BIN FRONTS for POTATO STORAGES

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UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This report is one of several issued on the results of research conducted for the purpose of developing information concerning potato-storage construction.

The research was conducted under the general supervision of Joseph F. Herrick, Jr., investigations leader, and Lewis A. Schaper, agricultural engineer, Handling and Facilities Research Branch, Transportation and Facilities Research Division, Agricultural Research Service. Alfred D. Edgar, Handling and Facilities Research Branch, retired, directed some of the initial work.

The work was performed at the Red River Valley Potato Research Center, East Grand Forks, Minn., and in a selected storage in the area.

The authors wish to thank Cliff Hagen, potato grower and storage operator, East Grand Forks, Minn., for making his facilities available for trials of the experimental fronts.

CONTENTS

This revision of Marketing Research Report 893 supersedes the July 1971 version. **All previous copies of MRR 893 should be destroyed.**

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BIN FRONTS FOR POTATO STORAGES

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SUMMARY

The use of bin fronts is justified because they provide better space utilization in the potato bin, but the other functions they perform, such as creating a level pile for better ventilation, separating bins from alleyways, and providing pressure relief at doors, are important also.

The design of bin fronts, the removable access panels to potato-storage bins, is discussed in this report and two experimental types of bin fronts suitable for spanning openings up to 24 feet wide are detailed. The experimental fronts consisted of a glued-tee panel and a "slotted" panel. Both designs were examined and tested for use on long-span applications. Both were effective in terms of the design criteria: (a) adequate strength, (b) reasonable weight, (c) convenient stacking capability for storing, and (d) reasonable cost. These experimental panels are illustrated in detail, and size-selection and cost charts are given.

Potato-pile pressure and its effect is also explained, and the proper steps in designing bin-front panels to resist this pressure are outlined in terms of strength in bending, vertical shear, horizontal shear, deflection, and crushing. These terms are discussed on page 9. Although strength in bending is usually the governing factor in designing pressure-resistant fronts, all factors pertaining to pressure must be checked carefully.

The need for careful design of bin front appurtenances such as starter sections, wall attachments, and anchoring plates is emphasized.

INTRODUCTION

The fall crop areas produce approximately 200 million hundredweights (cwt.) of potatoes annually. Almost all of this volume is stored before marketing. One of the primary concerns of the storage operator is providing easier methods of moving these large volumes of potatoes into storage as rapidly as possible during the harvest period and removing them from storage as easily as possible during the marketing period. "Bin fronts," the set of removable access panels to the storage bins used for both filling and emptying, can be a key in providing easy accessibility to the storage.

Reasons for Fronting Bins

The general reasons for using bin fronts are:

1. To provide full use of the storage bin.
2. To provide removable access sections to the storage bins for both filling and emptying.
3. To provide piece-by-piece closure of the bin that matches bin-filling progress.
4. To create a level pile of produce for ventilation purposes.
5. To provide for pressure relief at doors.
6. To separate bins from alleyways.
7. To divide bins.

The individual parts and assemblies used for fronting bins are known by various names, such as "bin fronts," "bulk heads," "bin boards," and "bin planks." The term "bin front" or simply "front" is used throughout this report when the authors refer to the total structure making up the removable wall section of the front of the bin. The term "panel" or "panel unit" is used in referring to the major components or assemblies that constitute a distinct part of the bin front.

Advent of the Bin-Front Problem

With the advent of aboveground storage in the 1950's, the method of filling potato bins was altered from vertical filling through the top of the bin to horizontal filling from one end of the bin to the other through the bin's doorway. Larger and wider bins were provided in these structures. The simultaneous evolution of potato-handling equipment resulted in larger trucks and much larger units of filling equipment. The bin doorways through which this equipment had to pass became constricted areas —bottlenecks in the filling operation.

Difficulties of Inadequate Bin Fronts

The problem of bin fronting is complicated by the pressure exerted by potatoes in bulk piles. Bin fronts must have adequate structural strength to withstand this pressure or they will crack and bulge and may even burst. When personnel are involved, safety becomes a consideration in designing bin fronts. Structural adequacy is also required in the bin walls and appurtenances that are affected by the fronts.

A bin front may be structurally adequate but economically impractical because it is made of too costly a material, the material is poorly utilized in the design, or fabrication costs are too high. The panels of the bin front may be functionally inadequate if they are difficult to install and remove, or if they are difficult to store during nonuse periods.

Types of Panels Used for Bin Fronts, and Their Limitations

The types of panels used by the industry for short-span applications in bin fronts may be classified as straight panels, clamped or bolted two-piece tee panels, trussed panels, and swinging door panels. The types used for wide spans include removable post, tie back, and semicircular sheet metal.

Straight Panels

Straight panels are constructed of 2- by 12-inch or 3- by 12-inch lumber, or of simple formed steel sheets. Figure 1 illustrates a straight panel bin front with the individual panels stacked vertically to form a narrow barrier across the doorway. Straight panels are limited to relatively short spans because those with enough strength for long-span applications would be too heavy to be handled easily.

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FIGURE 1.—Potato-bin front constructed of straight panels.

Two- and three-piece combinations of straight panels have been used in bin-front construction to reduce each panel's span and thus its size. A shallow V pointing into the bin is formed by using two pieces of lumber held together by connectors, or simply by contact. Three-piece panels are joined in the same way to form a semihexagon into the bin. Figure 2 illustrates such a front.

These fronts have the advantage of short, light panels, but a shifting of the potato pile can cause structural failures at the panel joints.

Clamped or Bolted Two-Piece Tee Panels

Two-piece tee panels are made up of a flange section and a web section bolted or clamped together to form a T. The size of the web section of the tee is altered to meet the strength requirements of a particular structural application. Figure 3 illustrates this type of panel. With long spans, slippage between the flange and web will result in bulging of the panel. When the web is bolted to the flange rather than clamped, the slipping is diminished, but the strength of the web is greatly reduced because of the hole bored through it.

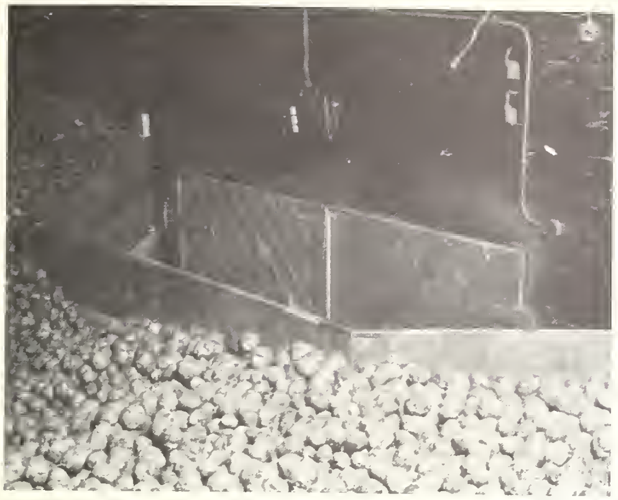

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FIGURE 2.—Potato-bin front constructed of three-piece straight panels.

Trussed Panels

The trussed-panel type of bin front is illustrated in figure 4. This design generally consists of a straight panel with a steel "bridge" to take up the pressure exerted by the potato pile. The bridge may be a unit with adjustable ends or simply a rod welded to anchor plates.

This design gives the straight panel strength, but fabrication of the truss can be a problem.

Swinging-Door Panels

Figure 5 illustrates a bin front consisting of swinging-door panels. Hinged panels are closed in pairs to form a very shallow V pointing into the bin. Each pair of panels, when in contact, resist further movement outward because together they are slightly larger than the doorway opening.

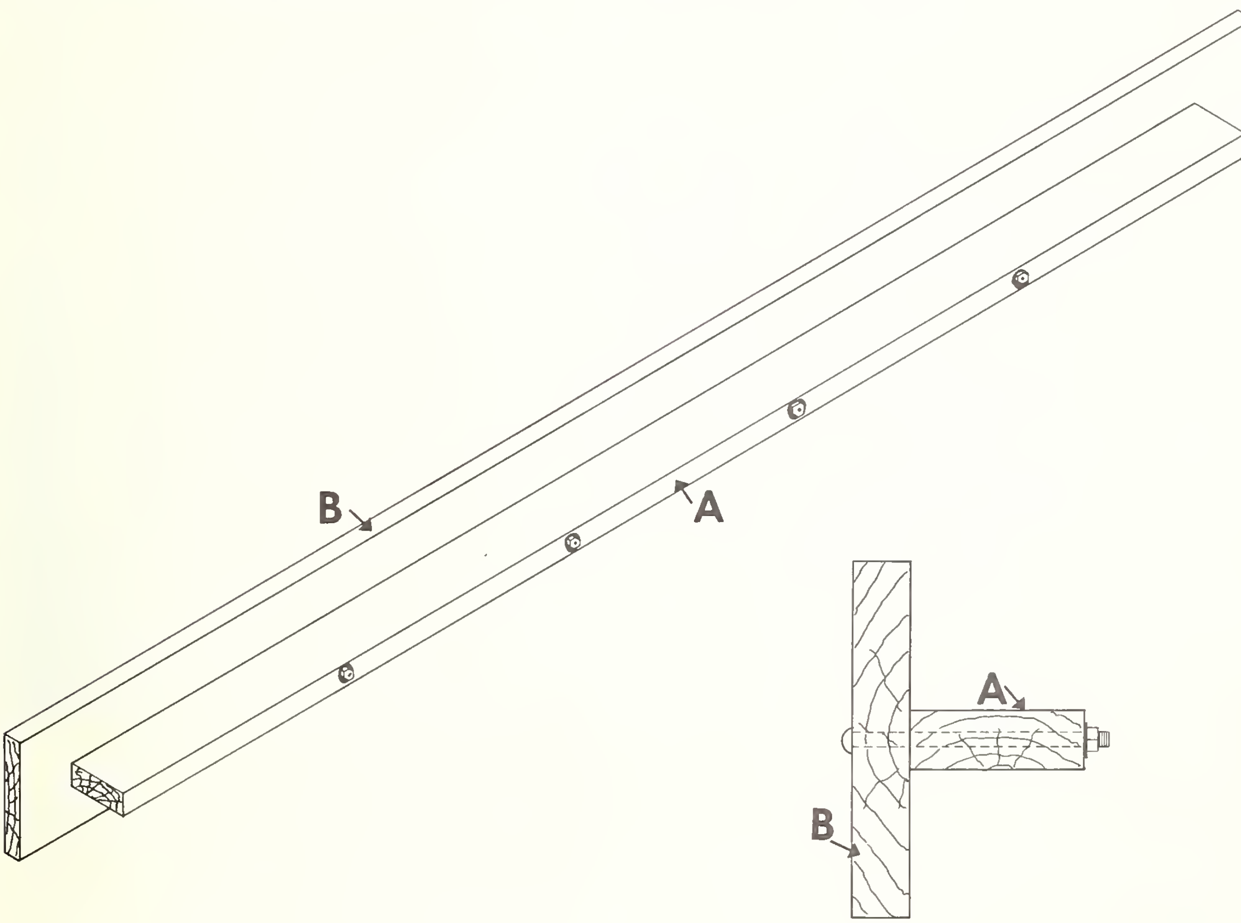

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FIGURE 3.—Diagram of a two-piece tee panel for fronting bins. The web (*A*) is bolted to the flange (*B*).

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FIGURE 4.—Potato storage bin front constructed of trussed panels. The trusses (arrows) strengthen the panels.

The swinging panels are constructed of plywood over an internal structural framework. When not in use, they are stored by being swung into the bin and positioned against the bin wall.

Removable Post

A few storage operators are attempting long-span bin fronting by using a removable post. The removable post is a steel I-beam or a large wood post placed in retainers at the floor and ceiling at the middle of the bin width to cut the span in half. Standard types of bin fronts are used to span the two halves. This approach is satisfactory, although the removable post must be quite heavy in high-ceiling storages. The post also forms an obstruction for bin-filling equipment.

Tie Back

Straight panels with tie backs provide another means of fronting wide-span doorways. A tie-back front generally consists of 2- by 12-inch straight panels with false posts and cable that "tie" the center section of the front to the bin walls. Figure 6 illustrates this type of front. The tie-back front is satisfactory and the panels are easy to handle because of their lighter weight, but the cables and attachments can be a nuisance when the bin is being filled or emptied.

Semicircular Sheet Metal

A semicircular sheet-metal front performs well in spanning wide doorways. Figure 7 shows this type of bin front. The front consists of 2- by 10-foot sheets of 20-gage metal attached to the bin walls and to each other so as to form a semicircle. This front, developed at the USDA Potato Research Center, is lightweight and strong, and can be conveniently stored. It presents some interference to the filling equipment, however.

PURPOSE AND METHODS OF STUDY

Purpose of Study

This study was undertaken as an auxiliary part of a USDA project aimed at providing improved storage designs for the potato industry. Initial experimental work for this part of the project began with the installation of glued-tee and slotted bin fronts at the Potato Research Center in 1964. The objectives of the study were threefold: (1) To determine the economics involved in fronting bins, (2) to determine the advantages and disadvantages of the various types of bin fronts, and (3) to design long-span bin fronts within the following criteria: (a) adequate strength, (b) reasonable weight, (c) reasonable cost, and (d) convenient stacking capability for storing.

Methods of Study

Typical bin configurations were examined to determine the volume of storage space made available when a vertical barrier was provided

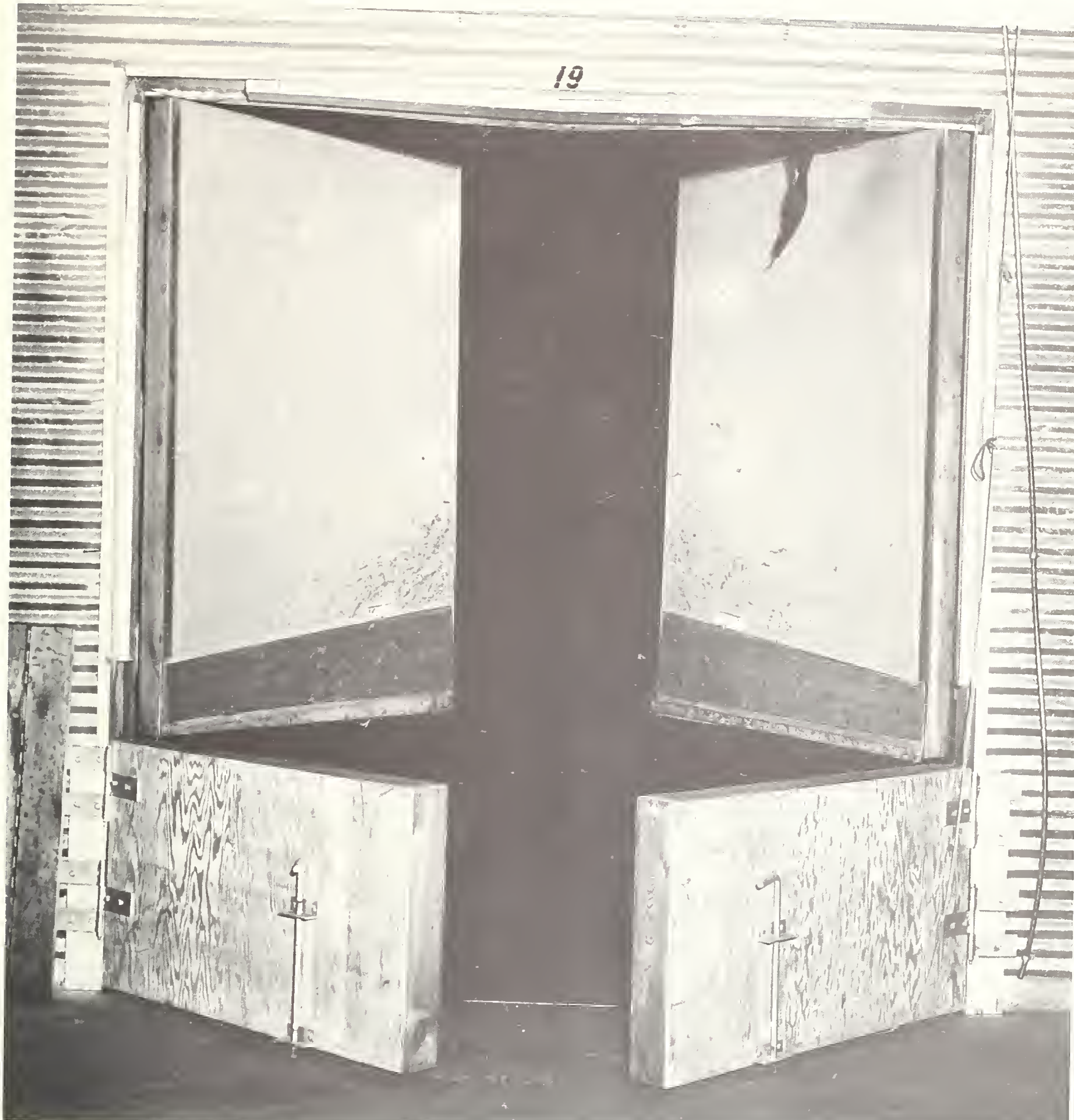

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FIGURE 5.—A bin front consisting of swinging-door panels.

to retain the bulk pile. The value of this space was compared with the cost of utilizing it through the use of bin fronts.

Specific types of bin fronts selected as representative of those used by the potato industry were analyzed for design advantages and disadvantages in short-span application. Limiting factors that preclude the use of these fronts in long-span application were identified.

Long-span bin front designs were developed on the basis of strength requirements and mathematical relations. Designs that combined strength and practicability were then fabricated and tested by using individual panels as

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FIGURE 6.—Tie-back type of bin front strengthens straight panels spanning wide doorways.

simulated bin-front structural units subjected to experimental loads. After the results of these load tests were analyzed, the designs were re-evaluated with the emphasis on standardised types and sizes of materials.

The experimental bin fronts that appeared promising were installed in commercial bins for further evaluation. As a result of this evaluation, bin-front designs adaptable to full-scale commercial use were identified.

Several basic forms of retainers (the panel component designed to prevent the potatoes from spilling out of certain types of bin fronts) and appurtenances were designed for the selected bin fronts and are described. Several alternative forms of the basic bin-front types are also described.

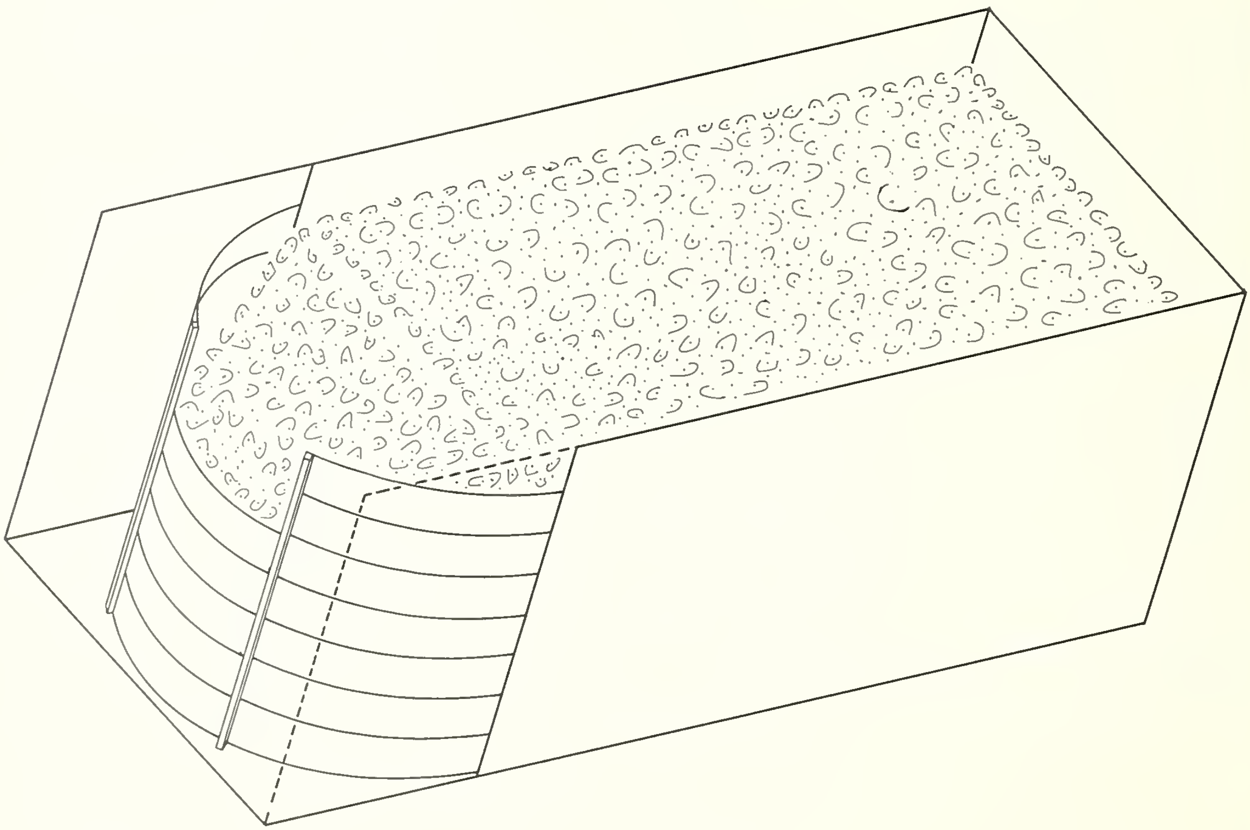

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FIGURE 7.—Diagram of semicircular sheet-metal bin front. The metal sheets provide a strong front for wide-span openings.

ECONOMICS OF FRONTING BINS

The amount of storage space made available by bin fronting was determined for two typical bin configurations. Bin widths of 16 feet and 20 feet were selected. Potato pile depth was considered to be 16 feet and the pile's angle of repose (described more fully on p. 8) was assumed to be 37.5 degrees. Figure 8 illustrates the volumes of space involved. This space was then converted to hundredweight of potato capacity by using the specific weight of 0.42 cwt. per cubic foot of storage volume established for bulk potatoes. With rental value of bin space estimated at $0.166 per hundredweight of potatoes, the capacity gained by bin fronting was converted to annual value. Table 1 gives the results of these calculations for each 1-foot inter-

TABLE 1.—*Volumes, capacities, and annual values of space gained by fronting 16- and 20-foot-wide potato storage bins*

Width of bin and height (in feet) of bin front	Volume of unused space [1]	Storage capacity gained per foot [2]	Cumulative storage capacity gained	Annual value of storage capacity gained per foot [3]	Cumulative annual value of storage capacity gained
16-ft.-wide bin:	*Cubic feet*	*Hundredweight*	*Hundredweight*	*Dollars*	*Dollars*
16	0	4.38	1,120.90	0.73	186.08
15	10.4	13.13	1,116.52	2.18	185.35
14	41.7	21.90	1,103.39	3.64	183.17
13	93.8	30.65	1,081.49	5.09	179.53
12	166.8	39.41	1,050.84	6.54	174.44
11	260.7	48.17	1,011.43	8.00	167.90
10	375.3	56.93	963.26	9.45	159.90
9	510.9	65.69	906.33	10.90	150.45
8	677.3	74.44	840.64	12.36	139.55
7	844.5	83.20	766.20	13.81	127.19
6	1,042.6	91.96	683.00	15.27	113.38
5	1,261.6	100.71	591.04	16.72	98.11
4	1,501.4	109.48	490.33	18.17	81.39
3	1,762.0	118.23	380.85	19.63	63.22
2	2,043.5	126.99	262.62	21.08	43.59
1	2,345.9	135.63	135.63	22.51	22.51
0	2,668.8	----------	----------	--------	--------
20-ft.-wide bin:	*Cubic feet*	*Hundredweight*	*Hundredweight*	*Dollars*	*Dollars*
16	0	5.47	1,401.12	0.91	232.58
15	13.0	16.42	1,395.65	2.73	231.67
14	52.1	27.37	1,379.23	4.54	228.94
13	117.3	38.32	1,351.86	6.36	224.40
12	208.5	49.26	1,313.54	8.18	218.04
11	325.8	60.21	1,264.28	9.99	209.86
10	469.2	71.16	1,204.07	11.81	199.87
9	638.6	82.11	1,132.91	13.63	188.06
8	834.1	93.05	1,050.80	15.45	174.43
7	1,055.6	104.00	957.75	17.26	158.98
6	1,303.3	114.95	853.75	19.08	141.72
5	1,577.0	125.90	738.80	20.90	122.64
4	1,876.7	136.84	612.90	22.72	101.74
3	2,202.5	147.79	476.06	24.53	79.02
2	2,554.4	158.74	328.27	26.35	54.49
1	2,932.4	169.53	169.53	28.14	28.14
0	3,336.0	----------	----------	--------	--------

[1] Based on pile depth of 16 feet and angle of repose of 37.5 degrees.

[2] Based on specific weight of 42 pounds per cubic foot for bulk potatoes.

[3] Based on bin-space rental estimated at $0.166 per hundredweight.

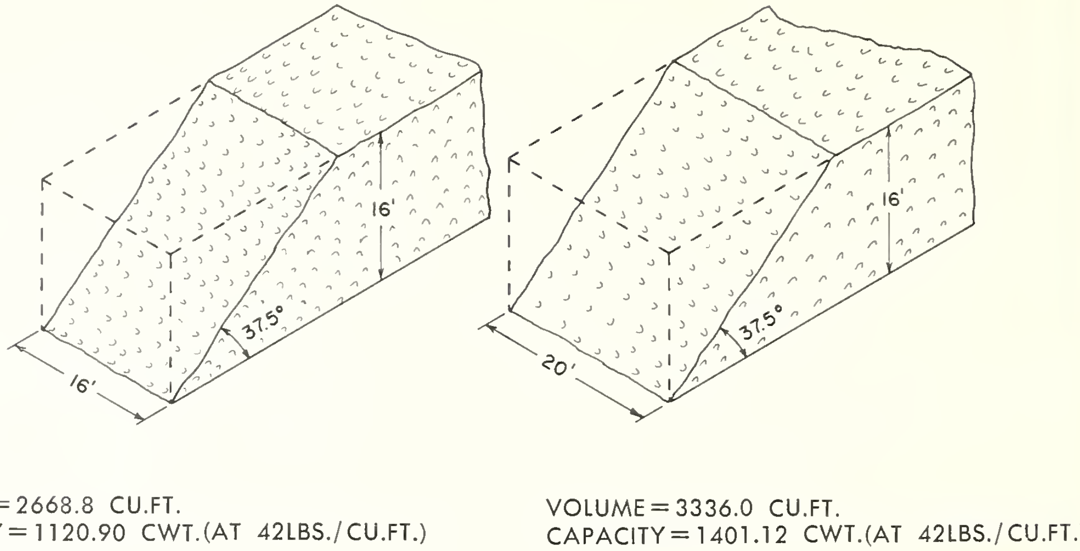

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FIGURE 8.—Volume and capacity gained by fronting potato-storage bins 20 feet and 16 feet wide.

val of bin-front height and for cumulative height. The estimated annual value of the capacity gained by fronting the bins for a pile depth of 16 feet is $186.08 for the 16-foot-wide bin and $232.58 for the 20-foot-wide bin.

The annual cost of obtaining this space by fronting these bins to a pile depth of approximately 16 feet was $22.71 for the 16-foot-wide bin and $29.55 for the 20-foot-wide bin, assuming the use of glued-tee, wide-span bin fronts (see "Experimental Fronts," p. 12). These estimated annual costs for bin fronts are based on ownership costs made up of depreciation, interest, taxes, and insurance; operating costs consisting of maintenance charges; and labor costs for installing and removing the fronts.

DESIGNING BIN FRONTS

Potato-Pile Pressure

Potato-pile pressure may be resolved into two components—horizontal pressure and vertical pressure. The designer of bin fronts is primarily concerned with the horizontal pressure. Pressure is usually defined as force per unit area. Therefore, when potato-pile pressure is referred to, the term is an expression of the number of pounds of push on each square foot of bin front or bin wall surface.

The angle of repose of a potato pile is generally accepted to be 37.5 degrees. The angle of repose is that angle subtended between the pile floor and the pile surface when potatoes are not restrained by a vertical wall (fig. 9). It is also the angle which the resultant of the horizontal and vertical forces assumes with respect to the horizontal.

The factor having the greatest effect on pressure is the pile depth. The pressure near the top of a pile is small; near the bottom, the pressure is at a maximum. Figure 10 shows horizontal pressures exerted on a bin 10 feet wide.

The horizontal and vertical pressures exerted by the potato pile are diminished near walls and floors by the friction force engendered by contact between pile and surface, particularly when the surface is rough. The effect of floor friction is demonstrated in bin fronting, where the second panel above the floor commonly shows more bulging than the bottom panel. Lateral pressure on the panels is also diminished near the

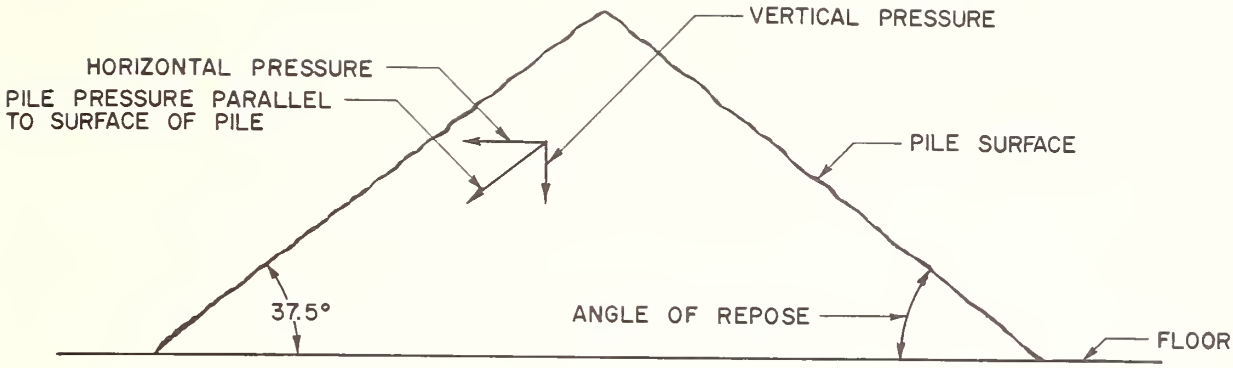

FIGURE 9.—Diagram showing normal angle of repose (37.5°) between surface of potato pile and bin floor, and the directions of pressures exerted by pile.

walls because of friction; again, the roughness of the surfaces affects the amount of the change. The vertical pressure at the wall may also be altered by friction, in accordance with the type of material from which the wall is constructed.

Bin configuration will also alter the amount of force that is exerted against a bin wall. A bin wall that slopes toward the pile (such as the wall of an arched-roof storage) will have less force exerted on it than will a vertical wall. This effect occurs because the wall orientation tends to approach the angle of repose of the potato pile.

A surface which angles away from the pile (such as a triangular air duct) actually has a certain number of potatoes to support, as well as horizontal pile pressure to resist. The analysis of this situation is given in the appendix.

Pressures are further affected by the relationship of the bin width, depth, and height. Figure 10 shows horizontal pressures exerted on a bin 10 feet wide. For bins over 10 feet wide, whose depth is greater than or equal to width, the value should be multiplied by the square root of the quantity "width of the bin divided by 10." When the width of the bin is greater than 10 feet and exceeds the depth of the pile of potatoes, the correction factor would be the square root of the quantity "height of the pile divided by 10."[1]

[1] Willson, G. B. Lateral pressure in walls of potato storage bins. U.S. Dept. Agr., Agr. Res. Serv., ARS 52-32, 15 pp., illus. 1968.

Design Requirements

Factors Affecting Panel Design

Several factors to be considered in designing bin fronts are: (1) Strength in bending, (2) vertical shear, (3) horizontal shear, (4) deflection, and (5) crushing. The appendix describes these factors and the calculations used in evaluating their effects.

The panel may be considered as a simply supported beam with a uniformally distributed load equal to the lateral pile pressure. The loading of the beam is not completely uniform because the lateral pile pressure varies from top to bottom of each panel. However, for simplicity in calculation and for common panel widths, this variation can be neglected.

The greatest concern of bin front designers is, generally, to design the panel so that it will have strength in bending. Failure in bending occurs when the internal fibers of the tension side of the panel separate.

Vertical shear refers to the tendency of the panel to shear off in a plane that is perpendicular to its length where it comes in contact with the post that retains it.

Failure in horizontal shear in many cases may not be as obvious as failure in bending or vertical shear. The internal fibers of a panel fail to resist shearing or slipping in a plane parallel to the panel length. The shearing stress at the extreme fibers of a panel is zero. Normally, the maximum unit horizontal shearing stress occurs at the neutral axis of a panel.

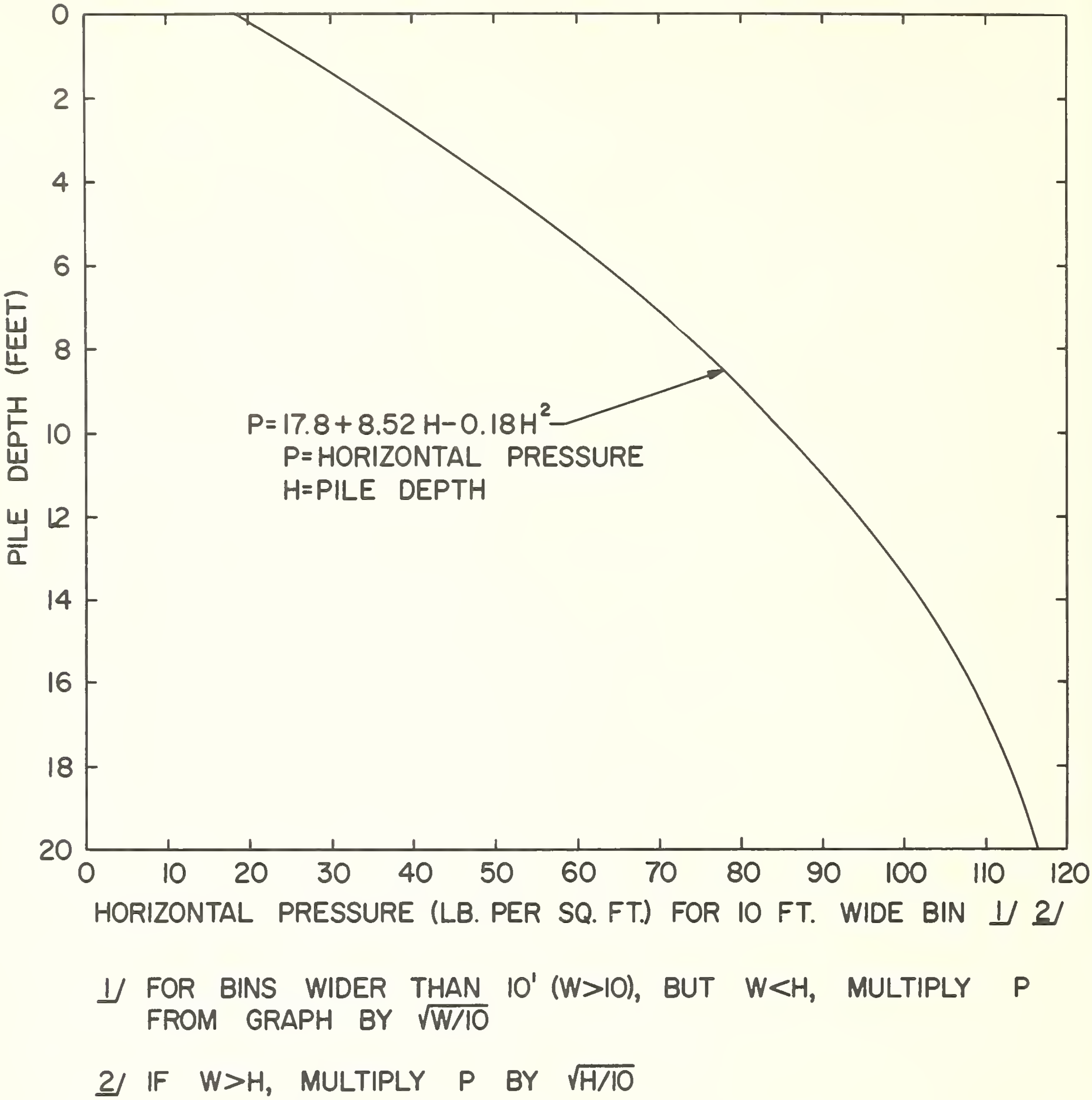

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FIGURE 10.—Diagram showing increases in horizontal pressure exerted by potato pile as depth of pile increases in a bin 10 feet wide.

Failure in deflection is not a true failure of the material; it is simply excessive bulging of the panel beyond some acceptable limit. This limit might be based on movement that does not cause the panel to extend beyond the thickness of the adjacent panels or impair overall appearance of the bin front.

Failure in compression or crushing may occur where the bin front comes in contact with the post or retainer that holds it in place. A failure of this nature involves the actual collapse or crushing of the cell structure of the material. In the case of wood, two values are given for compression; they are compression perpendicular to the grain and compression parallel to the grain. Compression parallel to the grain is sometimes referred to as "bearing." In the design of columns or posts, bearing strength becomes critical; however, in the case of bin fronts, the physical construction of the front generally prevents failure in bearing from becoming a severe problem.

Product and Storage-Structure Considerations

Bin fronts must be designed to minimize damage to the potatoes. Sharp or protruding edges must be avoided wherever the potatoes come in contact with a panel. If the potatoes at the bin front will be repeatedly exposed to light, the front must shield them to prevent greening.

To be useful, the bin fronts must be easily installed and removed. This requirement can present a problem when wide spans and high piles are combined in the bin-front design, for heavy materials must then be used for strength. If bin-filling equipment is present in the area where the bin fronts are to be installed, the difficulties of installing and removing the fronts will be aggravated. During potato storage, the bin fronts may become jammed or misalined, causing difficulty during bin opening. However, much of this difficulty can be resolved by proper design of appurtenances such as breakouts (appendages for opening the lower front panels during unloading), anchor plates, and wall attachments. Clearances must be such as to allow a certain amount of movement of the individual panels of the front while proper alinement is maintained by the other front components.

Ultimately, all or part of the pressure resisted by the bin front is transferred to the bin walls or posts. Accordingly, these units require careful design. The prime consideration in regard to these parts is resistance to bending and horizontal shear. The problems of design are similar to those of the individual panels—that is, a beam is resisting a load. However, the load distribution on the post is not uniform but tends to follow a curve, from a minimum load at the top of the potato pile to a maximum load near the floor.

The loading on the posts and walls must be resisted at the floor, ceiling, and any cross-bracing points. Anchors at these points must be able to resist the loading.

Potato storages require high relative humidities. High humidity may tend to weaken fiber strength in certain species of lumber. If glue is used, it should be a type that will maintain its bond in humid environments; thus, bonded plywood should be of an exterior grade when used in potato storages, whether for bin fronts or for other structural members.

Finally, bin-front design involves consideration of economic factors. The design should keep material costs and fabrication costs to a minimum. The use of standard types and sizes of materials provides for construction of the panels without special tools, techniques, or personnel.

Obtaining Efficient Section Modulus[2] for High-Strength Requirements

In the design of long-span bin fronts, straight panels such as wood 2 by 12's and 3 by 12's with the 12-inch side vertical do not have adequate strength to resist the high bending moment. For a narrow bin with a 10-foot span and a 16-foot pile depth, the lower panel would be required to have a resisting moment of 16,200 inch-pounds, as shown in the following equations[3]:

$$\text{Maximum moment} = \frac{WL^2}{8} = \frac{(108)\,(10)^2}{8} = 1{,}350 \text{ ft.-lb. or } 16{,}200 \text{ in.-lb.}$$

The resisting moment of a dressed 2- by 12-inch stress grade plank is only 6,469 in.-lb.

$$Mr = \frac{SI}{c} = \frac{Sbd^3}{12c} = \frac{(1{,}500)\,(11.5)\,(1.5)^3}{(12)\,(0.75)} = 6{,}469 \text{ in.-lb.}$$

[2] Section modulus is the quantity $\frac{I}{c}$ (see appendix, p. 29); it is the basis for comparing strengths of sections of different sizes and shapes.

[3] The symbols used in the equations are defined in the appendix, pp. 29–31.

This strength is not adequate to resist the pile pressure across a 10-foot span. Therefore, a 3- by 12-inch plank will be needed for the bottom panel. The dressed 3- by 12-inch panel has a resisting moment of 17,969 in.-lb.

$$Mr = \frac{Sbd^3}{12c} = \frac{(1{,}500)\ (11.5)\ (2.5)}{(12)\ (1.25)} = 17{,}969 \text{ in.-lb.}$$

If the span were increased to 20 feet (putting it in the classsification of a long-span panel), the required resisting moment would be 64,800 in.-lb.

$$\text{Maximum moment} = \frac{WL^2}{8} = \frac{(108)\ (20)^2}{8} = 5{,}400 \text{ ft.-lb. or } 64{,}800 \text{ in.-lb.}$$

The section modulus must be altered to increase the panels' strength. A T-section bin front constructed from a 2- by 12-inch flange and a 2- by 4-, 6-, 8-, 10-, or 12-inch web will greatly increase the strength of the front. This concept is used in the glued-tee panel described under the section "Experimental Fronts," pages 12–22.

If 2- by 12-inch lumber is placed with the 12-inch side in a horizontal plane, the advantage of increased section modulus is obtained. This arrangement of panels is also discussed under the section "Experimental Fronts."

Other Factors in Bin-Front Design

While the researchers were designing, evaluating, and testing the various types of bin fronts, certain factors applicable to bin fronting in general were noted. Vertical pressure on bin fronts caused by wall friction and pile settling can be less of a load factor if the entire bin front slopes slightly toward the pile from bottom to top. This finding is especially pertinent for the slotted front, where a slope of one-half inch per foot of bin-front height is helpful. The required slope can be acquired if the wall attachments are arranged so that each panel is extended into the bin one-half inch farther than the panel immediately below it. The panels should remain level, however. A certain amount of horizontal pressure is avoided, also, when bin fronts slope toward the pile.

If it is to resist the potato pile's pressure, shifting, and settling, the front's design must be a sturdy one. The bin-front panels, though designed as individual units, act somewhat as an integral unit, and a weak panel can cause an adjacent one to become overloaded.

Durability of the material used in the front is also a factor. The units are often roughly handled in practice and must be capable of long service under such treatment.

EXPERIMENTAL FRONTS

Glued-Tee Bin Fronts

Description of the Design

Analyses of tee panels as a means of spanning wide bins were begun at the Potato Research Center during the summer of 1964.

Initial calculations (shown in the appendix) indicated that a tee panel made up of a 2- by 12-inch flange and a 2- by 4-, 6-, 8-, 10-, or 12-inch web of construction-grade lumber could provide the required strength in bending, vertical shear, and deflection. However, the neutral axis of each panel lies very close to the junction of the web and flange forming the tee. Thus, a situation is created whereby the greatest horizontal shear occurs near the location of the least resistance to that shear. This situation is especially true with the smaller web sizes. Excessive bulging of these tee panels could be expected unless an attachment mechanism other than the usual clamping were used to secure the web to the flange. Figure 11*A* illustrates such bulging of a clamped tee panel. The researchers discarded the technique of drilling through the web and clamping it to the flange because this technique weakened the section. Gluing as a method of attachment was selected and tested. The web was attached to the flange in the manner shown in figure 11*B*, with glue placed at the area of contact, and the two units were drawn together with common nails. Resorcinol-resin glue was used to provide resistance to moisture

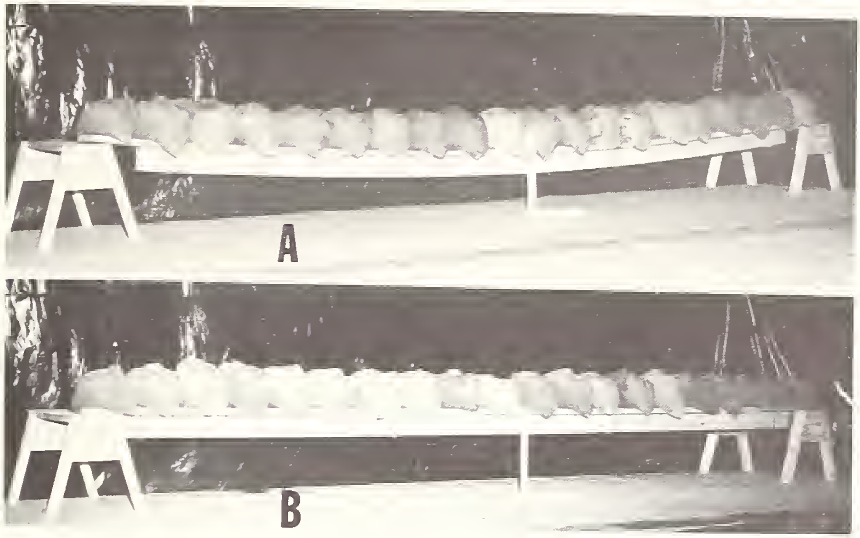

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FIGURE 11.—*A*, Excessive bulging occurred when 20-foot-long clamped tee panel was subjected to load in simulated bin-front test. *B*, Little bulging was evident when glued-tee panel of same length was similarly tested.

(potato-storage atmospheres often have relative humidities greater than 90 percent). The glue was in liquid form, but was accompanied with a dry powder catalyst that was added at the time the glue was mixed. (The instructions for gluing must be followed exactly to obtain a good bond.)

The glued-tee front was then tested under simulated loads. Figure 11*B* shows the glue resisting the slipping that occurred between the web and the flange when the clamps alone were used as the attachments.

The need for the clamps was evaluated during the loading tests. It was determined that the clamps were not essential to the attachment of the section; the glue alone was sufficient. However, later tests in actual storage conditions indicated the need for a clamp at each end of the web to limit the advancement of cracks near the end of the web.

The nails do not add to the strength of the unit in any practical amount; should the glue fail, they will either be retracted from the web or drawn through the flange. The sole purpose of the nails is to draw the web and flange together during gluing so that a firm bond will be obtained.

Selection of Material Sizes

Choice of material sizes was based on potato-pile pressure, resistance imparted by the wood, area of glue per nail, and component-part sizes.

Figure 10 illustrates the potato-pile pressures exerted at the various levels. These data were used as a basis for determining the correct tee sizes, as shown in figure 12. The calculations used in determining tee sizes are shown in the appendix. Figure 12 is a selection chart that includes the factors affecting tee size. The individual panel sizes were checked mathematically for resistance offered in pounds per square foot in bending, horizontal shear, vertical shear, and deflection. Minimum values were then plotted for lengths of front ranging from 11 feet to 24 feet. To select proper web sizes, the chart's user first finds the desired length of bin front and the pile depth. For example, a bin is 60 feet long, 30 feet wide, the panels are to be 20 feet long, and pile depth is expected to be 16 feet. What glued-tee sizes will resist the pile pressure? To obtain this information, the user reads up to find that two tees with 2- by 12-inch webs; five tees with 2- by 10-inch webs; four tees with 2- by 8-inch webs; three tees with 2- by 6-inch webs; and three tees with 2- by 4-inch webs are

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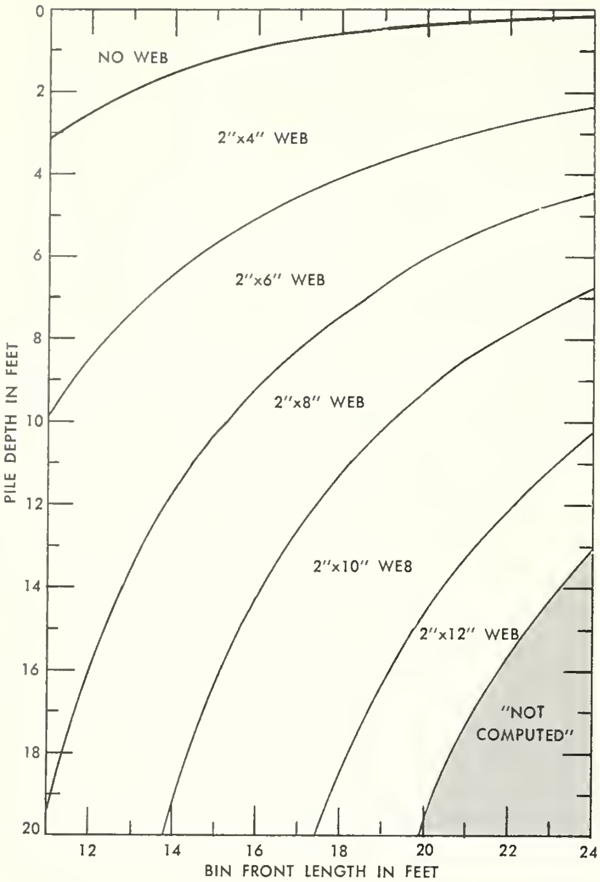

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FIGURE 12.—Selection chart shows suitable web sizes for glued-tee panels used to strengthen wide-span bin fronts in potato storages.

needed. The tee-size selection curves are based on bins that are wider and longer than deep. They can, however, be used for bins that are narrower or shorter than deep. In such a case, certain tee sizes indicated on the chart may be slightly larger than necessary.

The choice of nail size depends on the glued area. This area is a constant per nail for all of the web sizes. Sixteen-penny (16d) common nails were found to be adequate.

The bolt length for the clamps will vary with the size of the web used.

Glued-tee panels were constructed and installed in the Potato Research Center bins for the 1964–65 storage season (fig. 13). They have performed well for four storage seasons. During these storage periods, the need for clamps was further evaluated. The possibility of cracks advancing along the web to cause a failure in horizontal shear was noted, and clamping the web at each end was deemed advisable.

The glued-tee panel finally accepted is illustrated in figure 14.

Costs

Estimates of costs for the various sizes of tee panels were made. Table 2 gives the breakdown of cost factors and total cost for each panel for widths ranging from 15 to 24 feet. The appendix gives the factors used in estimating costs for the bin fronts. These costs do not include the retainer cleats at the wall and post anchors.

Slotted Bin Fronts

Initial work on a slotted bin front at the Potato Research Center began in 1964 with the installation of two small test panels in bulk storage bins. The objectives in designing such a front were to obtain the best use of material cross section for resisting the horizontal pressure that is encountered in bulk potato piles, and to avoid encountering this pressure by reducing the bin-front surface facing the bulk piles. The actual pressure encountered at each panel of the bin front could not be determined without resorting to pressure transducers and related instrumentation; however, the test panels indicated that the design had merit.

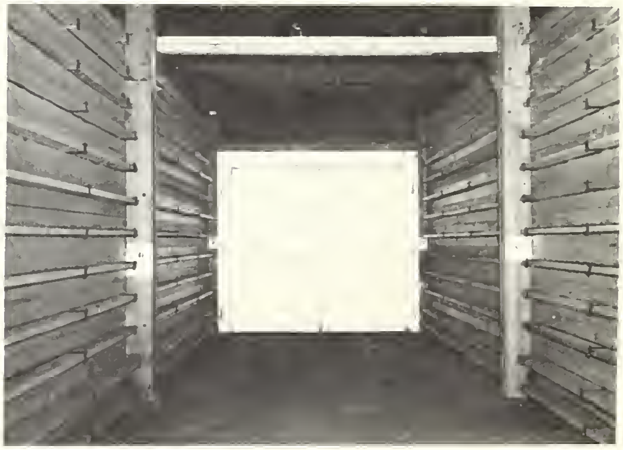

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FIGURE 13.—Glued-tee type of bin front constructed at USDA Potato Research Center.

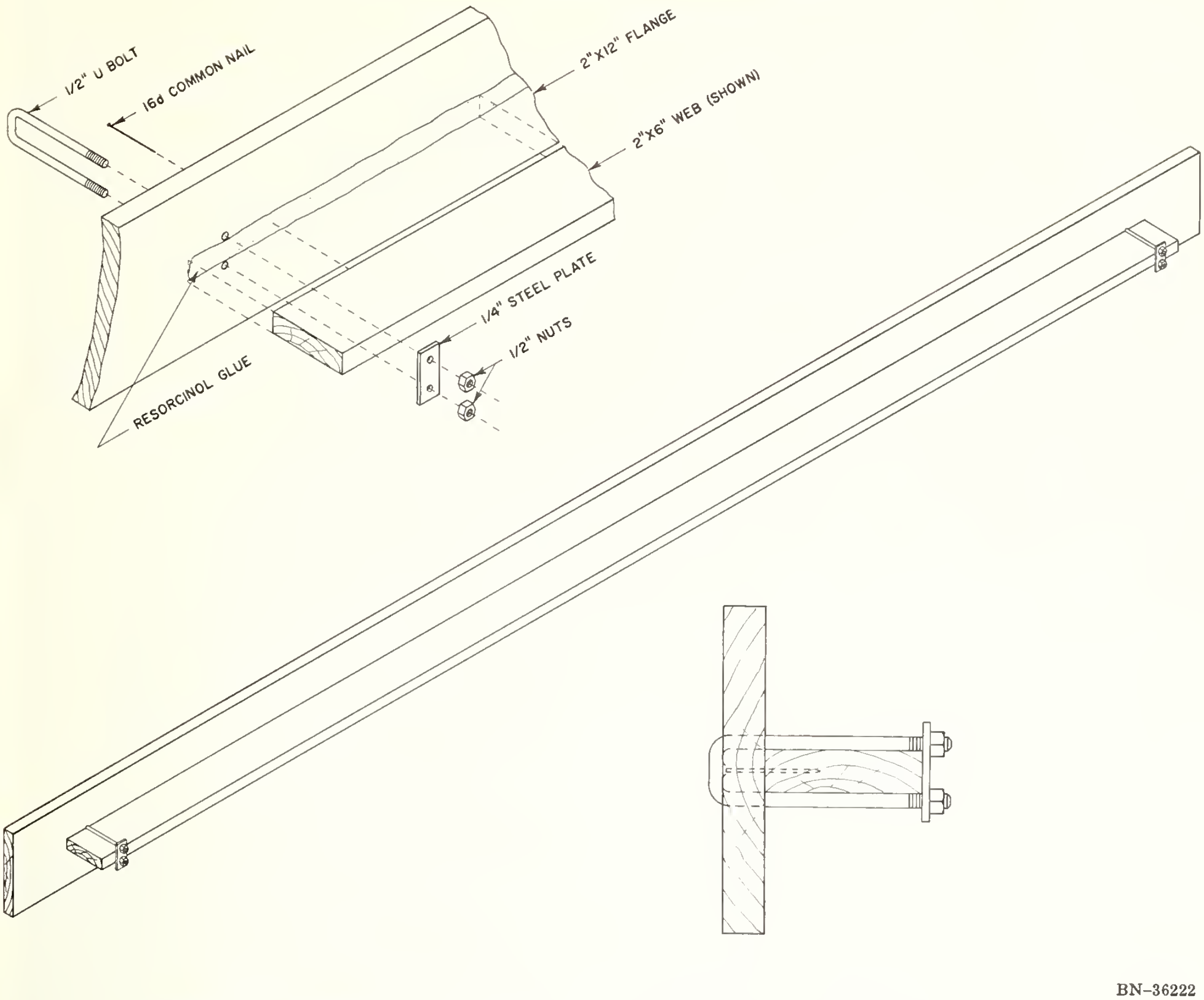

FIGURE 14.—Details of glued-tee panel developed by USDA Potato Research Center.

TABLE 2.—*Costs for 10 sizes of glued-tee panels*

Size of panel	Cost of panel parts in dollars							
	Flange	Web	Glue	Nails	Bolts	Steel	Labor	Total
2 in. by 12 in. by 15 ft. flange with:								
2 in. by 4 in. by 14 ft. web	5.25	1.54	0.33	0.05	0.54	0.08	0.50	8.29
2 in. by 6 in. by 14 ft. web	5.25	2.31	.33	.05	.70	.08	.50	9.22
2 in. by 8 in. by 14 ft. web	5.25	3.08	.33	.05	.88	.08	.50	10.17
2 in. by 10 in. by 14 ft. web	5.25	4.08	.33	.05	1.00	.08	.50	11.29
2 in. by 12 in. by 16 ft. flange with:								
2 in. by 4 in. by 15 ft. web	5.60	1.65	.35	.05	.54	.08	.50	8.77
2 in. by 6 in. by 15 ft. web	5.60	2.48	.35	.05	.70	.08	.50	9.76
2 in. by 8 in. by 15 ft. web	5.60	3.30	.35	.05	.88	.08	.50	10.76
2 in. by 10 in. by 15 ft. web	5.60	4.38	.35	.05	1.00	.08	.50	11.96

TABLE 2.—*Cost for 10 sizes of glued-tee panels*—Continued

Size of panel	Cost of panel parts in dollars							
	Flange	Web	Glue	Nails	Bolts	Steel	Labor	Total
2 in. by 12 in. by 17 ft. flange with:								
2 in. by 4 in. by 16 ft. web	5.95	1.76	.38	.05	.54	.08	.50	9.26
2 in. by 6 in. by 16 ft. web	5.95	2.64	.38	.05	.70	.08	.50	10.30
2 in. by 8 in. by 16 ft. web	5.95	3.52	.38	.05	.88	.08	.50	11.36
2 in. by 10 in. by 16 ft. web	5.95	4.67	.38	.05	1.00	.08	.50	12.63
2 in. by 12 in. by 18 ft. flange with:								
2 in. by 4 in. by 17 ft. web	6.30	1.87	.40	.06	.54	.08	.50	9.75
2 in. by 6 in. by 17 ft. web	6.30	2.80	.40	.06	.70	.08	.50	10.84
2 in. by 8 in. by 17 ft. web	6.30	3.74	.40	.06	.88	.08	.50	11.96
2 in. by 10 in. by 17 ft. web	6.30	4.96	.40	.06	1.00	.08	.50	13.30
2 in. by 12 in. by 19 ft. flange with:								
2 in. by 4 in. by 18 ft. web	6.65	1.98	.42	.06	.54	.08	.50	10.23
2 in. by 6 in. by 18 ft. web	6.65	2.97	.42	.06	.70	.08	.50	11.38
2 in. by 8 in. by 18 ft. web	6.65	3.96	.42	.06	.88	.08	.50	12.55
2 in. by 10 in. by 18 ft. web	6.65	5.25	.42	.06	1.00	.08	.50	13.96
2 in. by 12 in. by 18 ft. web	6.65	6.20	.42	.06	1.26	.08	.50	15.17
2 in. by 12 in. by 20 ft. flange with:								
2 in. by 4 in. by 19 ft. web	7.00	2.09	.45	.06	.54	.08	.50	10.72
2 in. by 6 in. by 19 ft. web	7.00	3.14	.45	.06	.70	.08	.50	11.93
2 in. by 8 in. by 19 ft. web	7.00	4.18	.45	.06	.88	.08	.50	13.15
2 in. by 10 in. by 19 ft. web	7.00	5.54	.45	.06	1.00	.08	.50	15.17
2 in. by 12 in. by 19 ft. web	7.00	6.65	.45	.06	1.26	.08	.50	16.00
2 in. by 12 in. by 21 ft. flange with:								
2 in. by 4 in. by 20 ft. web	7.77	2.33	.47	.07	.54	.08	.50	11.76
2 in. by 6 in. by 20 ft. web	7.77	3.50	.47	.07	.70	.08	.50	13.09
2 in. by 8 in. by 20 ft. web	7.77	4.67	.47	.07	.88	.08	.50	14.44
2 in. by 10 in. by 20 ft. web	7.77	6.17	.47	.07	1.00	.08	.50	16.06
2 in. by 12 in. by 20 ft. web	7.77	7.40	.47	.07	1.26	.08	.50	17.55
2 in. by 12 in. by 22 ft. flange with:								
2 in. by 4 in. by 21 ft. web	8.14	2.45	.50	.07	.54	.08	.50	12.28
2 in. by 6 in. by 21 ft. web	8.14	3.68	.50	.07	.70	.08	.50	13.67
2 in. by 8 in. by 21 ft. web	8.14	4.90	.50	.07	.88	.08	.50	15.07
2 in. by 10 in. by 21 ft. web	8.14	6.48	.50	.07	1.00	.08	.50	16.77
2 in. by 12 in. by 21 ft. web	8.14	7.77	.50	.07	1.26	.08	.50	18.32
2 in. by 12 in. by 23 ft. flange with:								
2 in. by 4 in. by 22 ft. web	8.51	2.57	.52	.07	.54	.08	.50	12.79
2 in. by 6 in. by 22 ft. web	8.51	3.85	.52	.07	.70	.08	.50	14.23
2 in. by 8 in. by 22 ft. web	8.51	5.13	.52	.07	.88	.08	.50	15.69
2 in. by 10 in. by 22 ft. web	8.51	6.78	.52	.07	1.00	.08	.50	17.46
2 in. by 12 in. by 22 ft. web	8.51	8.14	.52	.07	1.26	.08	.50	19.08
2 in. by 12 in. by 24 ft. flange with:								
2 in. by 4 in. by 23 ft. web	8.88	2.68	.52	0.08	0.54	0.08	0.50	13.28
2 in. by 6 in. by 23 ft. web	8.88	4.02	.52	.08	.70	.08	.50	14.78
2 in. by 8 in. by 23 ft. web	8.88	5.37	.52	.08	.88	.08	.50	16.31
2 in. by 10 in. by 23 ft. web	8.88	7.09	.52	.08	1.00	.08	.50	18.15
2 in. by 12 in. by 23 ft. web	8.88	8.51	.52	.08	1.26	.08	.50	19.83

Description of the Design

Figure 15 illustrates the slotted bin front using 2- by 12-inch lumber as the basic panel in each unit of the front. The basic design uses a shelf arrangement of the main panels, which are held apart by spacers. As the bin is filled, the bulk potatoes move into the slot spaces and onto the horizontal shelf panels that form the lower components of the front's panel units. Small potato semipiles are formed as the potatoes come to rest in each slot at a natural angle of repose. Once at rest, these potatoes no longer exert horizontal pressure against the fronts. A vertical lip or retainer is attached to the outer edge of each shelf panel to prevent spillout as the potatoes enter the slot apertures during filling. If there is a need for closing the bins completely, the retainers can serve this purpose also. Spacers keep the panel units separated and transfer part of the weight of panels and potatoes to the floor. The attachments at the wall of the bins serve to space the panels and transfer weight as well as to retain the panels against the bulk pile pressure.

Variations of the design were tried during successive storage seasons at the Potato Research Center. Commercial installations of the slotted type of bin were also evaluated.

Figure 16 shows a commercial installation of the slotted fronts with complete closure of the apertures by the spillout retainers. Correct spacing and panel sizes were evaluated. From these tests and others in commercial storages, the most practical designs were chosen. Figures 17, 18, and 19 show the basic 2-inch by 12-inch by 20-foot shelf panel with 3- by 12-inch spacers and three different variations of spillout retainers. Each figure represents one complete panel unit, shows a cross-section end-view, and illustrates the assembly in an exploded view. The simplest slotted-front unit is shown in figure 17. The retainer consists of a 1- by 6-inch board nailed to the edge of the 2- by 12-inch shelf panel. This unit will retain most of the potatoes when the bin is filled. A few potatoes that roll down the face of the pile during filling will move through the openings, but this spillage is generally minor. Wider sizes of the retainer can be used to reduce the aperture if desired. The attachment is the same for the wider retainer as for the narrower version shown in figure 17.

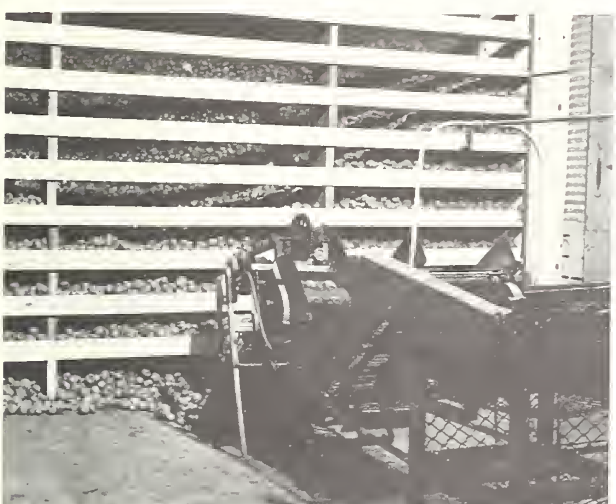

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FIGURE 15.—Slotted potato-bin front used in a commercial storage. The slot apertures have been left open in this front.

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FIGURE 16.—Slotted potato-bin front with the slot apertures completely closed by retaining panels. A slotted bin front with open apertures is shown in figure 15.

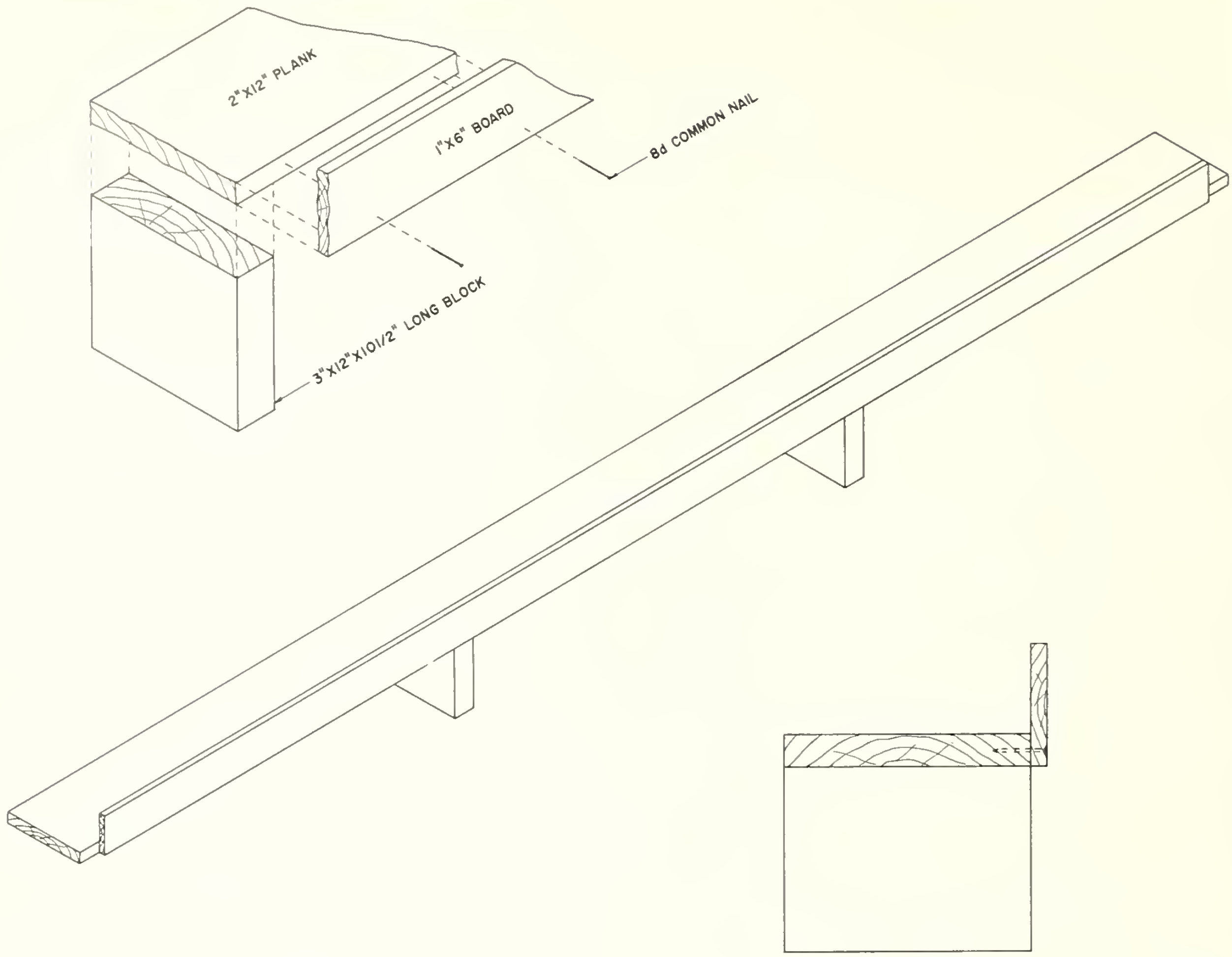

FIGURE 17.—Panel with rigid retainer designed for slotted potato-bin front.

Figure 18 shows a folding version of the slotted-front unit. Illustrated is a 1- by 4-inch board divided at the center and hinged. The retainer is divided into two sections, each of which is attached to the basic panel with a strap hinge. The sections swing up into service position. One-quarter-inch plywood strips are spaced along the top surface of the shelf panel to facilitate stacking, protect the hinges, and act as guides for inserting the spacers. Again, wider versions of the retainer board can be used. Figure 15 shows this type of retainer being used during a commercial scale test of a slotted front.

A third type of retainer, also hinged, is shown in figure 19. The main purposes of this arrangement are to completely close the bins and to provide clearing of the shelf panels as the bin is emptied. Good stacking during nonuse periods is also provided. This design also uses plywood strips to protect the hinges, provide for a square stacking pattern, and guide the spacer placement. The 1- by 10-inch retainer is attached beneath the shelf's outer edge. It swings down into service position and fits behind a 1- by 2¼-inch bumper (cut from 1- by 10-inch material) attached to the outer edge of the shelf below. The bumpers provide the retainers with the strength needed to hold the potatoes in the apertures. The retainer is divided into three separate sections. A canvas or polyethylene sheet is attached to the edge of each retainer

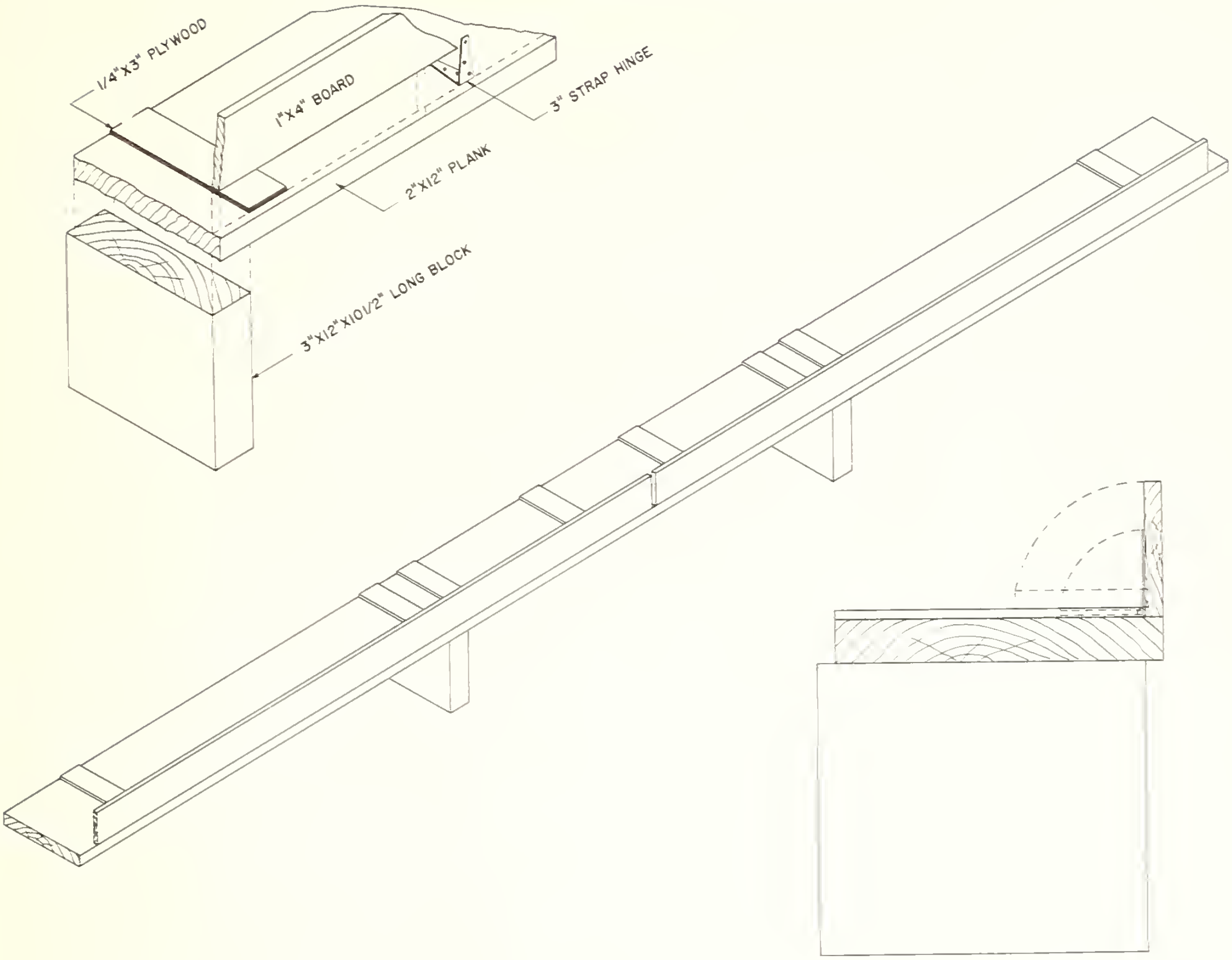

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FIGURE 18.—Panel with folding retainer designed for slotted potato-bin front.

section, as shown in figure 19. The potatoes on each shelf rest on the sheet attached to the panel unit above. With this arrangement, the potatoes that remain on the shelf panels during emptying of the bin are easily removed by simply pushing the folding retainer sections inward. Thus, the polyethylene sheet provides for complete removal of the potatoes in the aperture. With the other types of retainers, the potatoes remaining on the panels during unloading of the bin must be removed by hand.

Figure 20 illustrates the methods of storing the three types of slotted-front panel units. With the solidly attached retainer, the spacer blocks help form a square pile. When hinged retainers are used, the spacer blocks are piled separately. If the polyethylene sheets are attached, the sheets are placed so as to be protected between the retainer and the panel during nonuse.

Cost Estimates

Costs were estimated for the various sizes and types of panels. Table 3 gives the cost factors and total costs. The appendix gives the factors used in estimating costs for the panels. The attachments at the bin walls are not included in these costs. These attachments must be adapted to the individual storage wall and are generally not uniform in type and cost from storage to storage.

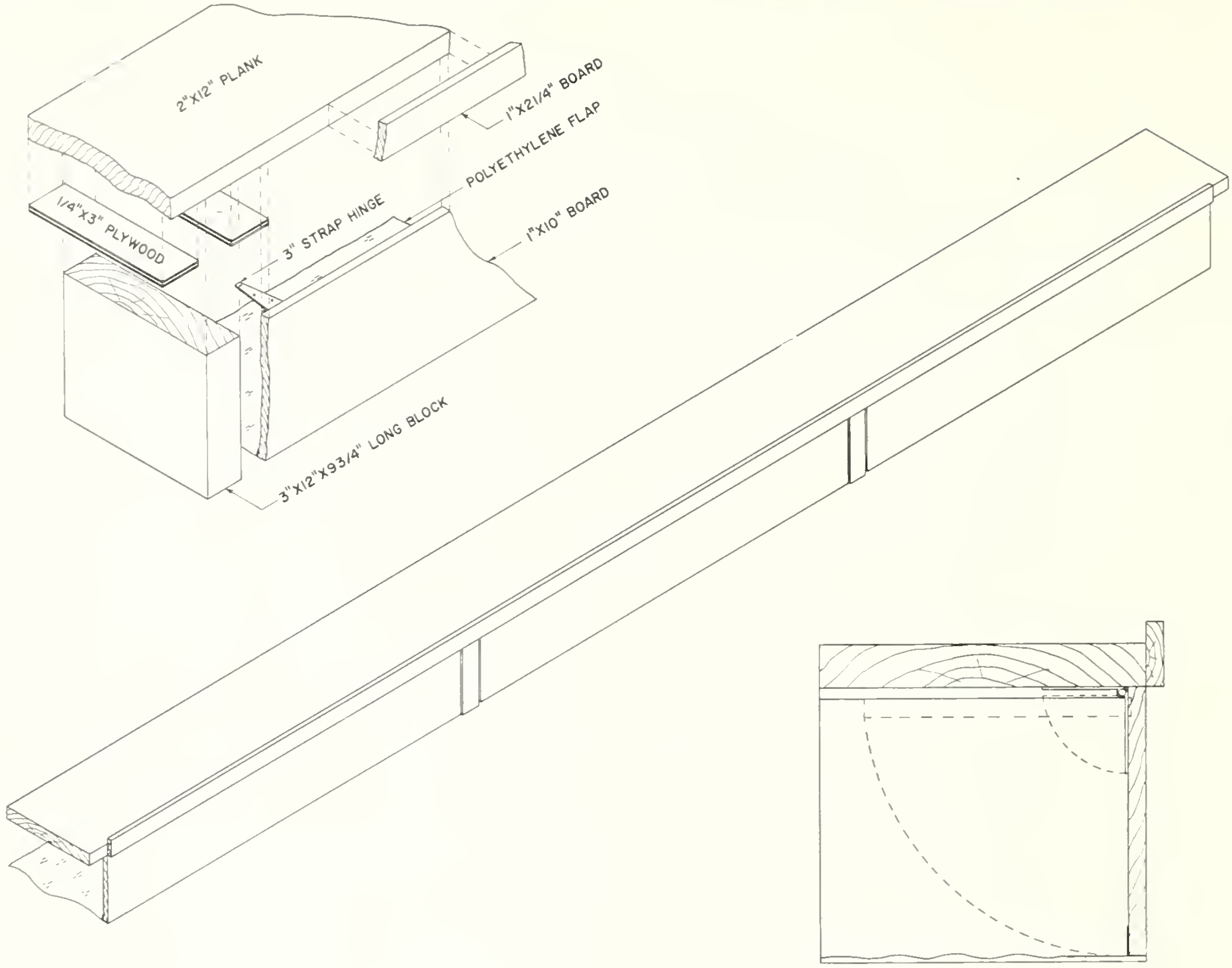

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FIGURE 19.—Panel designed with folding retainer has polyethylene sheet attached to facilitate removal of potatoes from slotted bin front.

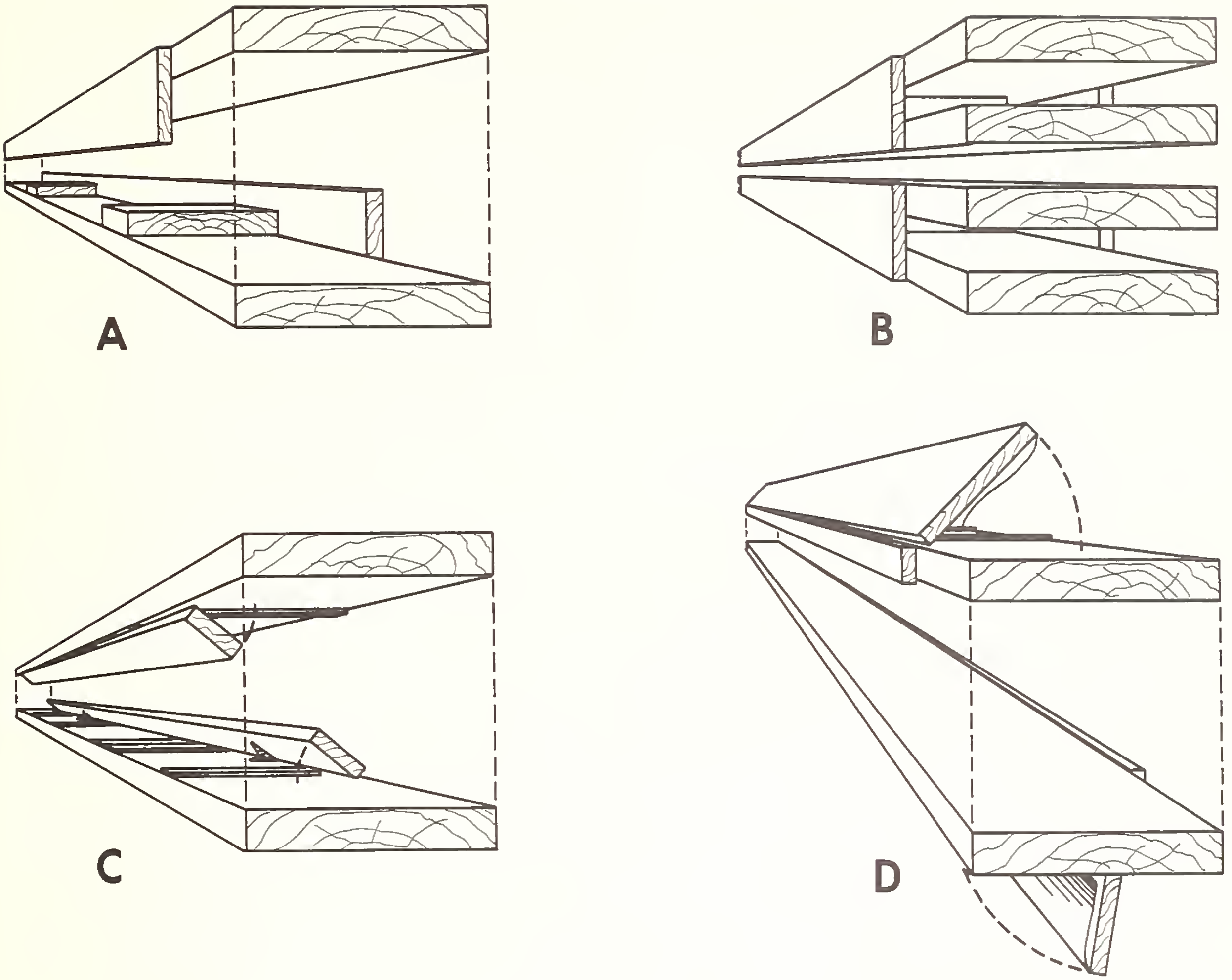

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FIGURE 20.—Methods of stacking panel units during nonuse periods. *A*, Spacer blocks help to support alternately positioned rigid retainers so that a square stacking pattern (*B*) is formed. *C*, Hinged retainers are also alternately positioned and are compactly folded after spacer blocks have been removed for separate storage. *D*, If the hinged retainers have polyethylene sheets attached, the sheets are protected between the folded retainer and basic panel during storage.

TABLE 3.—*Costs for 10 sizes and types of slotted bin-front panel units*

Size of panel and type of retainer	Cost of panel parts in dollars							
	2- by 12-in. panel	3- by 12-in. spacers	Retainer	Bumper	Hinges and nails	Plywood and poly-ethylene sheet	Labor	Total
Panel 15 ft. long with:								
Rigid retainer (1 by 6 in.)	4.80	[1] 0.54	1.23	-------	0.02	-------	0.35	6.94
Folding retainer (1 by 6 in.)	4.80	[1] .54	1.23	-------	.80	0.15	.50	8.02
Folding retainer (1 by 10 in.)	4.80	[1] .54	2.14	0.54	.82	.36	1.16	10.36
Panel 16 ft. long with:								
Rigid retainer (1 by 6 in.)	5.12	[1] 0.54	1.32	-------	0.03	-------	0.35	7.36
Folding retainer (1 by 6 in)	5.12	[1] .54	1.32	-------	.80	.15	.50	8.43
Folding retainer (1 by 10 in.)	5.12	[1] .54	2.29	.57	.83	.38	1.16	10.89
Panel 17 ft. long with:								
Rigid retainer (1 by 6 in.)	5.44	1.08	1.40	-------	.03	-------	.35	8.30
Folding retainer (1 by 6 in.)	5.44	1.08	1.40	-------	1.20	.15	.84	10.11
Folding retainer (1 by 10 in.)	5.44	1.08	2.40	.60	1.23	.39	1.50	12.64
Panel 18 ft. long with:								
Rigid retainer (1 by 6 in.)	5.76	1.08	1.49	-------	.03	-------	.35	8.71
Folding retainer (1 by 6 in.)	5.76	1.08	1.49	-------	1.20	.15	.84	10.52
Folding retainer (1 by 10 in.)	5.76	1.08	2.55	.64	1.23	.40	1.50	13.16
Panel 19 ft. long with:								
Rigid retainer (1 by 6 in.)	6.08	1.08	1.57	-------	.03	-------	.35	9.11
Folding retainer (1 by 6 in.)	6.08	1.08	1.57	-------	1.20	.15	.84	10.92
Folding retainer (1 by 10 in.)	6.08	1.08	2.70	.68	1.23	.42	1.50	13.69
Panel 20 ft. long with:								
Rigid retainer (1 by 6 in.)	6.40	1.08	1.66	-------	.03	-------	.35	9.52
Folding retainer (1 by 6 in.)	6.40	1.08	1.66	-------	1.20	.22	.84	11.40
Folding retainer (1 by 10 in.)	6.40	1.08	2.85	.71	1.23	.50	1.50	14.27
Panel 21 ft. long with:								
Rigid retainer (1 by 6 in.)	7.14	1.08	1.74	-------	.03	-------	.35	10.34
Folding retainer (1 by 6 in.)	7.14	1.08	1.74	-------	1.20	.22	.84	12.22
Folding retainer (1 by 10 in.)	7.14	1.08	3.00	.75	1.23	.52	1.50	15.22
Panel 22 ft. long with:								
Rigid retainer (1 by 6 in.)	7.48	1.08	1.83	-------	.03	-------	.35	10.77
Folding retainer (1 by 6 in.)	7.48	1.08	1.83	-------	1.20	.22	.84	12.65
Folding retainer (1 by 10 in.)	7.48	1.08	3.15	.79	1.23	.53	1.50	15.76
Panel 23 ft. long with:								
Rigid retainer (1 by 6 in.)	7.82	1.08	1.91	-------	.04	-------	.35	11.20
Folding retainer (1 by 6 in.)	7.82	1.08	1.91	-------	1.20	.22	.84	13.07
Folding retainer (1 by 10 in.)	7.82	1.08	3.30	.82	1.24	.55	1.50	16.31
Panel 24 ft. long with:								
Rigid retainer (1 by 6 in.)	8.16	1.08	2.00	-------	.04	-------	.35	11.63
Folding retainer (1 by 6 in.)	8.16	1.08	2.00	-------	1.20	.22	.84	13.50
Folding retainer (1 by 10 in.)	8.16	1.08	3.45	.86	1.24	.56	1.50	16.85

[1] Only one column of spacers was used for a bin this width.

EVALUATIONS OF OTHER BIN FRONTS

The experimental bin fronts described in the preceding section were designs that appeared to meet the requirements of strength, weight, convenience in storing, and economy. Other configurations were considered, however, and some were actually tested before being rejected as unsuitable. These were basically modifications of the slotted design. The types considered were: (1) Metal panels and spacers hinged in a Dutch-door arrangement; (2) arched panels; (3) temporarily spliced panels; and (4) fiber glass panel-retainers. A modified removable post design was evaluated also.

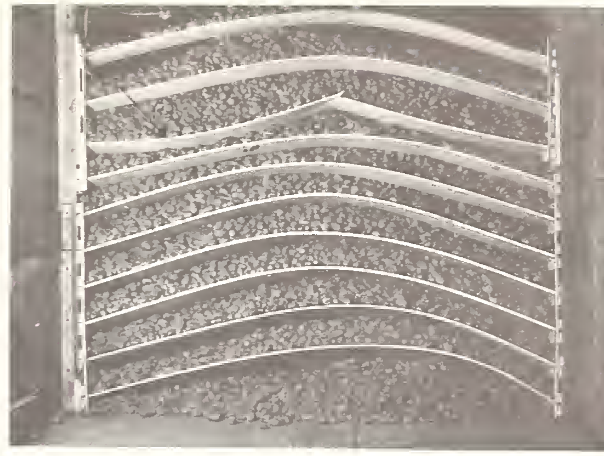

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FIGURE 21.—Experimental slotted potato-bin front with arched panels. One panel (arrow) broke when bin was filled.

Metal-Panel Dutch Door

The metal Dutch-door slotted front was not satisfactory when tested in a commercial storage. The vertical movement of the potato pile when it settled tended to bend the panels. Horizontal pressure of the pile caused bulging of the door arrangement when the units were buckled together. This test (and that of the temporarily spliced wood panels described further in this section) emphasize the need for continuous, unjointed panels in slotted bin fronts.

Arched Panels

Arched 1- by 12-inch dressed lumber panels appeared to have merit for use in temporary bins with widths up to about 12 feet. These panels (fig. 21) use the strengthening features of the arch; thus, light material can carry the weight of the potatoes without the use of spacers. The material must be selected to withstand the bending required to form the arch.

The front shown in figure 21 had one cracked panel before the bin was filled. This panel failed, as shown in the illustration. Fairly uniform loading of the panels is required when the bin is filled. The panels tend to warp after being in the high-humidity atmosphere of a potato storage and will not readily straighten again after being removed from the storage.

Temporarily Spliced Panels

Dressed 2- by 12-inch lumber is not commonly available in lengths beyond 24 feet. Thus, an experiment in spanning fronts longer than 24 feet with slotted panel units involved splicing the main panels. To keep the panels short enough for easy handling, a temporary splice was adapted rather than a permanent one.

A temporary splice was used to adapt two 20-foot-long panels of 2- by 12-inch dressed lumber into one 40-foot-long panel. Figure 22 illustrates the splice. The arrangement of spacers along the panel was similar to that used for the experimental slotted fronts already described. The movable splice unit provided for easy installation of the fronts, but allowed excessive bulging of the entire bin front at the center. This test was made in an actual storage bin and again illustrates the need for using continuous panels in slotted bin fronts.

Fiber Glass Panel-Retainers

The use of fiber glass as a strong, light material for fronting bins was considered. A design using the geometry of the slotted bin front was considered. Figure 23 illustrates this concept. Such a design would provide lightness and convenience in storing, but the cost limited its application.

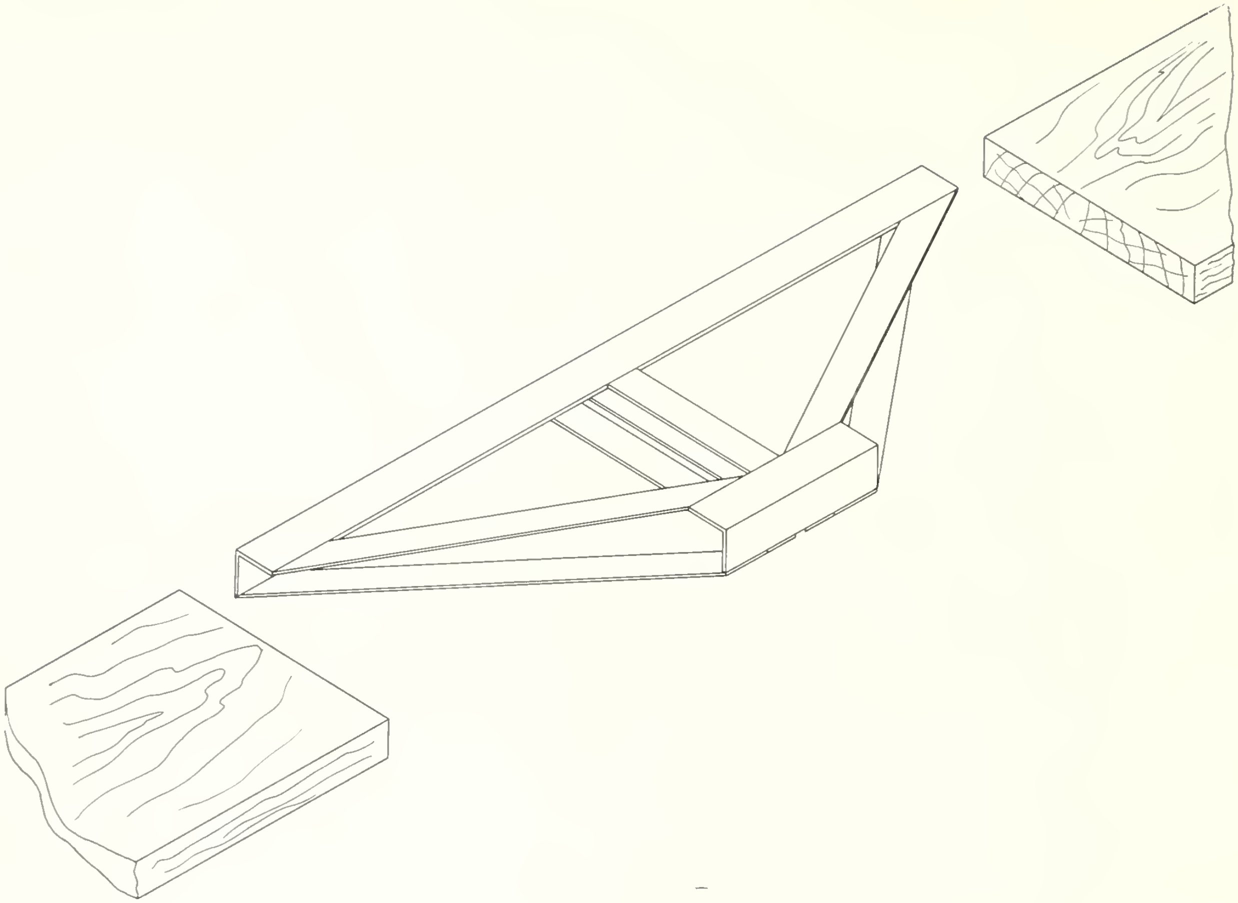

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FIGURE 22.—Configuration of temporary metal splice used to join slotted panel units in experimental potato-bin front designed for wide spans.

Modified Removable-Post Bin Front

The usual concept of a removable-post bin front is that of a removable vertical member extending from the floor to the ceiling and roughly dividing the span in half. A design for dividing the span with a modified version of the removable post was considered.

This design consists of two removable members angled from the floor to the wall posts to form a V. Two- by 12-inch lumber can then be used in the form of straight panels to close up the bin. The removable members provide the front with the additional required strength and divide the span so that each panel covers an area with dimensions commensurate with the change in pressure from the potato pile. With this design, straight panels without tees could be used to front a bin 16 feet wide and with a pile depth of 16 feet.

The primary purpose of the vee design, however, was to facilitate the filling operation. The design provides full access to all parts of the bin for filling without interference (even when the front is only partially installed) and does not restrict the side-to-side movement of the

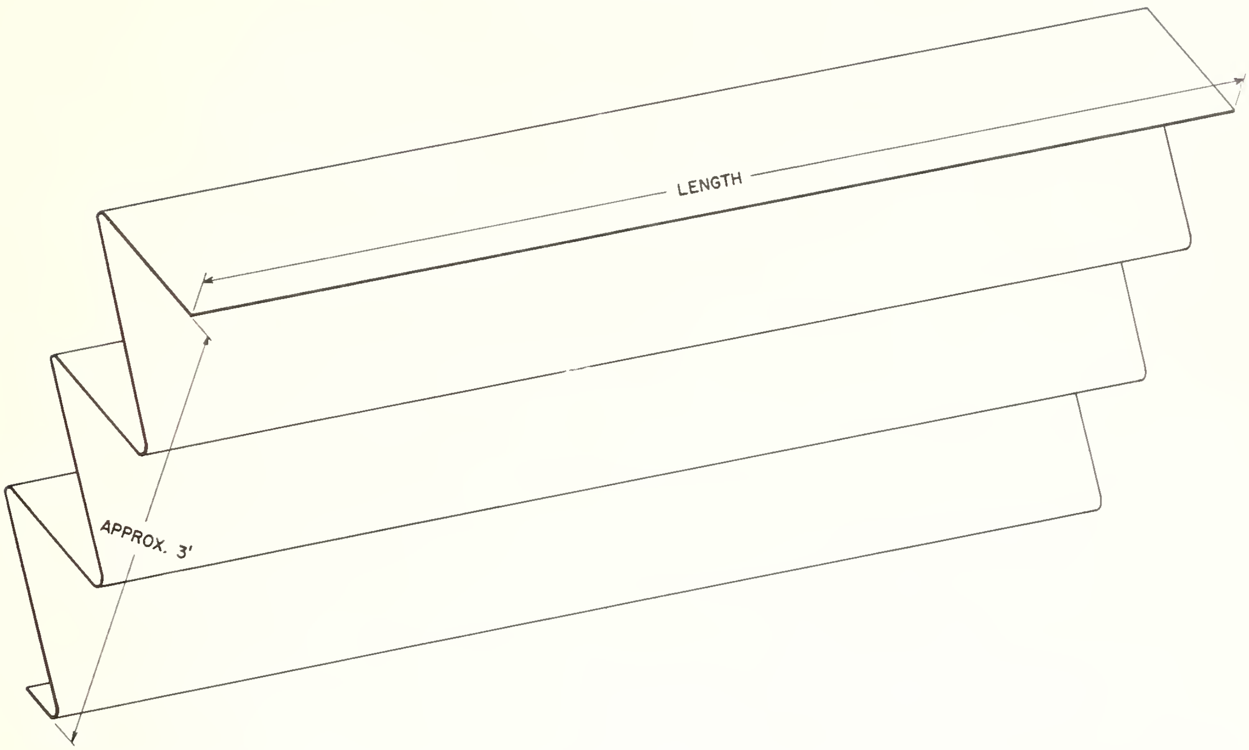

FIGURE 23.—Conceptual design for fiber glass bin front uses basic principles of slotted wood-panel front.

bin-filler boom. However, with this design, the distribution of the pressure on the panels requires that 6-inch steel beams (6-WF-25) be used as the angled vee members. This beam weight and size was thought to be too large to justify the use of the design.

STARTER SECTIONS

To initiate and regulate outflow when the potato bin is broached, potato handlers require an opening that will allow controlled removal. Accordingly, "starter" sections must be included in potato-bin front designs.

Starter sections for short spans can be relatively simple units, such as those shown in figure 24. Wide-span applications require more substantial units.

A starter section that can be used with the glued-tee bin front, shown in figure 25, includes the necessary anchoring plates and wall-attachment cleats. Inasmuch as tee panels cannot be altered for starting purposes without critically altering their strength, this "end-release" starter is suitable for the glued-tee front. An end-release starter has worked well in storage use at the Potato Research Center. For powered bulk scooping, the starter section should provide for removal of several panels. When the potatoes are hand forked or flumed from the bin, a single starter board is sufficient.

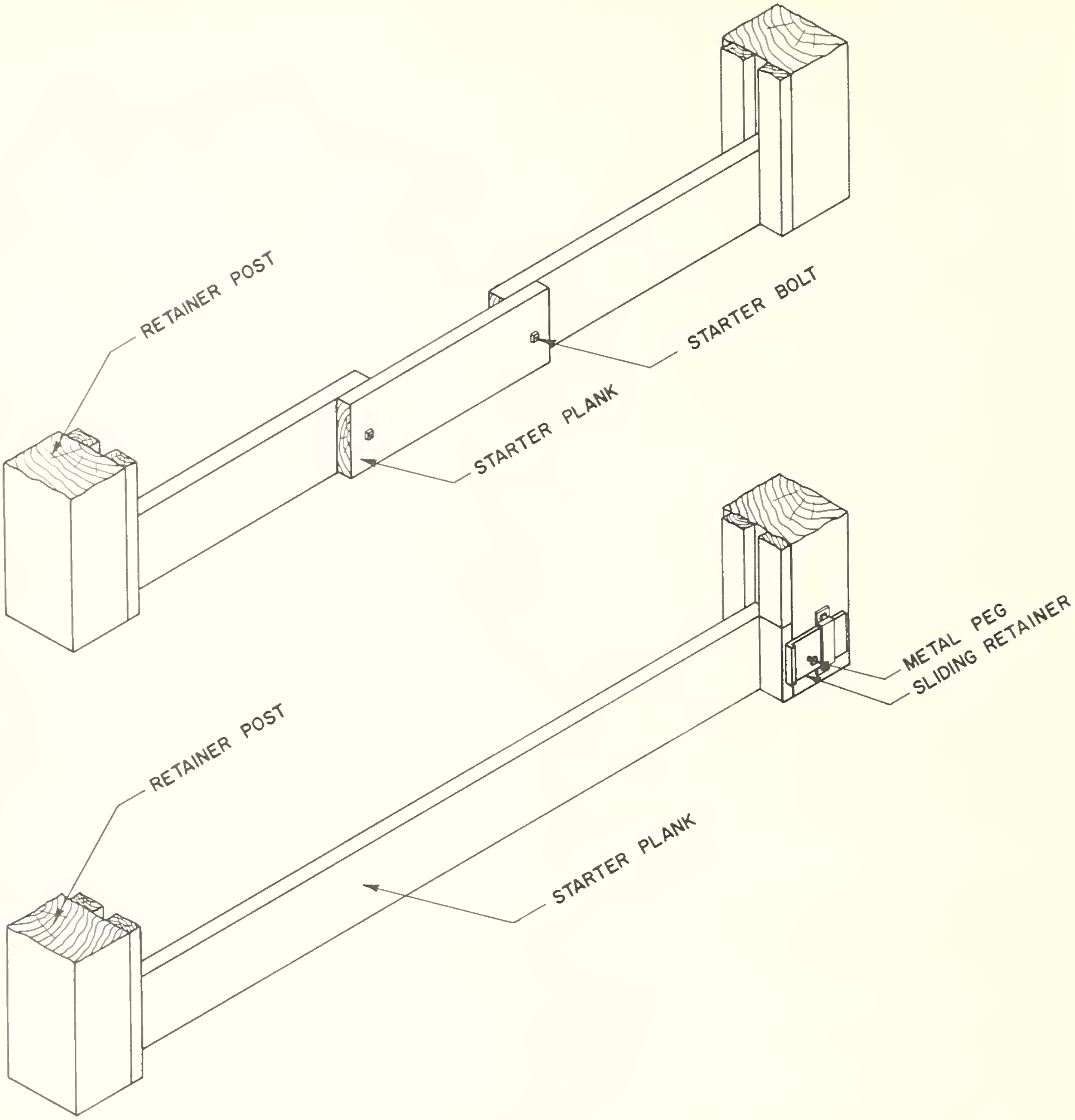

FIGURE 24.—When short-span bin fronts are used, potatoes can be released through starter panels with simple constructions, similar to those shown in the drawings.

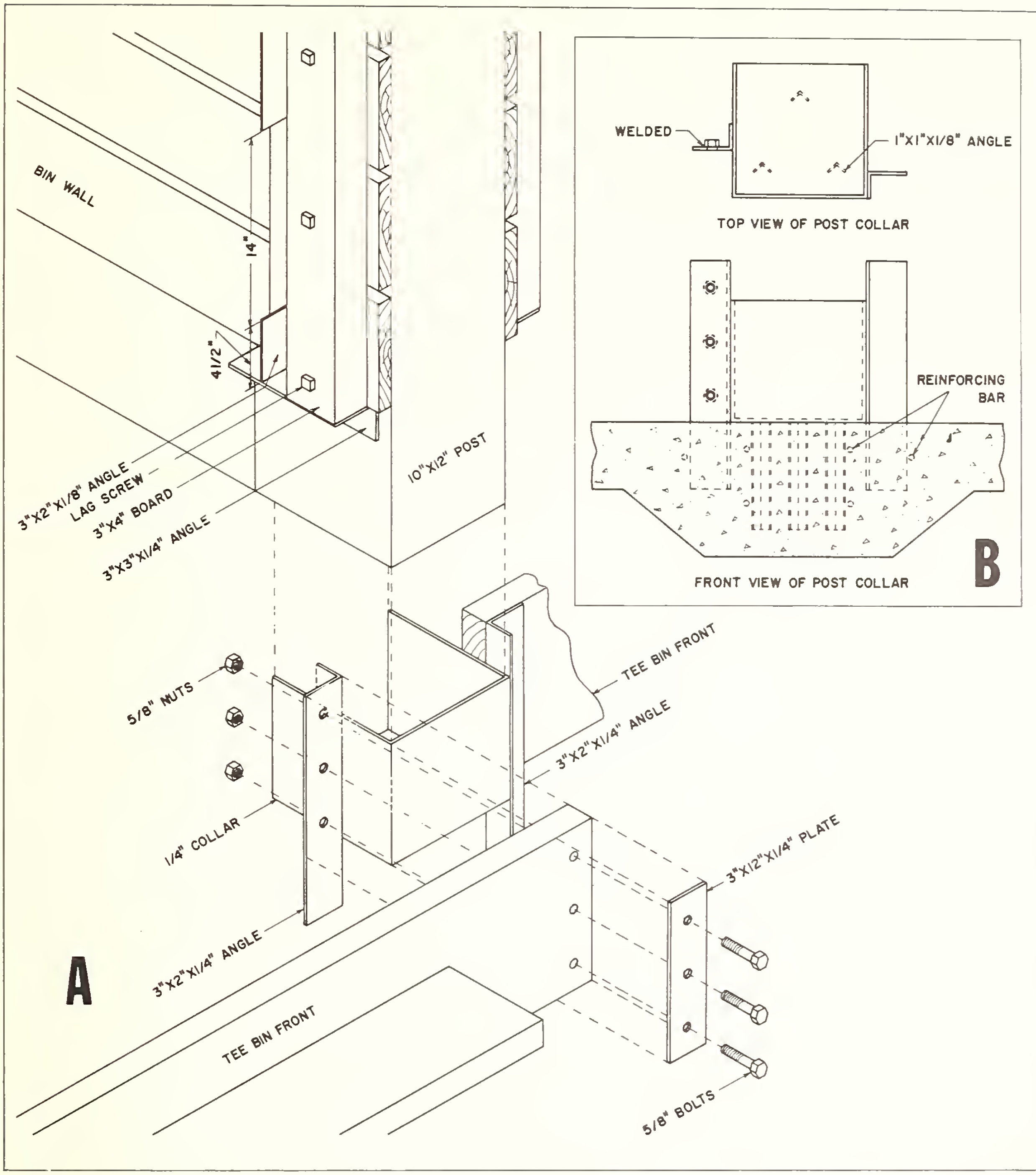

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Figure 25.—*A*, Starter arrangement designed for releasing potatoes from a glued-tee bin front. *B*, Top and front views of collar attached to the panel-support post used in the starter arrangement.

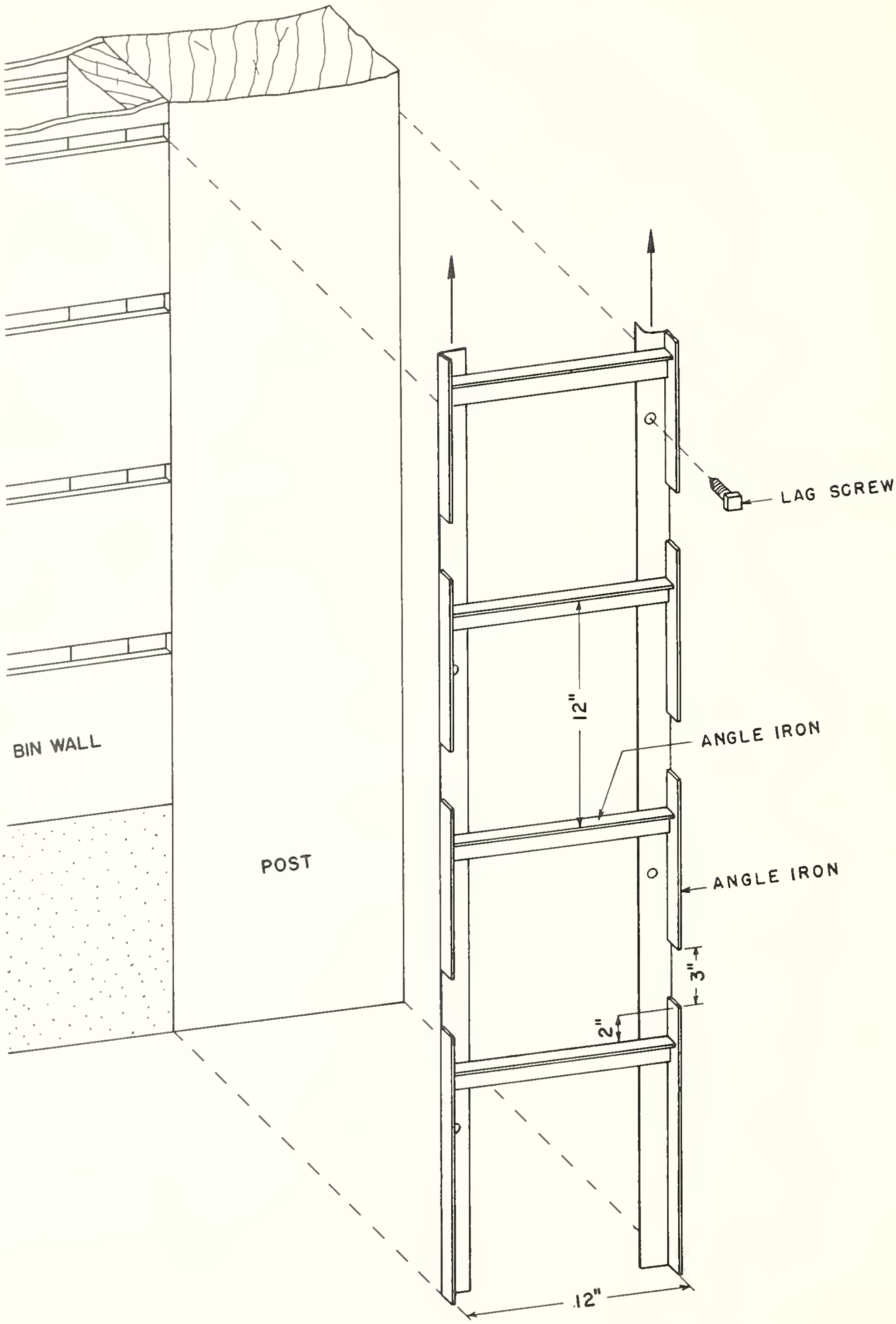

FIGURE 26.—Wall attachments used for slotted potato-bin front designed without a special starter section.

The inherent construction of the slotted front provides a base opening for hand forking or fluming the potatoes from the bins. However, when the folding 1- by 10-inch retainer is used, it must be left off of the bottom panel for these methods of handling. Figure 26 illustrates the wall attachments used with slotted front panel units when no special starter sections are required. For powered bulk scoop operation, however, the slotted front design must provide for the removal of the lowermost panels. Figure 27 illustrates an arrangement which provides for this removal. The wall attachment and hinge features of the arrangement are shown in figure 28. The tee section (which is actually a glued-tee panel placed horizontally to support the slotted panels not removed for scooping) must be capable of carrying the two concentrated loads applied by the spacer block columns. In some cases, double webs may be required on the glued-tee panel.

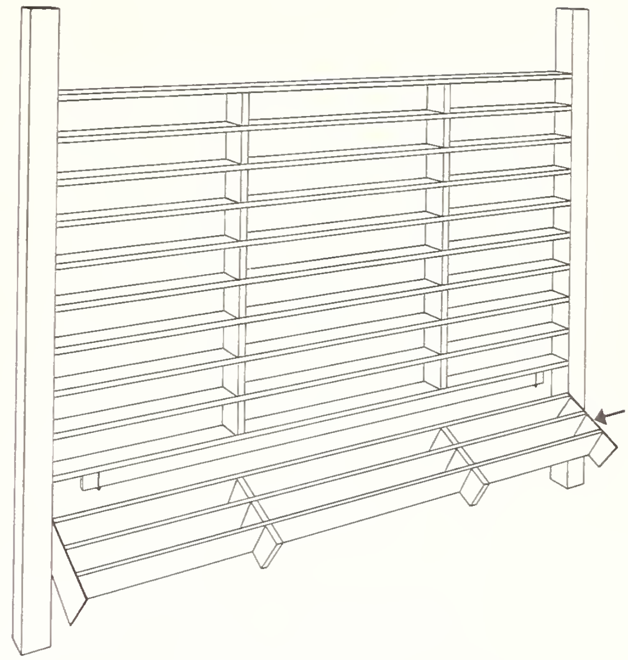

FIGURE 27.—Starter arrangement for slotted potato-bin front. The bottom section of panels is hinged (arrow) to facilitate use of powered bulk scoop.

CONCLUSIONS AND RECOMMENDATIONS

From the standpoint of providing for full use of storage-bin space, bin fronts are worth using. They have other advantages also, such as creating level piles for ventilation and providing pressure relief at doors. Like all other components of a potato-storage structure, bin fronts must be properly designed. A haphazard approach to bin fronting can result in unsatisfactory performance of this important part of the storage structure.

Straight panels are probably the simplest units to use on very short spans. However, when potato pressure is high because of pile depth or when the resisting moment in the panel is lowered because of the length of span, other types of panel units should be considered. These include glued-tee, slotted, bolted or clamped tee, swinging door, and trussed panels.

For wide-span bin fronting, the slotted bin front or the glued-tee bin front are recommended. Semicircular sheet metal or tie-back fronts may be used also.

Starter sections for removing the potatoes by forking, fluming, or bulk scooping should be designed to open easily, even after the potatoes have undergone much settling and shifting.

APPENDIX

Symbols

The symbols used in the analyses included in this appendix are defined as follows:

A = cross-sectional area or area
b = width of a cross section
c = distance from neutral axis to extreme fibers in stress in a cross section
d = depth or height of a cross section
Dm = maximum deflection due to load
E = modulus of elasticity
I = moment of inertia of the cross section
L = span in feet

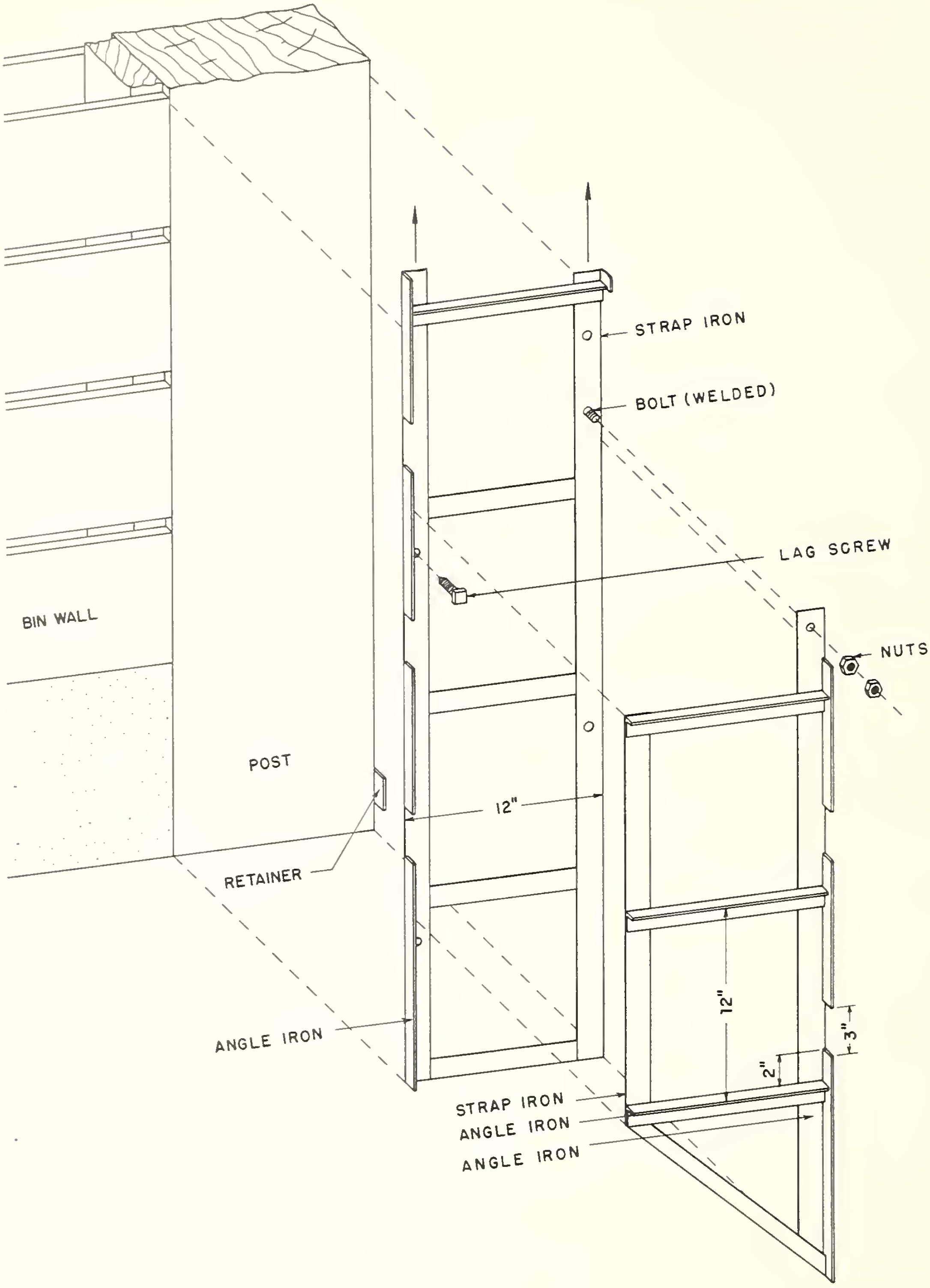

FIGURE 28.—Wall-attachment and hinge arrangement for starter in slotted potato-bin front designed for powered bulk-scoop operation.

l = span in inches
Mm = maximum bending moment
Mr = maximum resisting moment
P = concentrated load
Q = static moment of the cross-sectional area above or below the neutral axis
R = end reaction
S = unit stress of the material
V = total vertical shear
V_h = horizontal shear
W = uniform load per unit length

Design of Panels as Beams

When straight-panel and tee-type bin fronts are oriented vertically, the individual panels may be assumed to act as simply supported beams carrying a uniformly distributed load. The load, shear, and moment diagrams will be similar to the diagram shown in figure 29.

The end reactions may be determined by

$$R = \frac{WL}{2} \ ;$$

the total shear by

$$V = \frac{WL}{2} \ ;$$

and the maximum bending moment by

$$Mm = \frac{WL^2}{8} \ .$$

Once these loading values are determined, the particular member can be evaluated for its resistance values in terms of allowable stress of the material or by a comparison of resistance values and loading values.

The basic equation for maximum resistance offered by a beam in bending is

$$Mr = \frac{SI}{c} \ .$$

This value is compared to the maximum bending moment caused by the loading.

The ratio $\frac{I}{c}$ is commonly referred to as the "section modulus" of the member. The moment of inertia I depends on the location of the cross-sectional area of the material from the neutral axis of the member.

The equation for vertical shear is

$$S = \frac{P}{A} \ .$$

The value of S is checked against the allowable unit stress for vertical shear of the material.

Horizontal shear in the member is checked in the same manner; the general equation for shear at the neutral axis of a member is

$$V_h = \frac{VQ}{Ib}$$

Crushing is evaluated by

$$S = \frac{P}{A} \ .$$

The value of S is compared to the allowable stress for the material. For wood, this involves two values: (1) Allowable stress parallel to the grain, and (2) allowable stress perpendicular to the grain.

The maximum deflection of the member may be checked by

$$Dm = \frac{5 \ Wl^4}{384 \ EI} \ .$$

The value Dm is generally compared to some allowable deflection which is a fraction of the length of the span.

Mathematical Evaluation of Glued-Tee Panels

Values used for developing the chart for selection of glued-tee panel sizes (fig. 12) were determined in the following manner:

(1) Resistances offered by the tee for each size of web in bending, vertical shear, horizontal shear, deflection, and compression perpendicular to the grain were determined and converted to a value of uniform load per square foot for lengths of span ranging from 11 to 24 feet.

(2) The minimum value of the load resistances offered for these factors was selected.

(3) This load resistance value was compared to the pressure-depth relationship of potato piles (fig. 10), and the maximum allowable pile height above the panel for each size of web was determined.

(4) The allowable pile height above the individual panel was plotted for the range of spans considered. The curves were then drawn (fig. 12).

Illustrative calculation—2- by 8-inch web on 2- by 12-inch flange (dressed lumber):

Bending..........1,500 lb. per sq. in. (p.s.i.)

Vertical shear..........120 p.s.i.

Horizontal shear..........120 p.s.i.

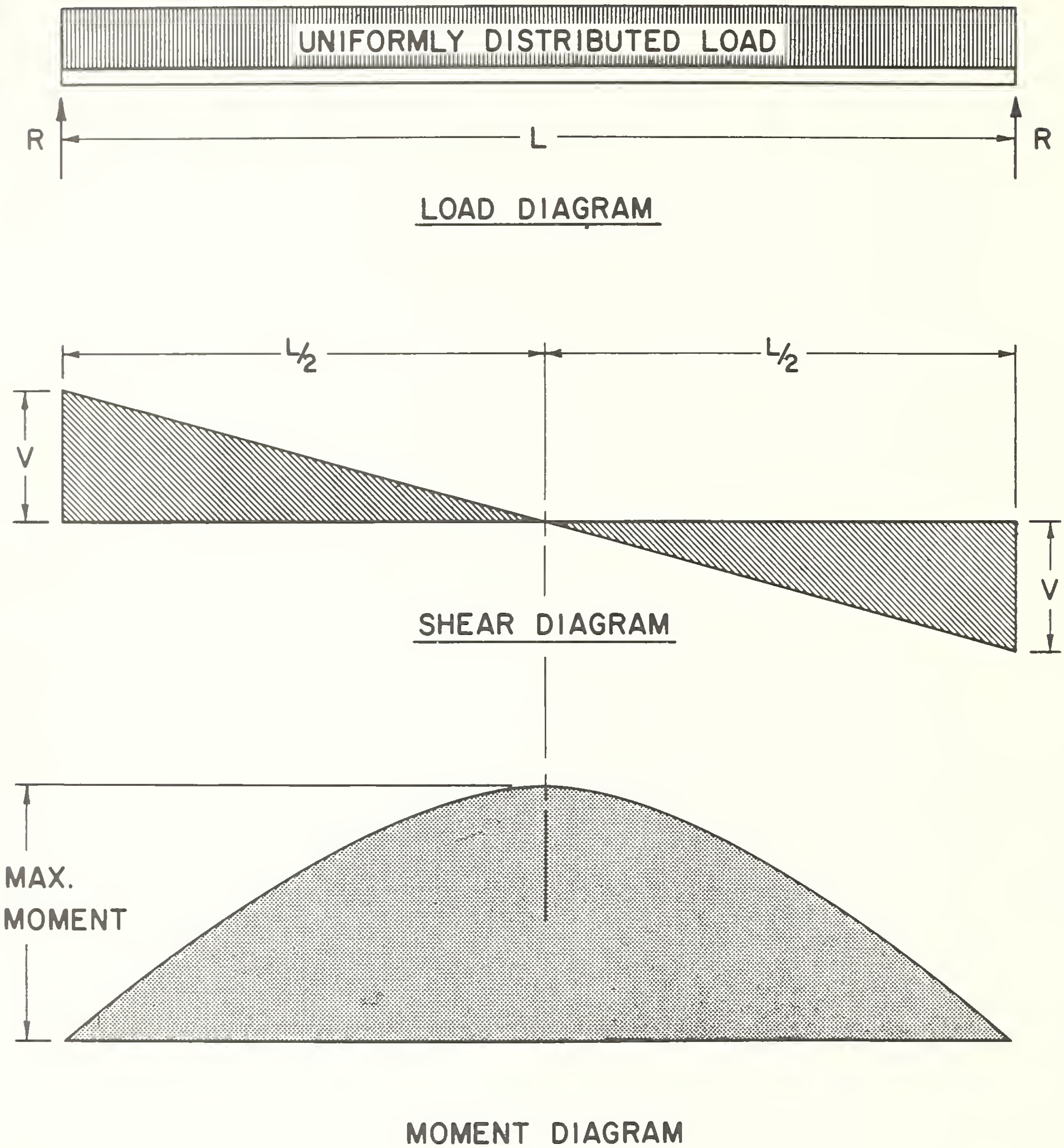

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FIGURE 29.—Load, shear, and moment diagram for simply supported beam.

Deflection .... $\frac{1}{100}$ of span maximum

Span .... 20 feet

Modulus of elasticity ... 1,760,000 p.s.i.

Compression perpendicular to grain .... 390 p.s.i.

Figure 30 illustrates a typical tee panel in cross section.

$$A_1 = (1.5)\ (11.5) = 17.25 \text{ sq. in.}$$

$$A_2 = (1.5)\ (7.5) = 11.25 \text{ sq. in.}$$

$$c = \frac{(17.25)\ (8.25) + (11.25)\ (3.75)}{17.25 + 11.25} = 6.47 \text{ in.}$$

$$I_1 = \frac{bd^3}{12} = \frac{(11.5)\ (1.5)^3}{12} = 3.23 \text{ in.}^4$$

$$I_2 = \frac{bd^3}{12} = \frac{(1.5)\ (7.5)^3}{12} = 52.73 \text{ in.}^4$$

I transfer & total $= (17.25)\ (1.78)^2 +$

$(11.25)\ (2.72)^2 + 3.23 + 52.73 = 193.85 \text{ in.}^4$

RESISTING MOMENT OF PANEL:

$$Mr = \frac{SI}{c} = \frac{(1{,}500)\ (193.85)}{6.47} = 44{,}942 \text{ in.-lb. or } 3{,}745 \text{ ft.-lb.}$$

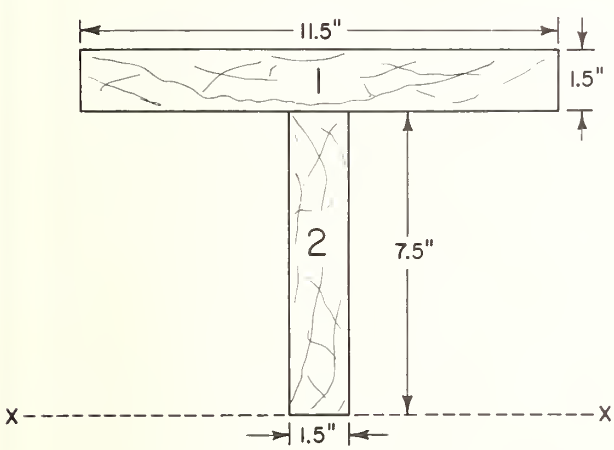

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FIGURE 30.—Typical tee panel in cross section.

Conversion to load-resistance:

$$W = \frac{8\ Mr}{L^2} = \frac{(8)\ (3{,}745)}{(20)^2} = 74.90 \text{ lb./linear ft.}$$

convert to lb./sq. ft. $\frac{(74.90)\ (12)}{11.5} = 78.16$ lb./sq. ft.

VERTICAL SHEAR AT SECTION CHANGE:

$$S = \frac{P}{A} = \frac{WL}{2A} \text{ where } A = (1.5)\ (11.5) = 17.25 \text{ sq. in.}$$

Conversion to load-resistance:

$$W = \frac{2SA}{L} = \frac{(2)\ (120)\ (17.25)}{(20)} = 207 \text{ lb./linear ft.}$$

convert to lb./sq. ft. $\frac{(207)\ (12)}{11.5} = 216$ lb./sq. ft.

HORIZONTAL SHEAR AT NEUTRAL AXIS:

$$V_h = \frac{VQ}{Ib} = \frac{WLQ}{2Ib}$$

Conversion to load-resistance:

$$W = \frac{2\ V_h\ Ib}{QL} = \frac{(2)\ (120)\ (193.85)\ (1.5)}{(6.47)\ (1.5)\ (3.24)\ (20)} = 110.97 \text{ lb./linear ft.}$$

convert to lb./sq. ft. $\frac{(110.97)\ (12)}{11.5} = 115.79$ lb./sq. ft.

DEFLECTION:

$$Dm = \frac{5\ Wl^4}{384\ EI}$$

Conversion to load-resistance:

$$W = \frac{384\ EI\ Dm}{5l^4}$$

$$= \frac{(384)\ (1{,}760{,}000)\ (193.85)\ (2.40)}{(5)\ (240)^4}$$

$= 18.95$ lb./linear in. or 227.4 lb./linear ft.

convert to lb./sq. ft. $\frac{(227.4)\ (12)}{11.5} = 237.3$ lb./sq. ft.

COMPRESSION PERPENDICULAR TO GRAIN:

Use 3 in. retainers at posts

$$A = (3)\ (11.5) = 34.5 \text{ sq. in.}$$

$$S = \frac{P}{A} = \frac{WL}{2A}$$

Conversion to load-resistance:

$$W=\frac{2SA}{L} = \frac{(2)\ (390)\ (34.5)}{(20)} = 1{,}345.5 \text{ lb./linear ft.}$$

$$\text{convert to lb./sq. ft.}\ \frac{(1{,}345.5)\ (12)}{11.5} = 1{,}404.0 \text{ lb./sq. ft.}$$

From the above calculation, the bending moment value of 78.16 pounds per square foot was the factor that offered the minimum amount of load-resistance and thus becomes the critical design factor. This factor converts to a potato-pile depth of 9½ feet for a 20-foot span.

Each glued-tee panel was examined in this same manner for lengths from 11 to 24 feet, and the resulting curves were drawn. In all cases, bending moment was the critical factor except for the 2- by 12-inch dressed panel without a tee. For that section, deflection proved to be the critical factor in the design.

Potato-Pile Pressure on a Sloped Surface

In figure 31, a triangular ventilation duct is shown at the base of the wall. Point *A* is the base of the duct, point *B* is the intersection of a vertical line through *A* and the surface of the pile of potatoes, and point *C* is at the wall and the top of the pile. Point *D* is the intersection of the wall and the duct, and point *E* is the intersection of line *AB* and a horizontal line through point *D*.

The weight of the trapezoid *ABCD* is equal to the product of the area and the unit weight of the potatoes, and is designated by *W*. There must be equilibrium between force W and the forces across surfaces *AB*, *AD*, and *CD*. The lateral force on AE designated by L may be determined from figure 10. Assuming the lateral force on BE is equal and opposite the force exerted along *CD*, the resultant thrust (*P*) on the duct is the vector sum of *L* and *W*. A precise theoretical analysis indicates that the magnitude and the direction of the pressure will vary along the surface *AD*. However, for design of triangular air ducts, use of average pressure should provide satisfactory working results.[4]

[4] See footnote 1, p. 9.

Calculations Used in Estimating Material and Labor Costs of Panel Construction[5]

Glued-tee panels

1. Lumber

Size	*Price/100 bd. ft.*
2- by 12-in. up to 20-ft. length	$17.50
2- by 10-in. up to 20-ft. length	17.50
2- by 8-in. up to 20-ft. length	16.50
2- by 6-in. up to 20-ft. length	16.50
2- by 4-in. up to 20-ft. length	16.50

(For lengths over 20 feet, add $1 per 100 bd. ft.)

2. Resorcinol glue at $3.40 per pint. (144 ft. of 2-in. glue strip per pint)equals $0.0236 per ft.
3. Common nails at $0.16 per lb. (16d nails give 49 nails per lb.) at 1 nail per ft. equals $0.0033 per ft.
4. Flat steel at $0.15 per lb. (1.42 lb. per ft.) equals $0.04 per piece.
5. U-bolts with nuts at $0.25 per ft. of total bolt length:

Web size	*Bolt size*	*Price*
2- by 12-in.	½-in. by 13½-in.	$0.63
2- by 10-in.	½-in. by 11½-in.	.50
2- by 8-in.	½-in. by 9½-in.	.44
2- by 6-in.	½-in. by 7½-in.	.35
2- by 4-in.	½-in. by 5½-in.	.27

6. Labor at $2 per hour (¼hr. per front) equals $0.50 per front.

Slotted panels

1. Lumber

Size	*Price/100 bd. ft.*
2- by 12-in. up to 20-ft. length	$16.00
3- by 12-in. up to 20-ft. length	18.00
1- by 10-in. up to 20-ft. length	18.00
1- by 6-in. up to 20-ft. length	17.00

(For 2- by 3-in. material over 20-ft., add $1 per 100 bd. ft.)

2. ¼-in. external A-C plywood at $11.80 per 100 bd. ft.
3. 6 mil polyethylene at $14.95 per 1,000 sq. ft.
4. Hinges and screws at $0.20 each.
5. Common nails at 0.16 per lb. (8d nails give 106 nails per lb.) at 1 nail per ft. equals $0.0015 per ft.
6. Labor at $2 per hr.

Man-hours	*Cost per panel*
0.175 hr. per solid retainer front	$0.35
.250 hr. per folding 1- by 6-in. front (1 spacer block—4 hinges)	.50
.420 hr. per folding 1- by 6-in. front (2 spacer blocks—6 hinges)	.84
.580 hr. per folding 1- by 10-in. front (1 spacer block—4 hinges)	1.16
.750 hr. per folding 1- by 10-in. front (2 spacer blocks—6 hinges)	1.50

[5] Computations included in this section are based on 1968 prices.

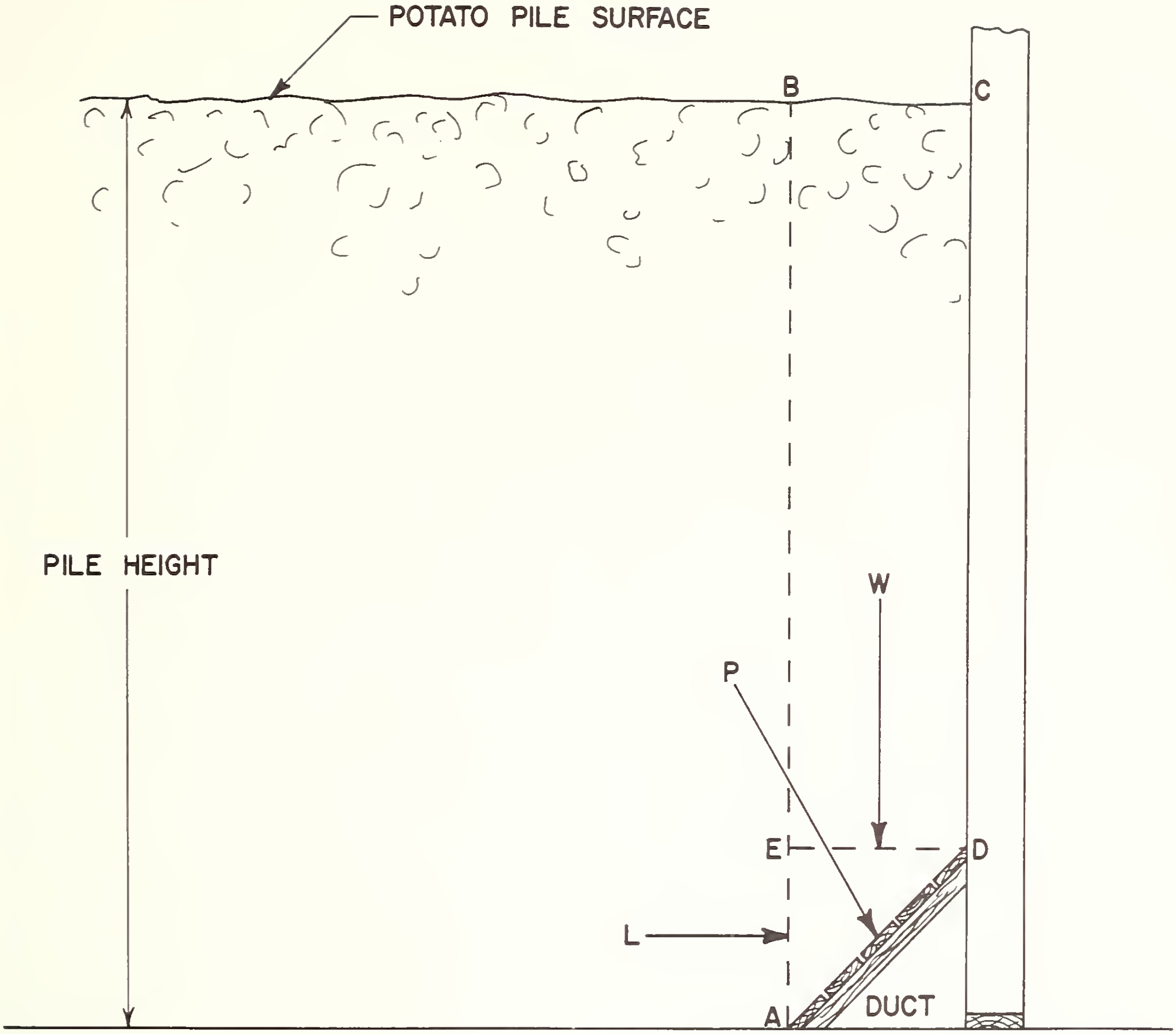

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FIGURE 31.—Diagram of potato-storage bin with triangular ventilation duct.

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