an etched eightpenny common nail. Under most conditions, these nails have higher withdrawal resistance than plain nails. If, however, clinching is required because the total thickness of all parts is no greater than 3 inches, plain nails are suitable.

## Fabrication Nailing for Sheathed Crates

The sides, ends, and tops of sheathed crates are fabricated by placing the precut frame members in their proper positions and fastening them together with corrugated fasteners or staples. When a considerable number of crates of the same size and construction are to be made, jigs are often used to hold the members in position while the sheathing is applied. In lumber-sheathed crates, waterproof paper can be installed between the frame members and the sheathing of side and end panels to seal the joints between sheathing boards. Tops are waterproofed by various means; one effective way is to place waterproof paper between two layers of the lumber sheathing. Plywood-sheathed crates do not require this type of waterproofing, as all plywood joints are made over a frame member and are securely nailed (fig. 11).

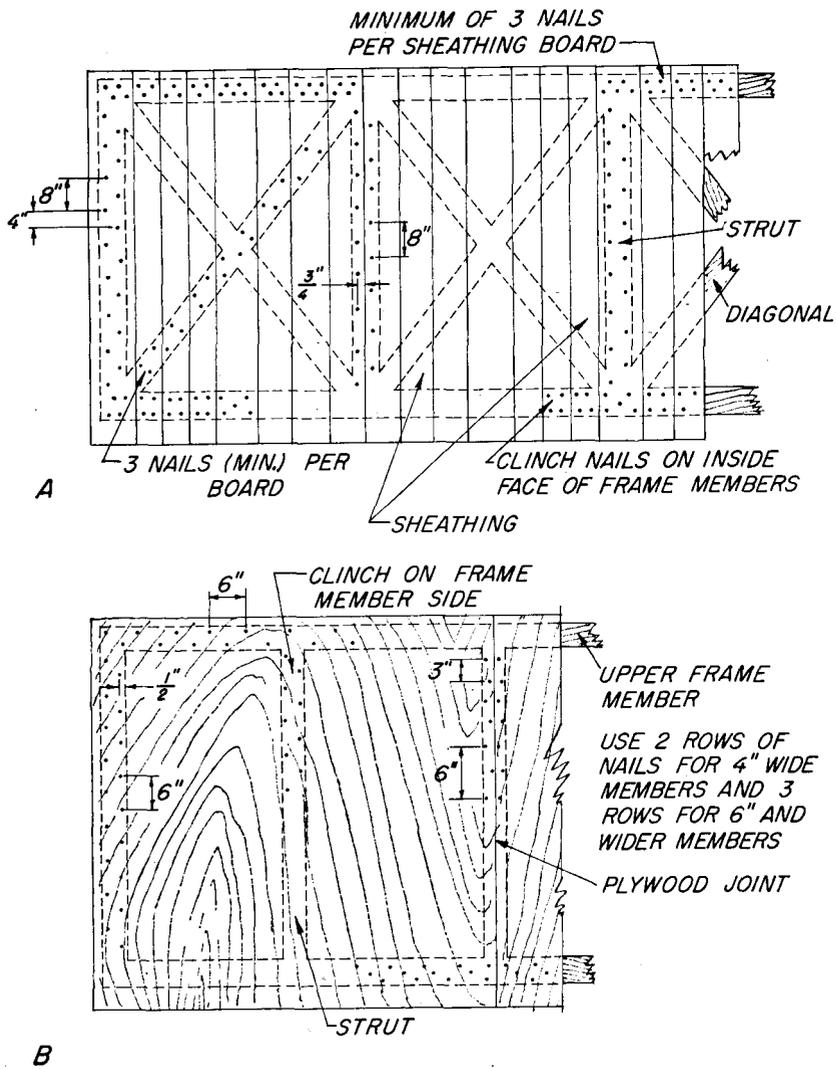
Nails are driven through both the sheathing and the frame members. If the total thickness of the wood is less than 3 inches, the nails are clinched. The length of the clinch depends on the size of the nails required for the joint, and the general rule outlined for open crates should be followed. Coated, etched, or deformed-shank nails recommended for fastening plywood  $\frac{3}{8}$  inch or less in thickness to 2-inch frame members need not be clinched, but should penetrate to a depth of at least  $1\frac{1}{2}$  inches into the frame member.

Figure 11 shows recommended spacing and placement of nails used to fabricate side, end, and top panels of sheathed crates. Drive the nails through the thinner into the thicker member; if these members are of equal thickness, convenience is the controlling factor.

Crate tops often have joists or similar supporting members that are usually installed on edge either before or during crate assembly. Nails are driven through the top sheathing and frame members into the joists. Use two nails where each joist crosses diagonal or longitudinal frame members. Twelvepenny nails are suitable when both sheathing and frame members are nominally 1 inch thick, and tenpenny nails are used with  $\frac{3}{8}$  or  $\frac{1}{2}$ -inch plywood sheathing. When nailing through a strut of the top into a joist, space the nails about 8 to 10 inches apart.

## Assembly Nailing of Open Crates

It is relatively simple to assemble open crates, because there is no great amount of "blind" nailing involved. Most of the nailing is "direct": that is, the pieces holding the nailheads and those holding the points are in plain view (fig. 12). Most nailing, therefore, does not require accurate marking for alinement of the assembly nails. However, it is good practice to indicate by some method the number and placement of the nails.

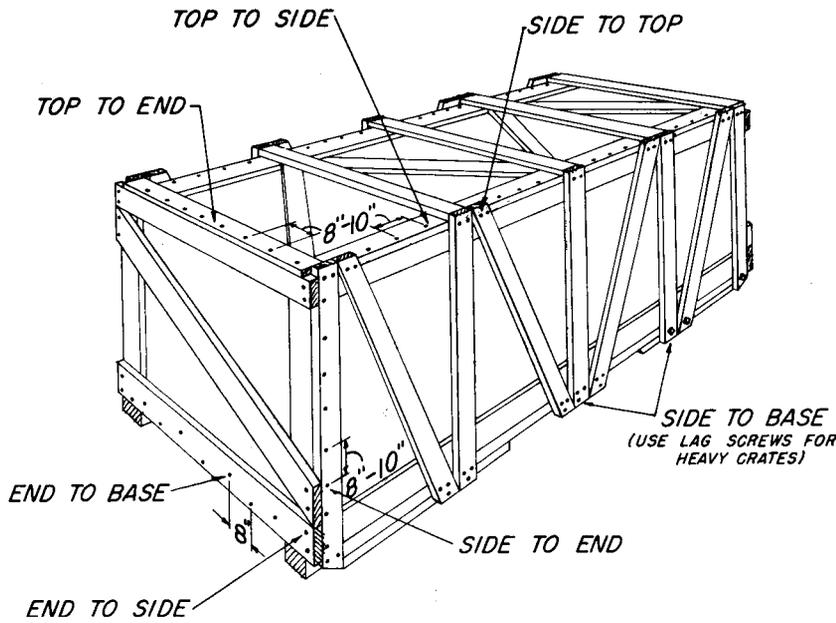


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FIGURE 11.—Typical construction for sides, ends, and tops of sheathed crates: A, Lumber-sheathed crates; B, plywood-sheathed crates.

### Fastening Sides and Ends to Base

Fasten the struts of the side panels to the base by nailing them to the skids or other large base members. Nail diagonals that are in the same plane as the struts and extend below the lower frame member to the skid also. The number of nails used depends on the gross weight of the crate and its contents. In properly designed crates, the greater the weight of the article, the larger the struts, diagonals, and skids; hence greater nailing area is automatically provided.



M-111522

FIGURE 12.—Typical assembly nailing for open crates.

Nail each strut and diagonal of the sides to 2-inch skids with at least three nails for 1 by 4's and four nails for 1 by 6's. When skids are 3 inches deep or more, use at least four nails for 1 by 4's and five nails for 1 by 6 diagonals and struts. Heavy loads or small crates, however, may require a greater number of nails to fasten the sides to the base. The total number of nails required is shown in table 6 by nail sizes and types for various gross loads.

Stagger the nails in patterns similar to those shown in figure 9, and the struts and diagonals nailed to the skids or sills as shown in figure 12. In table 5, eightpenny, ninepenny, and tenpenny nails are listed, any of which may be used to fasten nominal 1-inch members to the base.

For heavily loaded crates, the number of nails required may be so great that their use would not be practical without additional struts and diagonals. Under these conditions, the use of lag screws is recommended. For example, the allowable lateral resistance of a lag screw  $\frac{3}{8}$  inch in diameter and penetrating  $1\frac{1}{2}$  to 2 inches into the skid is at least 4 times that of an eightpenny or ninepenny sinker nail. Thus, two lag screws will do the work of eight nails and require a small total fastening area.

The ends are fastened to the base by nailing the lower frame member of the end to the end header. Eightpenny or ninepenny nails spaced about 8 inches apart are used in a staggered pattern (fig. 12).

TABLE 5.—*Total minimum number of nails required to fasten sides to base of open crates*<sup>1</sup>

Gross load— weight of crate and contents (pounds)	Sinker or cooler nails		Corker nails		Common nails	
	8d and 9d	10d	8d and 9d	10d	8d and 9d	10d
1,000.....	20	18	18	16	16	14
2,000.....	38	36	34	30	30	26
3,000.....	58	54	52	46	46	40
4,000.....	76	72	68	60	60	52
5,000.....	96	90	86	76	76	66
6,000.....	114	108	102	90	90	78
7,000.....	134	126	120	106	106	92
8,000.....	152	144	136	120	120	104

<sup>1</sup> Use one-half on each side of crate and divide evenly between struts and diagonals according to their respective widths.

### ***Fastening Sides to Ends and Top***

In most open crate designs, the frame members are arranged so that the sides can be fastened to both the end and the top panels. The edge struts of the sides overlap the edge struts of the ends (fig. 12), and the nails should be placed about 8 to 10 inches apart. For nominal 1-inch members, eightpenny or ninepenny nails are driven through the edge struts of the sides.

The upper ends of the struts and the diagonals are fastened to the edge longitudinal members of the top with eightpenny or ninepenny nails (fig. 12). The nailing patterns for open crates shown in figure 9 may be used. Nails placed too near the end often cause boards to split, especially those of the denser woods. Reduce splitting by slightly blunting the ends of the nails. If splitting persists, either predrill nail holes or select nails that are onepenny smaller. If smaller nails are used, more nails will probably be required.

### ***Fastening Ends to Sides***

In the design and construction of most open crates, the cross members and the diagonals of the ends extend beyond the edge struts. Nail these to the edge struts of the side panels (fig. 12). Two eightpenny or ninepenny nails are used for 1- by 4-inch members, three nails for 1- by 6-inch members, and four nails for 1- by 8-inch members.

### ***Fastening Top to Ends and Sides***

The construction of top panels for open crates differs according to the position of the longitudinal members and the cross members. These variations may change the method of nailing the tops to the

ends. In most cases, the longitudinal edge members of the top are nailed to the upper frame members of the sides (fig. 12). For group I and most group II woods, use eightpenny or ninepenny nails spaced 8 to 10 inches apart.

In panels where the cross members are over the longitudinals, nail the edge struts of the top to the upper frame members of the ends. Use eightpenny or ninepenny nails spaced 8 to 10 inches apart (fig. 12). In top panels where the top longitudinal members pass over the cross struts and diagonals, the upper frame member of the end is fastened to the edge strut of the top with nails spaced 8 to 10 inches apart.

These nailing principles can be applied to many styles of crates other than the basic ones described here.

### **Assembly Nailing of Sheathed Crates**

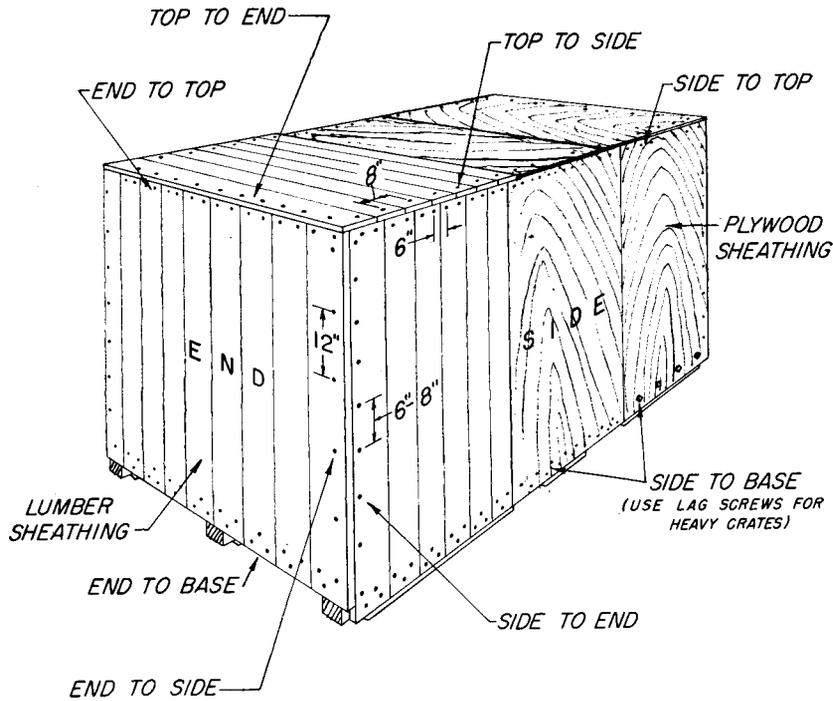
The assembly nailing procedures recommended for sheathed crates, while similar to those for open crates in some respects, also differ considerably. The reason is that much assembly nailing consists of driving the nails through the sheathing directly into a structural member. There is also more nailing surface. This allows more uniform nail spacing and eliminates the concentrations of nails. The latter, common in open crates, is often the primary cause of splits when the loaded crates are stressed by rough handling during transit.

Sheathed crates can be designed to carry greater loads than open crates. The greater fastening area available allows the use of more nails, which contributes greater resistance to lateral load stresses. In small open crates, for example, only two or three struts may be available to receive nails, but a sheathed crate can be nailed along its entire length. As in all assembly procedures, coated, etched, or deformed-shank nails provide superior withdrawal resistance.

### ***Fastening Sides and Ends to Base***

In sheathed crates? the side panels are nailed to the skids and the end panels are nailed to the end headers of the base. When 2- by 4-inch skids or headers are used flat, stagger the nails slightly (fig. 9). If skids or sills 3 or 4 inches deep are used, place the nails in two rows in a staggered pattern; for skids or sills deeper than 4 inches, three rows of nails are used (fig. 13).

Generally, eightpenny and ninepenny nails are used for nominal 1-inch lumber sheathing and  $\frac{1}{2}$ -inch and thicker plywood, and sevenpenny nails for plywood sheathing less than  $\frac{1}{2}$  inch thick. The minimum number of nails for the side-to-base nailing is governed by the gross weight of the crate and its contents. Table 6



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FIGURE 13.—Typical assembly nailing for sheathed crates.

lists, by types of nails and wood groups, the number of nails required for each 1,000 pounds of gross load.

Good practice calls for at least two nails in each lumber sheathing board. In addition, space nails used to fasten sides and ends to the base no farther apart than 3 inches when in single rows, 6 inches in double rows, and 9 inches when three rows are used. Nails spaced too closely will split the sheathing. If nail requirements result in spacing of less than  $1\frac{1}{2}$  inches, nails should be replaced with lag screws installed as described for the side-to-base assembly of open crates.

### *Fastening Sides to Ends*

The side panels are fastened to the end panels with nails driven through the sheathing of the sides into the edge struts of the ends. The nails are spaced about 6 to 8 inches apart (fig. 13). Nail sizes are the same as those recommended for side-to-base assembly. The end panel is fastened to the side panel with nails through the sheathing and edge strut of the end into the edge strut of the side. The edge strut of the side is usually a 2-inch or thicker member.

TABLE 6.—Number of nails<sup>1</sup> needed to fasten sides of sheathed crates to base for each 1,000 pounds of gross load, by wood group

Nail type <sup>2</sup> and size	Group II woods	Group III woods	Group IV woods
Sinker or cooler:			
7d.....	23	26	19
8 or 9d.....	19	21	16
10d.....	18	19	14
Corker:			
8 or 9d.....	17	19	14
10d.....	15	16	12
Common:			
7d.....	19	21	16
8 or 9d.....	15	17	13
10d.....	13	14	10

<sup>1</sup> Use one-half of total required for each side.

<sup>2</sup> Should have coated, etched, or deformed shanks.

For lumber sheathing, this requires twentypenny nails and pre-drilled nail holes to prevent splitting of the members. Holes  $\frac{1}{8}$  inch in diameter should be satisfactory. When  $\frac{3}{8}$ -inch plywood sheathing is used, a twelvepenny nail is satisfactory. Space nails about 12 inches apart (fig. 13).

Fastening the sides and ends to each other in this manner results in a rigid crate corner, because no matter how the corner is stressed during handling and shipping, at least one set of nails will be in lateral resistance.

### *Fastening Top to Sides and Ends*

The construction of the top panels of sheathed crates varies a great deal. Narrow crates do not require top joists to support top loads, since the sheathing alone has sufficient strength. In wider crates, however, joists are used to carry these loads. Because of these and other variations, such as joist support systems, the nailing procedure for fastening tops to sides and ends may be quite different. Whenever possible, however, nailing should be in two directions: from top to side and from side to top.

The nails for fastening the sides and ends to the top are driven through the sheathing into an edge or other frame member of the top. Use eightpenny or ninepenny nails for lumber sheathing and sevenpenny nails for plywood sheathing less than  $\frac{1}{2}$  inch thick. Space nails about 6 inches apart (fig. 13).

The top is fastened to the sides and ends with nails driven through the sheathing and edge members of the top, and into the upper frame members or joist spacers of the sides and ends. For top frame members 1 inch thick, twelvepenny nails are needed to get

at least  $\frac{1}{2}$  inches of penetration into the side or end members. For  $\frac{3}{8}$ - or  $\frac{1}{2}$ -inch plywood sheathing, tenpenny nails are adequate. Space nails about 8 inches apart.

These assembly nailing methods may not be strictly applicable to all styles of sheathed crates, but the principles on which they are based apply fairly generally. In addition to assembly with nails and lag screws, many crates are strapped with a metal corner-reinforcing strap. This affords some additional measure of safety under the severe handling that may be encountered in export shipping. However, for domestic shipment, and for crates that have a large amount of two-way nailing, strapping is often unnecessary. Tension straps are sometimes used to fasten tops to sides and ends of special crates; for example, to permit removal of the top simply by cutting the straps.

### Rules for Nailing Crates

1. Unless nails are clinched, use cement-coated, etched, or deformed-shank nails to gain increased withdrawal resistance. Nails used for assembling crates should have a diameter at least equal to that of the sinker nail (table 1).

2. In fabrication of panels for large sheathed crates, fasten adjacent frame members to each other with corrugated fasteners or staples before the sheathing is applied, unless jigs are used. This aids in the alinement of the various frame members.

3. Whenever possible, drive nails through the thinner into the thicker frame member. This is recommended especially when plywood is fastened to nominal 1- or 2-inch members.

4. When nailing two pieces of lumber together flatwise, as in panel fabrication, clinch the nails if the combined thickness is 3 inches or less. Use a  $\frac{1}{4}$ -inch clinch for nails up to sevenpenny in size, a  $\frac{3}{8}$ -inch clinch for eightpenny through tweldepenny nails, and a  $\frac{1}{2}$ -inch clinch for larger nails. Plywood  $\frac{3}{8}$  inch or less in thickness may be nailed to nominal 2-inch members without clinching if the nails penetrate  $1\frac{1}{2}$  inches into the members.

5. When the combined thickness of two pieces of lumber nailed together flatwise is more than 3 inches, or when the flat face of one member is nailed to the edge of another, nails are not clinched. Tenpenny and smaller nails should penetrate into the piece holding the nail point for a distance equal to about 2 to  $2\frac{1}{2}$  times the thickness of the piece holding the nailhead. Tweldepenny and larger nails should penetrate at least  $1\frac{1}{2}$  inches into the piece holding the point.

6. If diamond-point nails split the wood, blunt the points slightly with a hammer, clipper, or other convenient tool. If blunting does

not prevent splitting, use nails of the next smaller penny size and space them a little closer together. Lead holes about three-fourths as large as the nail in diameter will also reduce splitting. Except for very large members, predrilling is usually used for twentypenny nails and larger.

7. In general, drive nails no closer to the edge of a piece than a distance equal to one-half the thickness of the piece and no closer to its end than the thickness of the piece. Smaller nails of a given type can be driven closer to the edges or ends than larger ones because they are less likely to split the wood.

8. To minimize wood splits, either stagger the nails or place them in two or more rows.

9. When nailing two pieces of lumber together facewise and at right angles to each other, use nailing patterns similar to those shown in figure 9. Use the patterns and recommended numbers of nails for fabrication of crate panels where nails are clinched when fastening pieces of lumber together flatwise. Use also when nailing a piece of lumber flatwise to the edge of another or to the face of a larger frame member.

10. When attaching two members so that their grain is parallel, such as sheathing to struts, the number of nail rows is usually determined by the width of the surface in contact. Use one row, staggered when possible, for surface widths up to 2 inches, two rows for widths from 2 inches through 4 inches, and three rows for widths greater than 4 inches.

11. When nailing plywood to struts or other members, space nails not more than 4 inches on center and stagger them in rows spaced not less than  $\frac{3}{4}$  inch apart. Space the rows as far apart as possible to increase the racking resistance of the joint.

12. When nailing a 1-inch-thick frame member flatwise to a 2-inch-thick member to form a laminated beam or similar member, use sevenpenny nails with the heads placed on the thinner member. Space nails about 16 inches apart in the rows. Use two rows for 4- and 6-inch pieces and three rows for wider pieces. Stagger the nails between rows. Longer nails may be used and then clinched. Place nails about 1 to  $1\frac{1}{2}$  inches from the edges.

13. When nailing two members, each 2 inches thick, together flatwise, as when making laminated joists or beams, use twelvepenny nails placed 1 to  $1\frac{1}{2}$  inches from the edges, according to the width, and approximately 16 inches apart in the rows. Use two rows of nails for members 4 to 6 inches wide and three rows for wider members. Drive nails in each row alternately from opposite sides of the pieces. Stagger the nails between rows.

14. When three pieces of 2-inch lumber are to be nailed together, first nail two of the pieces together with twelvepenny nails spaced

and located as described in rule 13, except that all nails are driven from the same side. Nail third piece to the piece that contains the nail points with twelvepenny nails spaced about midway between the points of the first nails.

15. In fabrication of sheathed crate panels, drive at least two nails through each sheathing board into each member it crosses. In assembly, also, use at least two nails to fasten each sheathing board to each framing member, including skids.

16. When two pieces of plywood sheathing are butt jointed, position the joints at the center of a vertical or horizontal frame member. Nail the abutting edge of each sheet of plywood with two rows of clinched nails, staggering the nails between rows.

## **RESISTANCE OF NAILS TO DIRECT AND LATERAL FORCES**

During handling and shipping of boxes and crates, the nails used in their construction are subjected to direct-withdrawal and lateral forces. The ability of nails to resist these stresses depends not only on the species and condition of the wood but also on the kind and type of nail used (fig. 4).

Withdrawal resistance is the resistance of a nail to forces that tend to pull it from a piece of wood. Lateral resistance is the resistance of a nail to forces applied at right angles to its length. Lateral resistance depends principally on the diameter of the nail, the density of the wood, and the depth of penetration. A nail should penetrate wood to a distance at least 10 times its diameter in dense species and 14 times its diameter in species of moderate or low density.

Direct-withdrawal and lateral forces can be calculated. Later sections of this handbook give methods used to determine the resistance of nails under many conditions, and tables that list allowable loads for various constructions.

### **Factors Affecting Nail Resistance to Removal Forces**

In calculating withdrawal resistance, the allowable load primarily depends on depth of nail penetration, the specific gravity of the wood, and the diameter of the nail. Other mechanical factors, however, also affect withdrawal resistance ; among these are surface condition of the nail, type of nail point, type of nailhead, direction of driving, whether the nail is clinched or unclinched, moisture content of the wood when nailed and while in use, and amount of wood splitting.

### *Surface Condition of Nails*

The surface condition of nails is sometimes modified during the manufacturing process to increase their withdrawal resistance. These modifications consist of surface coating, surface roughening, or surface deformation.

*Surface-Coated Nails.*—One of the most common surface treatments for nails used in the assembly of boxes and crates is cement coating. In many specifications, use of cement-coated nails is required where nails are not clinched. In low-density woods, cement coating adds materially to withdrawal resistance if it has been properly applied. In denser woods, much of the nail's coating may be removed while it is being driven into the wood. Cement-coated nails from different lots may vary greatly in withdrawal resistance according to the way in which they were processed. Different techniques for applying the coating, and variations in the ingredients used, cause large differences in the nail's resistance to withdrawal.

Under such conditions, cement-coated nails may have only a slight initial advantage over bright nails. The greater withdrawal resistance of cement-coated nails is not permanent; it may drop off within a few months.

Nails that have special coatings, such as zinc, are intended for use where corrosion is an important factor in performance or appearance. Over a period of time, uniformly galvanized nails have some advantage in withdrawal resistance over plain nails.

*Roughened-Shank Nails.*—The chemically etched nail has a roughened shank and is somewhat superior to a cement-coated nail because its finish does not deteriorate as does the cement coating. Under impact loads, however, the withdrawal resistance of an etched nail differs little from that of the plain or cement-coated nail.

Sandblasted nails perform much as do chemically etched nails, in that both types provide roughened surfaces that engage wood fibers and resist withdrawal.

*Deformed-Shank Nails.*—The majority of nails used in the construction of boxes and crates have smooth, cylindrical shanks. Any variation from this form is usually intended to increase the surface area without adding weight. Nails with barbed, spirally grooved, annular-grooved, and other types of deformed shanks are widely sold (fig. 4). In wood that does not change in moisture content the withdrawal resistance of these nails, except for some types of barbed nails, is somewhat greater than that of a common wire nail. Under changing moisture conditions, however, some of these nails have much greater withdrawal resistance than the common wire nail. In general, the annular-grooved nails sustain larger static-with-

drawal loads and the spirally grooved nails sustain greater impact-Withdrawal loads than do other nail forms.

Some types of deformed-shank nails are more difficult to drive than the plain-shank nails. This is especially so in the denser species of wood and in species that have a marked difference between springwood and summerwood.

### *Nail Points*

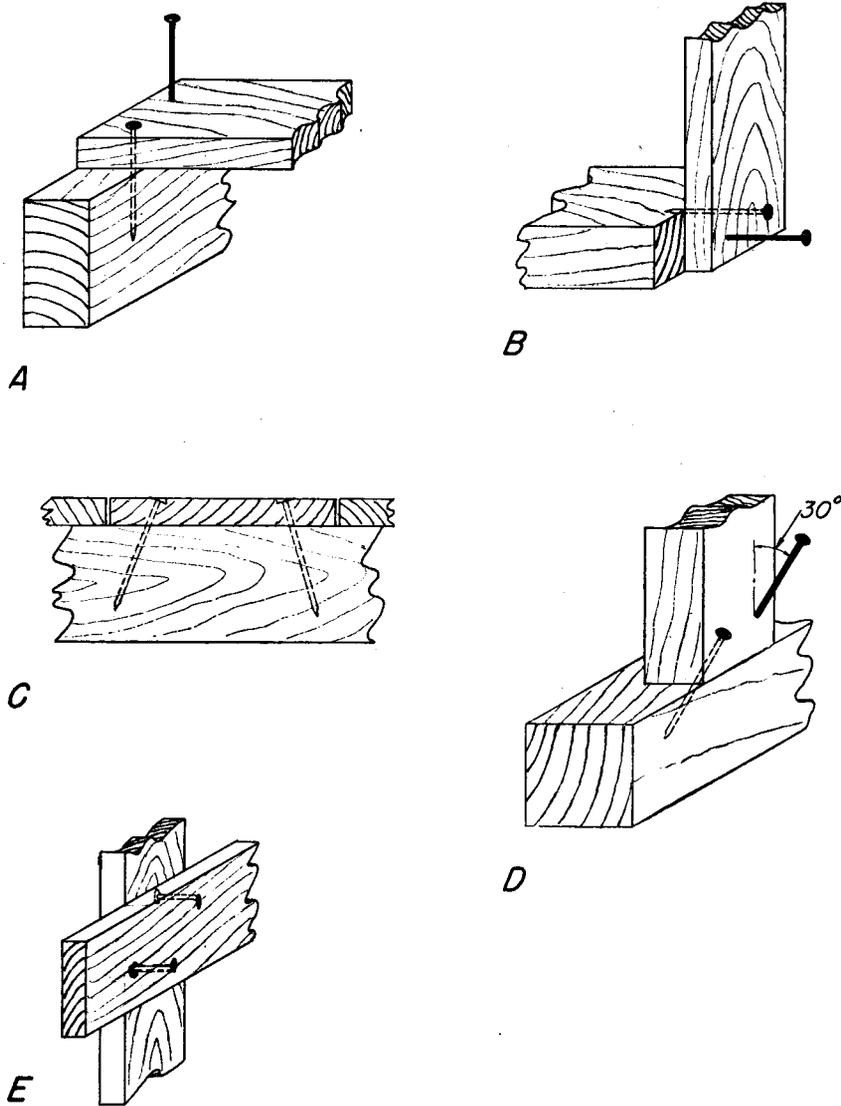
The shape of the nail point has some influence on withdrawal resistance. Nails with long, sharp, conical points will usually have higher withdrawal resistance than nails with diamond points, such as most common and cement-coated nails have (fig. 5). However, the sharp-pointed nail's tendency to split the denser species of wood lowers its withdrawal resistance. When such a point is blunted to form a truncated point, there is less splitting than with the common nail and, in the heavier woods, about the same withdrawal resistance. In the less dense woods, however, nails with truncated points have less resistance to withdrawal than diamond-pointed nails. Nails with blunt or flat, untapered points do not split wood so easily. They tear the wood fibers much more, however, and therefore have lower withdrawal resistance than common wire nails.

### *Nailheads*

Nailheads prevent the pieces holding them from pulling loose when a force is applied. Nailheads vary in size and shape, but most nails commonly used in box and crate construction have a round, flat head. The sinker nail has a head with reinforcing fillet underneath, and this is called a countersunk head (fig. 5). The countersunk nailhead is strong enough to withstand the force required to withdraw the nail from most species of woods. Nails with thin, flat heads should not be used in the denser woods, because the nailhead may be broken off or damaged when the nail is driven, or when stresses are applied. When nailheads are damaged, the strength of the joint is greatly reduced.

### *Direction of Driving*

The resistance of nails to withdrawal is greatest when they are driven perpendicular to the grain of the wood, as in side-grain nailing (fig. 14). When they are driven parallel to the wood fibers, as into the ends of a piece, their holding power may drop to as low as 50 percent of the side-grain values. Slant driving has some advantages over straight driving when nails are driven into the end grain of the wood.



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FIGURE 14.—Method of nailing: *A*, Through side grain of both pieces; *B*, through side grain into end grain; *C*, slant-driven nails; *D*, toenailing; *E*, clinched nails.

Toenailing, often used in the framing of large structures, consists of driving the nails at an angle through the end or edge of one member into another member (fig. 14). The best results with this type of nailing are obtained when (1) the largest nail that will not split the wood excessively is used, (2) the distance from the end of the member to the point where the nail enters it is at least one-third the length of the nail, (3) the nail is driven at an angle of

30 degrees to the face of the piece it enters first, and (4) the head of the nail is buried without excessively mutilating the wood. Toenailing requires greater skill but provides greater strength than end-grain nailing.

### ***Clinched Nails***

Because their pointed ends are bent against the wood (fig. 14), clinched nails normally have much higher withdrawal resistance than unclinched nails. However, this advantage varies a great deal with the size of the nail, the moisture content of the wood, and other factors. This increase in withdrawal resistance can vary from 50 to almost 450 percent. Nails clinched across the grain of the board have approximately 20 percent more resistance to withdrawal than nails clinched parallel to the grain. In box and crate construction, clinched nails are ordinarily used in fabrication of panels or other container parts, and unclinched nails are used to assemble the panels.

### ***Overdriving***

Overdriving of nails occurs most often in machine nailing boxes. It may be caused by variations in sheathing thickness, by differences in the density or species of the boards, or by improper setting of the machine. Overdriving is undesirable in fabrication nailing of container panels and may be seriously detrimental in assembly of parts. It reduces the amount of wood under the nailhead and consequently decreases the withdrawal resistance, especially when thin sheathing is used.

### ***Prebored Lead Holes***

To prevent splitting of the wood, it is often necessary to drill lead holes for the larger nails, especially in dense woods. Nails driven into lead holes, which are usually about three-fourths the diameter of the nail, have slightly higher withdrawal resistance than nails driven without lead holes.

### ***Nails in Plywood***

One advantage of plywood is its greater resistance to splitting, so that nails can be placed close to the edges. The nail-withdrawal resistance of plywood is from 15 to 30 percent less than that of solid wood of the same species and thickness. However, for plywood less than  $\frac{1}{2}$  inch thick, the high splitting resistance tends to offset the lower withdrawal resistance as compared with solid wood.

### *Placement of Nails*

Figure 15 illustrates improper and proper placement of nails along the edges of end sheathing or end cleats. The nails in *A* and *B* are forced outward because of severe grain divergence. Improper sloping of the nail is shown in *C*, and *D* shows the result of too close edge and end spacing. In *E*, the nail was placed so far in from the end that it missed the cleat. So placed it may damage the contents. In *F*, the nail is shown properly placed with respect to the thickness of the cleat, but contact with a knot has bent it outward, causing a "shiner." What happens when corner nails come in contact with each other is shown in *G*. Finally, *H* shows a properly placed and driven nail.

### *Diameter of Nails*

Nail diameter has much to do with both lateral resistance and direct withdrawal resistance. The greater the diameter, however, the greater the likelihood that the wood will split. This is especially true of dense species when the moisture content of the wood is low.

### *Depth of Nail Penetration*

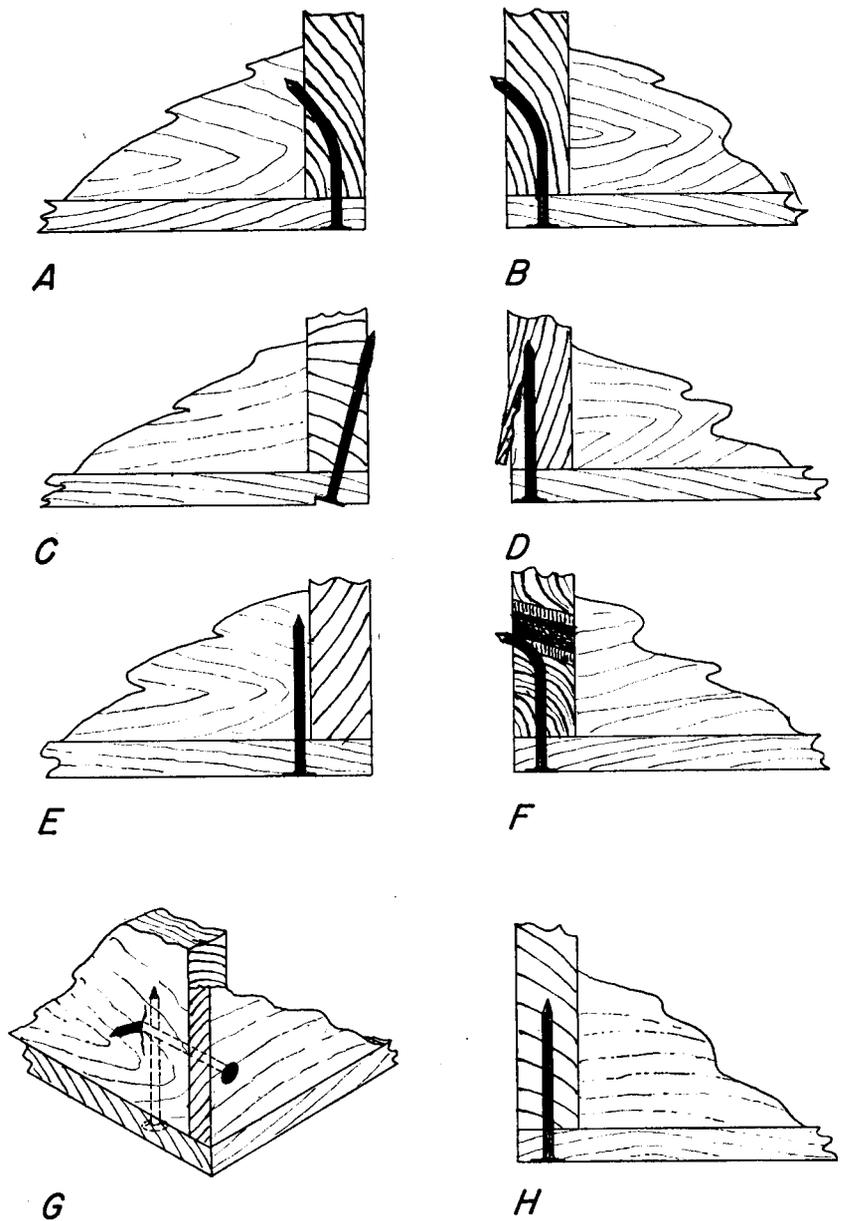
The depth to which a nail penetrates is directly related to its withdrawal resistance because the deeper the penetration, the greater the contact with wood fibers. Withdrawal resistance is calculated on the basis of the depth of penetration in inches. In lateral resistance, a minimum penetration is required and no premium is allowed for greater penetration. However, in actual handling of crates and boxes, the same nail is often subjected to both lateral and withdrawal stresses; hence good penetration has advantages.

### *Species and Density of Wood*

Species and density of wood definitely influence the withdrawal resistance of nails, and the two are generally related. In withdrawal tests<sup>2</sup> at the Forest Products Laboratory, it was found that withdrawal resistance was more than doubled when the density of the wood tested was twice as high. For example, for an average density of 0.33, the average withdrawal resistance of a cement-coated nail was 150 pounds, as compared with 440 pounds for an average density of 0.66. These tests were made on wood that had a moisture content of about 10 percent or less. The nail was withdrawn immediately after it was driven.

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<sup>2</sup> U.S. FOREST PRODUCTS LABORATORY. NAIL-HOLDING POWER OF AMERICAN WOODS. Tech. Note 236. 1958.



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FIGURE 15.—Impropeand proper nailing; *A* and *B*, Nail bent by divergent grain; *C*, slanted nail; *D*, nail too close to edge; *E*, too great end spacing; *F*, nail bent by contact with knot; *G*, nail bent by contact with another nail; *H*, nail properly placed and driven.

### Moisture Content of Wood

The moisture content of wood has a definite effect on the withdrawal resistance of nails, on ease of driving, and on the wood's tendency to split. Changes in moisture content have an even greater effect on withdrawal resistance. As green lumber dries, the withdrawal resistance of nails falls off. A nail driven into and immediately pulled from green wood has almost 4 times the withdrawal resistance it would have if it were left there 1 year while the wood dried and was then pulled.

It is good practice to use wood that has a moisture content of less than 19 percent for building containers. However, wood with an extremely low moisture content is not desirable for containers, since subsequent moisture pickup and loss will also reduce withdrawal resistance of nails and may cause the lumber to warp and split.

### How To Determine Nail Resistance

The two main calculable functions of nails used for assembly in box and crate construction are their resistance to direct withdrawal and their resistance to lateral stresses. In rough-handling tests of

TABLE 7.—Average allowable loads <sup>1</sup> for nails in direct withdrawals<sup>2</sup> (nails equal in diameter and length to sinker nails)

Wood species	Allowable load					
	Six-penny	Eight-penny	Ten-penny	Twelve-penny	Sixteen-penny	Twenty-penny
Basswood, cottonwood, true firs, pines (except southern yellow), spruces, yellow-poplar, and similar species.....	<i>Pounds</i> 18	<i>Pounds</i> 27	<i>Pounds</i> 35	<i>Pounds</i> 42	<i>Pounds</i> 49	<i>Pounds</i> 58
Western hemlock, red pine, redwood, other species of similar density.....	25	37	48	58	66	79
Soft elm, sweetgum, black ash, soft maple, other species of similar density.....	34	51	66	81	93	111
Douglas-fir, western larch, southern yellow pine, other species of similar density.....	38	56	73	89	102	121
White ash, beech, birch, hard maple, oaks, rock elm, other species of similar density.....	59	88	114	140	159	190

<sup>1</sup> Based on normal conditions for containers.

<sup>2</sup> When driven into side grain of seasoned lumber to a depth equal to two-thirds of its length.

wood boxes, both types of failures have been noted. In drop tests made with crates, the nail failures noted in the joints between sides and base were caused primarily by lateral forces.

Formulas have been developed<sup>3</sup> to determine the allowable loads for direct withdrawal resistance and lateral resistance of nails. These formulas have been based on nails used for construction, as for nailing of wood trusses, and for fabrication and assembly of other structural units. They are applicable under conditions of long-continued or permanent loading; however, they can be modified for loads of short duration or where the loading conditions are not so severe. Thus, the formulas in the text and the allowable load values for containers given in tables 7 and 8 have been increased about 20 percent above those for permanent loading. They are considered satisfactory for loading and storage conditions to which boxes and crates are normally subjected. Under extreme shipping, storage, or handling conditions, however, allowable loads may be reduced from those included in tables 7 and 8. Only side-grain nailing is considered in the calculations that follow.

TABLE 8.—Average allowable loads<sup>1</sup> for nails in lateral resistance<sup>2</sup> (nails having diameters equal to sinker nails)

Wood species	Allowable load					
	Six-penny	Eight-penny	Ten-penny	Twelve-penny	Sixteen-penny	Twenty-penny
Basswood, cottonwood, true firs, pines (except southern yellow), spruce, yellow-poplar, other species of similar density-----	<i>Pounds</i> 30	<i>Pounds</i> 41	<i>Pounds</i> 45	<i>Pounds</i> 54	<i>Pounds</i> 62	<i>Pounds</i> 81
Western hemlock, red pine, redwood, other species of similar density-----	37	51	57	67	77	101
Soft elm, sweetgum, black ash, soft maple, other species of similar density-----	42	57	63	75	86	112
Douglas-fir, western larch, southern yellow pine, other species of similar density-----	46	63	69	82	94	123
White ash, beech, birch, hard maple, oaks, rock elm, other species of similar density-----	56	78	85	101	117	152

<sup>1</sup> Based on normal storage and handling conditions.

<sup>2</sup> When driven in side grain of seasoned lumber, minimum distance of penetration equal to two-thirds of its length in the softer woods and one-half in the denser woods.

<sup>3</sup> U.S. FOREST PRODUCTS LABORATORY. WOOD HANDBOOK. U.S. Dept. Agr., Agr. Handb. 72, 528 pp., illus. 1955.

*Direct-Withdrawal Resistance*

The resistance of nails with circular, uncoated, plain shanks to direct withdrawal depends on the specific gravity of the wood, the nail diameter, and the depth of penetration. The following formula may be used to determine the allowable direct-withdrawal load for nails of any size under normal conditions of use typical of containers:

$$P = 1,380 G^{\frac{5}{2}} D$$

where  $P$  is the allowable load in pounds per inch of penetration into the member receiving the point (side grain of seasoned wood),  $G$  is the specific gravity of species of wood, based on weight and volume when ovendry,<sup>4</sup> and  $D$  is the diameter of the nail in inches.

Table 9 lists the specific gravity,  $G$ , and  $G^{\frac{5}{2}}$  for a number of woods commonly used for the construction of boxes and crates.

Table 10 lists nail diameters and other data used in the formulas for determining withdrawal values as well as for calculating the lateral resistance of nails. If nails other than bright, common

TABLE 9.—*Values for specific gravity (G) of ovendry wood used in calculating direct-withdrawal loads for nails*

$G$	$G^{\frac{5}{2}}$	$G$	$G^{\frac{5}{2}}$	$G$	$G^{\frac{5}{2}}$
0.32	0.06	0.47	0.15	0.62	0.31
.35	.07	.50	.18	.65	.34
.38	.09	.53	.20	.68	.38
.41	.11	.56	.23	.71	.42
.44	.13	.59	.27	.74	.47

TABLE 10.—*Sizes of bright common wire nails*

Size (penny)	Gage	Length	Diameter	
			$D$	$D^{\frac{3}{2}}$
4	12½	Inch 1½	Inch 0.098	Inch 0.0307
6	11½	2	.113	.0380
7	11½	2¼	.113	.0380
8	10¼	2½	.131	.0474
9	10¼	2¾	.131	.0474
10	9	3	.148	.0570
12	9	3¼	.148	.0570
16	8	3½	.162	.0652

<sup>4</sup> MARKWARDT, L. J., and WILSON, T. R. C. STRENGTH AND RELATED PROPERTIES OF WOODS GROWN IN THE UNITED STATES. U.S. Dept. Agr. Tech. Bul. 479, 99 pp., illus. 1935.

wire nails are used (such as sinker nails), the gage, length, and other values will change from those in the table.

The sinker nail is the type most often used in the assembly of boxes and crates. Table 7 lists the average allowable loads for direct withdrawal of sinker nails, or nails of equal diameter and penetration, in box and crate construction. These are average values, however, and values for individual species or pieces may be somewhat higher or lower than those listed in the table. The values in table 7 do not allow for any shank treatment, shank roughening, or deformation.

### *Lateral Resistance*

Lateral resistance is the resistance of the nail to lateral loads applied at right angles to the length of the nail. For example, this is the type of force to which nails used to fasten ends and sides of a crate are subjected. As in the method used for determining the allowable direct-withdrawal values, the specific gravity of wood and the diameter of the nail must be considered in calculating allowable loads. The formulas are based on the penetration of an uncoated, circular-shank nail into wood. The nail should penetrate into the lower density species a distance of about two-thirds its length. In the higher density species, nails should penetrate to a distance about one-half their length.

The following formulas can be used for determining the allowable lateral resistance of nails driven into the side grain of various species of wood. The values are based on stresses normally placed on containers.

Species	Formula
Basswood, cottonwood, true firs, pines (except southern yellow), spruces, yellow-poplar, other species of similar density-----	$P=1,080 D^{\frac{3}{2}}$
Western hemlock, red pine, redwood, other species of similar density-----	$P=1,350 D^{\frac{3}{2}}$
Soft elm, sweetgum, black ash, soft maple, other species of similar density-----	$P=1,500 D^{\frac{3}{2}}$
Douglas-fir, western larch, southern yellow pine, other species of similar density-----	$P=1,650 D^{\frac{3}{2}}$
White ash, beech, birch, hard maple, oaks, rock elm, other species of similar density-----	$P=2,040 D^{\frac{3}{2}}$

In these formulas,  $P$  is the allowable load per nail in pounds and  $D$  is the diameter of the nail in inches.

The values for  $D^{\frac{3}{2}}$  are given in table 10 for various sizes of nails.

Table 8 is included for the convenience of builders of boxes and crates, and formulas need not be used except for special conditions. The values are based on the sinker nail or other nails of equal diameter.

## Wood Groups

Many species of wood are adaptable for use in the construction of boxes and crates. The various species commonly used are divided into four groups, largely on the basis of their density. Other factors on which the groupings are based include their nail-holding power, ease of working, and their splitting tendency. It is always good practice, in the construction of containers, to use species in the same group for similar parts. For example, the sheathing of a crate should consist of species in one group. The cleats of a nailed wood box should also be selected from one group, although not necessarily the same one. By doing so, the builder can use a single set of lumber sizes and nailing practices. Most container specifications designate the size of members and the size and spacing of nails according to wood groups. The denser woods are used in smaller sizes and fastened with fewer nails.

In the following groups are listed the various species of woods commonly used for the construction of containers:

GROUP I includes the softer woods of both the coniferous (softwood) and broad-leaved (hardwood) species. These woods do not split readily when nailed, have moderate nail-holding power, moderate strength as a beam, and moderate shock-resisting capacity. They are soft, lightweight, and easy to work, hold their shape well after manufacture, and usually are easy to dry.

Aspen (popple)	Magnolia
Basswood	Pine (except southern yellow)
Buckeye	Redwood
Cedars	Spruces
Chestnut	Willow
Cottonwood	Yellow-poplar
Cypress	
Firs (true)	

GROUP II consists of the heavier coniferous woods. No hardwood species are included. These woods usually exhibit a pronounced contrast in the hardness of the springwood and the summerwood. They have greater nail-holding power than the group I woods, but they tend to split more readily. The hard summerwood bands often deflect the nails and cause them to protrude from the side of the piece.

Douglas-fir	Tamarack
Hemlock	Western larch
Southern yellow pine	

GROUP III 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 II woods,

but are less inclined to split and shatter under impacts. Group III species are the most useful woods for box ends and cleats. This group includes those woods from which most of the rotary-cut lumber for wirebound and plywood boxes is obtained.

Ash (except white)	Sweetgum
Softelm	Sycamore
Soft maple	Tupelo

GROUP IV woods are the heavy hardwood species. They have both the greatest shock-resisting capacity and the greatest nail-holding power. Because of their extreme hardness it is difficult to drive nails into them and they have the greatest tendency to split. They are the heaviest and hardest domestic woods and are difficult to work. They are especially useful where high nail-holding power is required. Many of them make excellent rotary-cut lumber for wirebound and plywood boxes.

Beach	Oaks
Birch	Pecan
Hackberry	Rockelm
Hickory	White ash
Hard maple	