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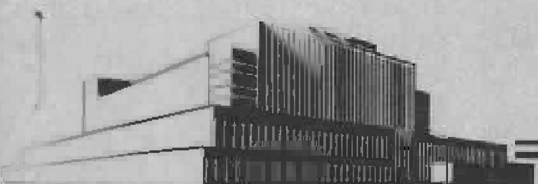

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

EFFECT OF VENTILATING AND HANDHOLES ON COMPRESSIVE STRENGTH OF FIBERBOARD BOXES

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Introduction

Holes are frequently put in the side and end panels of fiberboard boxes for fresh fruits and vegetables to facilitate ventilation and handling. Such holes can logically be assumed to reduce the stiffness of a box. To determine whether loss of stiffness thus caused significantly affects the utility of these fruit and vegetable containers, experiments were conducted on boxes with holes of various sizes and shapes variously located in side and end panels. The relationship between the amount of material removed and the extent of strength reduction was also investigated. Since, however, the variety of sizes, kinds, and shapes of fruit and vegetable containers currently used precluded an extensive study, this exploratory investigation was limited to establishing trends and information that can be used by others as a guide in planning more detailed tests of specific box types.

Boxes and Material Tested

For this exploratory work, a box size was selected that would be representative of the average of those included in the railroad carrier regulations, Freight Container Tariff IE. The box selected was 16 inches long, 12 inches

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

wide, and 8 inches deep, of the regular slotted style with stapled manufacturer's joints, and was closed with staples. Test boxes were made from either 200- or 175-pound, B-flute, corrugated fiberboard.

Several methods were used to make the ventilation holes. One method consisted of drilling the holes with a conventional wood bit to prevent crushing of the corrugations adjacent to the holes. Another consisted of cutting the holes with a tubular-type punch similar to those commonly used in commercial practice. When large areas were removed from a panel, two holes were cut by means of a circle cutter; then the holes were connected by two parallel cuts made with a knife. The handholes were made in the ends of the box by cutting two round holes 1-1/4 inches in diameter whose centers were 2-1/2 inches apart. The holes were then connected with two parallel knife cuts, thus providing a handhole 1-1/4 inches wide and 3-3/4 inches long.

The sizes, numbers, and locations of the holes are given in tables 1, 2, and 3.

Methods of Tests

Boxes with various kinds of ventilation or handholes were compression tested in a universal testing machine. Force was applied in the top-to-bottom direction after the boxes had been conditioned in an atmosphere maintained at 73° F. and 50 percent relative humidity. Values of compressive resistance thus obtained were compared to values obtained for control boxes made from similar material but having no areas cut from them. Three or more replicas with each kind of ventilating or handhole were tested to obtain an average value. Each set of replicas was assigned a group number.

Discussion and Results of Tests

A considerable part of the compressive resistance of a fiberboard box comes from the four vertical edges at the corners when the crushing load is applied top to bottom. For loads applied in this direction, previous work with plywood plates[2] has shown that stresses are concentrated in the areas adjacent to these corner edges. The work with plywood plates indicated that relatively large areas of material could be removed from the center of the plywood without significantly reducing the maximum load the panels could withstand. If the material were removed from the areas of stress concentration, however, it appeared logical that appreciable losses in compressive resistance would

[2] "Buckling of Flat Plywood Plates in Compression, Shear, or Combined Compression and Shear." FPL Report No. 1316-E.

occur. Using this information as a guide, the corner areas were avoided in some ventilation patterns, while in other patterns the holes were actually placed in the areas of concentrated stresses.

It was found that, when four holes were centered in a square cluster on each of the two opposite side panels of the box, as shown in figure 1, the strength of the box was reduced less than 7 percent. This finding agrees with the hypothesis regarding plywood plates, that material can be removed from the central area of the panel without appreciably affecting the load.

If material was removed from two opposite side panels along a central line of the panel, as shown in figure 2, there was also no appreciable loss. In fact, in these tests there even resulted increases in compressive strength of as much as 8 percent for boxes in groups 4 and 5. These apparent increases in strength may be due primarily to the variability of the material and an insufficient number of samples to obtain a realistic average. Or this may be explained by the fact that, when force is applied downward, the center portion of the panel tends to bow. When this occurs, the outer material in the bowed portion is placed in tension. Some of the tensile stresses may be transferred to the corner edges of the box, increasing the total stress on them. When the tensile stresses are relieved across the bowed area because of the horizontal line of ventilation holes, however, additional stress is not transferred to the corner edges of the panel. It may be assumed, therefore, that the corners are capable of carrying a greater load and thus contribute to a greater overall resistance to crushing. A significant number of tests would be required, however, to prove this theory.

When four holes were centered in a square cluster on each of the four panels, as shown for groups 6 and 7 in figure 3, the reduction in strength was not as great as when the same cluster was cut from only two panels, groups 2 and 3. In this instance the reduction was less than 2 percent, which may be considered insignificant.

When four holes were placed in a horizontal line in both the side and end panels of the box, as shown for groups 8 and 9 in figure 4, a resistance to crushing slightly higher than that of the control box was found when the holes were made with a drill. When the holes were made with a die-type punch, the compressive strength of the box was slightly less than that of the control box. Both sets of values were within the limits of variation that may be expected with corrugated material, but the fact that the average strength value for the boxes with the drilled holes was 2.5 percent above the average for the control boxes and the average for the boxes with punched holes was 2.6 percent below indicates that the subject needs further investigation.

The groups involving handholes were included as 10, 11, and 12 and are shown in figures 5, 6, and 7, respectively. Greater reduction in resistance to crushing resulted with these groups than for any of the groups previously discussed. Although the reductions were not as great as might be expected, a reduction of 10.5 percent resulted for group 10. The reduction was not quite as great when a cluster of four holes was centered on each side panel and handholes were placed in the ends, as in group 11 (fig. 6). Here the total strength reduction of the box was 9.5 percent. When ventilation holes were placed on a horizontal line in the side panels, and handholes in the ends, as shown in group 12 (fig. 7), the reduction was 8.0 percent.

It is believed that handholes were the primary cause of strength reduction in groups 10, 11, and 12 as they were placed in the stiffer pair of panels. Also, the handholes, being above the center of the panels, may have been too close to the top edge of the box, where compressive stresses were concentrated.

The results of tests for groups 1 through 12 may be found in table 1. The greatest reduction in strength was 10.5 percent. As already noted, some combinations of holes apparently improved the strength of some boxes. Although, as explained, the holes in the panels tended to disrupt or relieve the normal progression of concentrated stress lines, it is not recommended that material be removed from the panels of a box as a means of increasing box strength.

In a second series of tests, the size and number of ventilation holes put in the boxes were in accordance with the requirements of Tariff IE. In these tests it was found that the location of the holes in the 175-pound test boxes was a critical strength factor; and, although each box in the series had the same number of 1-1/8-inch diameter holes, the effect on strength varied considerably.

For example, the reduction in strength was as little as 6.3 percent for box No. 6L, which had four holes centered in each side and end panel. When the 16 holes were arranged on diagonal lines extending from the corners in box 3L, the reduction in strength was almost four times as great, or 22.5 percent, because the holes were placed on lines of concentrated stress. Boxes in this group are shown in figures 8 and 9, and the results of the tests are included in table 2.

Because of these moderate reductions--and in some instances increases--in strength, it was decided to conduct additional tests involving boxes from which relatively large areas of the side panels had been removed. The large cutouts were not intended to simulate any ventilation pattern. The sole purpose was to remove large areas of panel surface to obtain appreciable reductions in strength.

This was accomplished, and reductions in box strength of up to 50 percent were attained, but only after as much as 25.3 percent of the box panel area had been removed. This reduction occurred with box No. 7F, in the sides and ends of which a total of 36 holes 2 inches in diameter had been cut. From box No. 7C, an even greater amount of material was removed--31.8 percent--yet the reduction in strength was 12 percent less than for box No. 7F. This may be accounted for by the fact that, for box No. 7C, the cutouts were farther from the corner areas and not as directly on the concentrated stress lines.

Boxes Nos. 7D, 7E, and 7G had about the same amount of material removed as box No. 7F, from 24.8 to 25.9 percent, but the reductions in strength were not as great. This may be attributed to the fact that the cutouts were more strategically placed than in box No. 7F. This is especially true for areas that were removed from the ends of boxes Nos. 7D, 7E, and 7G, as the cutouts were taken from the center of each panel, which was a less critical location than the area near the edges and corners. Boxes Nos. 7A and 7B are shown in figure 10, Nos. 7C, 7D, and 7E in figure 11, and Nos. 7F and 7G in figure 12. Test values obtained in this third series of tests are given in table 3.

Conclusions

It must be noted that the tests made in this exploratory study were limited in number and were made on boxes of one size. Some of the apparent effects of the location and size of holes could be attributed to the inherent variability of the corrugated boxes. All conclusions must be qualified, they are not intended to cover conditions other than those included in this group of tests. These conclusions are as follows:

1. When areas are removed from the panels of a box for the purpose of providing ventilation or handholes, the reduction in box compressive strength usually did not exceed 10 percent when the amount of area removed was in accordance with the carrier regulations.

2. Reductions in strength were greatest when material was removed from areas of concentrated stress, usually extending diagonally from the corners, and when material was removed from areas too close to the horizontal and vertical edges of the box.

3. The location of cutout areas is more significant than the amount of material removed, as shown by the fact that removal of 3.6 percent of an area caused a reduction in strength of 22.5 percent, while in another instance as much as 24.8 percent of the panel area was removed with about the same reduction in strength.

Table 1.--Effect of drilled or punched ventilation and handholes of various patterns, numbers, and sizes on the compressive strength of fiberboard boxes 8 by 12 by 8 inches in size (first series)

Box group No.	Total number of holes	Hole diameter and size	Panel area removed	Drilled or punched	Hole pattern and location	Maximum load drilled[1]	Maximum load punched[1]	Change in strength due to holes
		Inches	Percent			Pounds	Pounds	Percent
1	[2]0	0	0	None	....	693	693	....
2	8	1	1.4	Drilled	Four centered, each side	666	....	-3.8
3	8	1	1.4	Punched	Four centered, each side	....	647	-6.6
4	8	1	1.4	Drilled	Four horizontal, each side	748	....	+8.1
5	8	1	1.4	Punched	Four horizontal, each side	....	731	+5.6
6	16	1	2.8	Drilled	Four centered, sides and ends	680	....	-1.9
7	16	1	2.8	Punched	Four centered, sides and ends	....	692	-0.1
8	16	1	2.8	Drilled	Four horizontal, sides and ends	710	....	+2.5
9	16	1	2.8	Punched	Four horizontal, sides and ends	....	675	-2.6
10	2	1-1/4 by 3-3/4	2.1	....	Handhole, each end	620	....	-10.5
11	10	1-1/4 by 3-3/4	3.5	....	Handhole, each end; and four centered, each side	627	....	-9.5
12	10	1-1/4 by 3-3/4	3.5	....	Handhole, each end; and four horizontal, each side	637	....	-8.0

[1] Average of five specimens.

[2] Control boxes.

Table 2.--Top-to-bottom compressive strength of 16- by 12- by 8-inch boxes having 3.6 percent of their area removed as 1-1/8-inch diameter holes in various arrangements (second series)

Group No.	Total number of holes	Hole pattern and location	Maximum load[1]	Loss of Load
			Pounds	Percent
1L	[2]0	....	676	....
2L	16	One each corner, sides and ends	528	21.9
3L	16	Two each corner, top of sides and ends	524	22.5
4L	16	Two centered each edge, sides and ends	591	12.6
5L	16	Four staggered, sides and ends	546	19.3
6L	16	Four centered, sides and ends	634	6.3
7L	16	Four horizontal, sides and ends	617	8.8

[1]Average of five specimens.

[2]Control boxes.

Table 3.--Top-to-bottom compressive strength of 16- by 12- by 8-inch boxes having large areas removed from the side and end panels (third series)

Box group No.	Total number of holes	Hole diameter and size	Panel area removed	Hole location	Maximum load[1]	Loss of load
		Inches	Percent		Pounds	Percent
13	[2]0	0	0	....	723	....
7A	2	4 by 12	21.4	One each side	492	32.0
7B	2	4 by 12	19.9	One each side, rounded	552	23.7
7C	4	4 by 11-1/2, 4 by 7-1/2	31.8	One each side, one each end	447	38.2
7D		4 by 11-1/2, 4-inch diameter	24.8	One each side, one each end	556	23.1
7E	4	5 by 10, 4-inch diameter	25.9	One each side, one each end	503	30.4
7F	36	2	25.3	Ten each side eight each end	352	51.3
7G	26	5	25.6	Twelve each side, one each end	483	33.2

[1]One specimen.

[2]Control boxes.

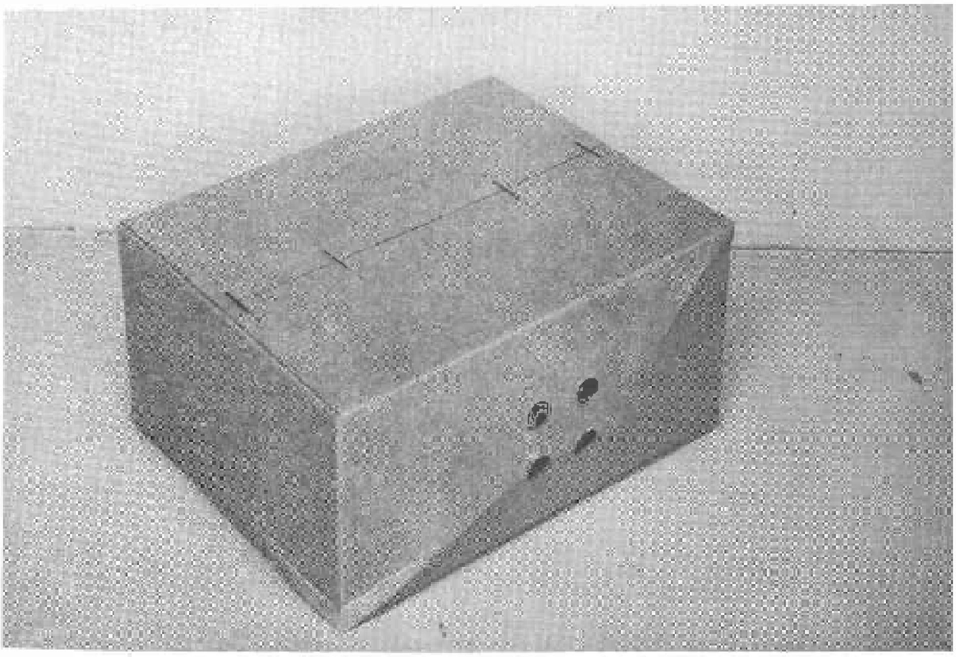

Figure 1.--Fiberboard box with four holes, each 1 inch in diameter, clustered in a side panel; the opposite panel has the same arrangement. Resultant compressive strength reduction was less than 7 percent. The box was one of groups 2 and 3.

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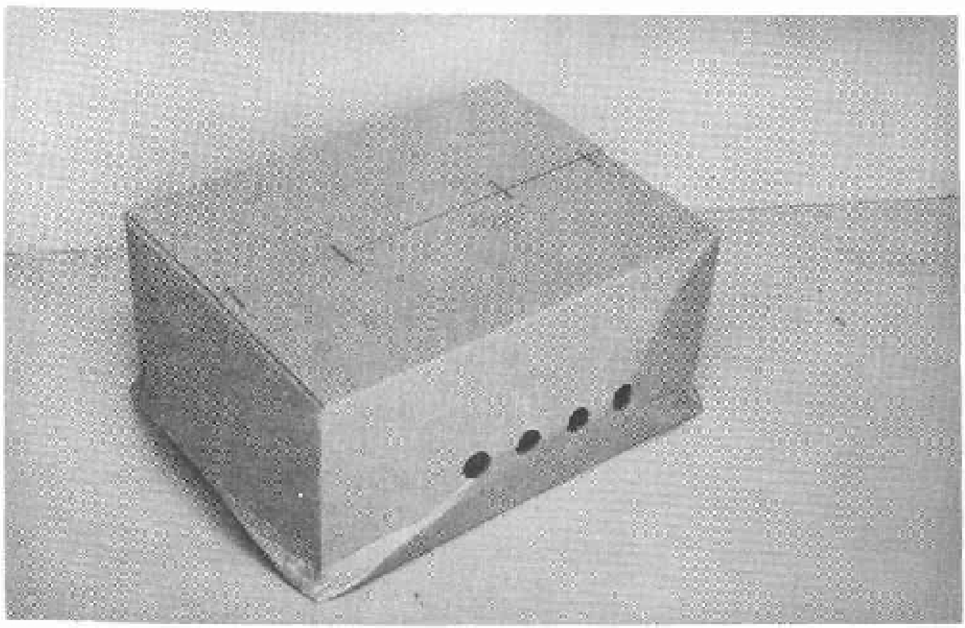

Figure 2.--Fiberboard box with four holes on a horizontal line in the center of a side panel; the opposite panel has the same arrangement. Boxes with this pattern showed no appreciable strength loss. The box was one of groups 4 and 5.

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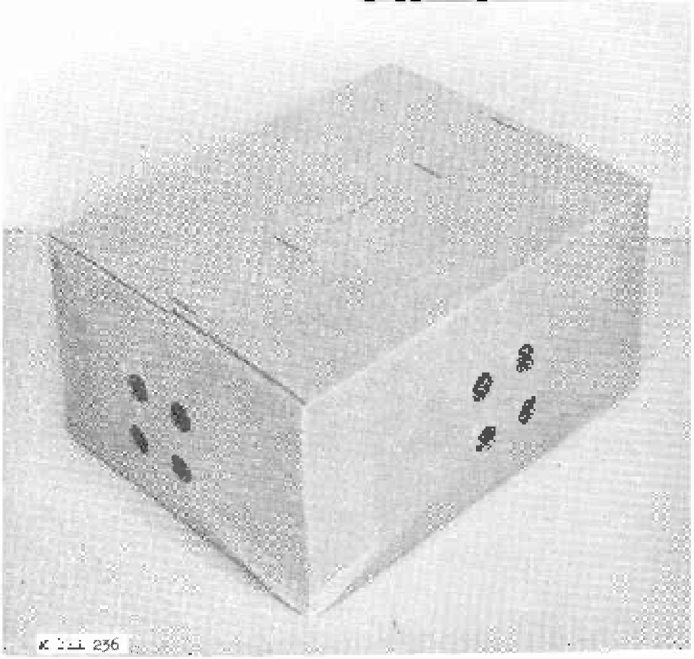

Figure 3.--Fiberboard box with cluster of four holes in end and side panels; similar arrangement in panels on the opposite sides. This ventilation-hole pattern was provided in boxes of groups 6 and 7 and accounted for a strength reduction of less than 2 percent.

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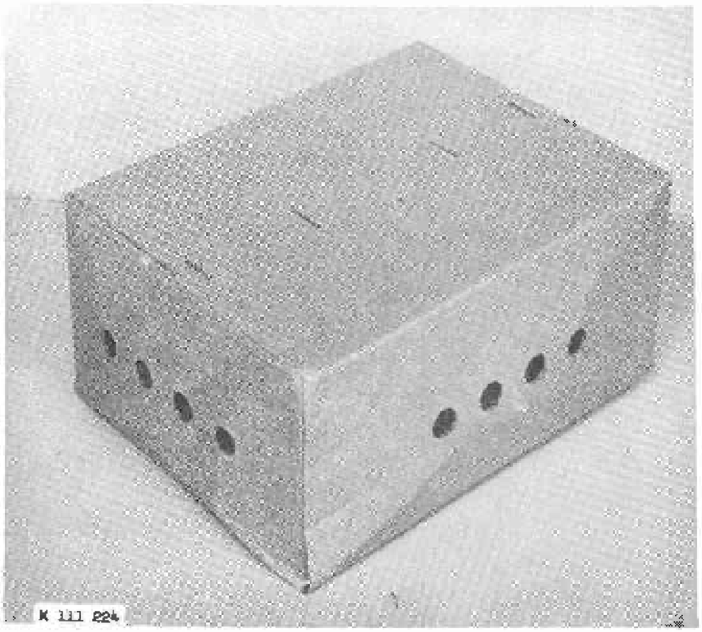

Figure 4.--Fiberboard box with four holes on a horizontal line in the end and side panel, with same arrangement of holes on opposite panels. Boxes with this pattern, groups 8 and 9, sustained almost no strength loss, and some showed gains.

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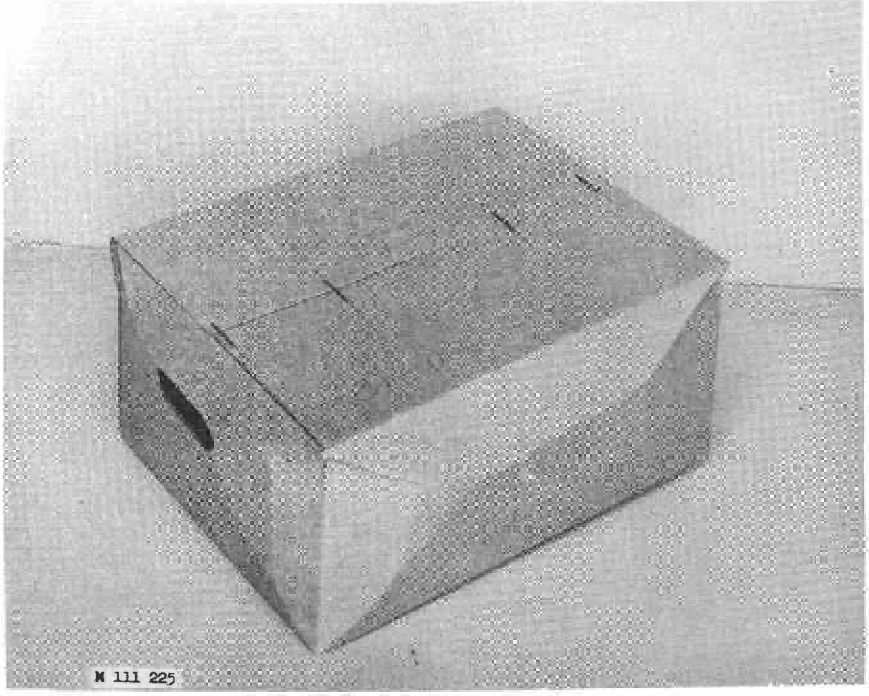

Figure 5.--Handholes in both ends of boxes of group 10 developed concentrated stress lines during compression test, shown radiating from the corners.

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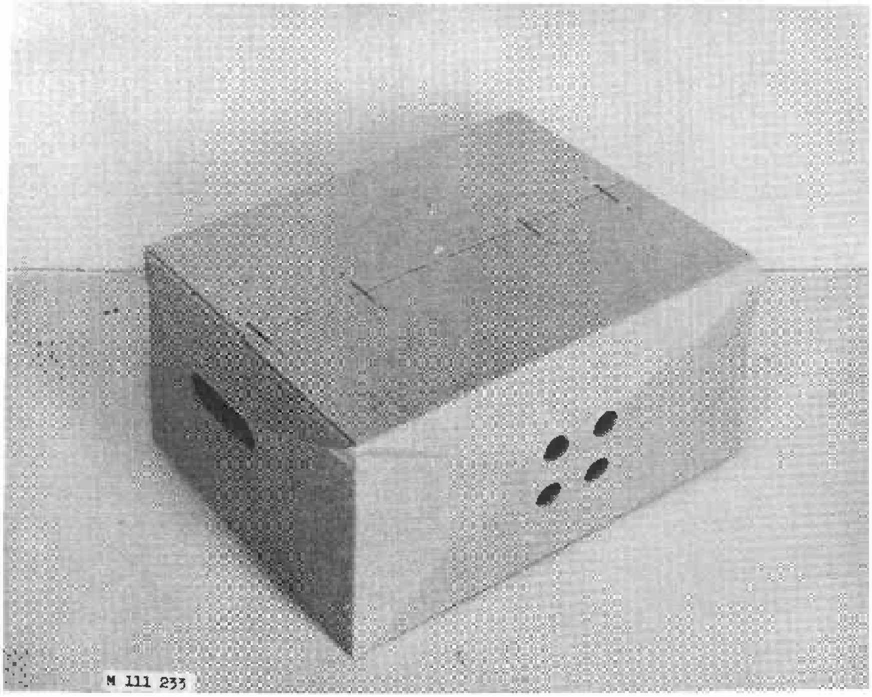

Figure 6.--Handholes in ends and clusters of four ventilating holes in sides of boxes of group 11 caused stress lines to radiate from the corners to the holes during compression tests.

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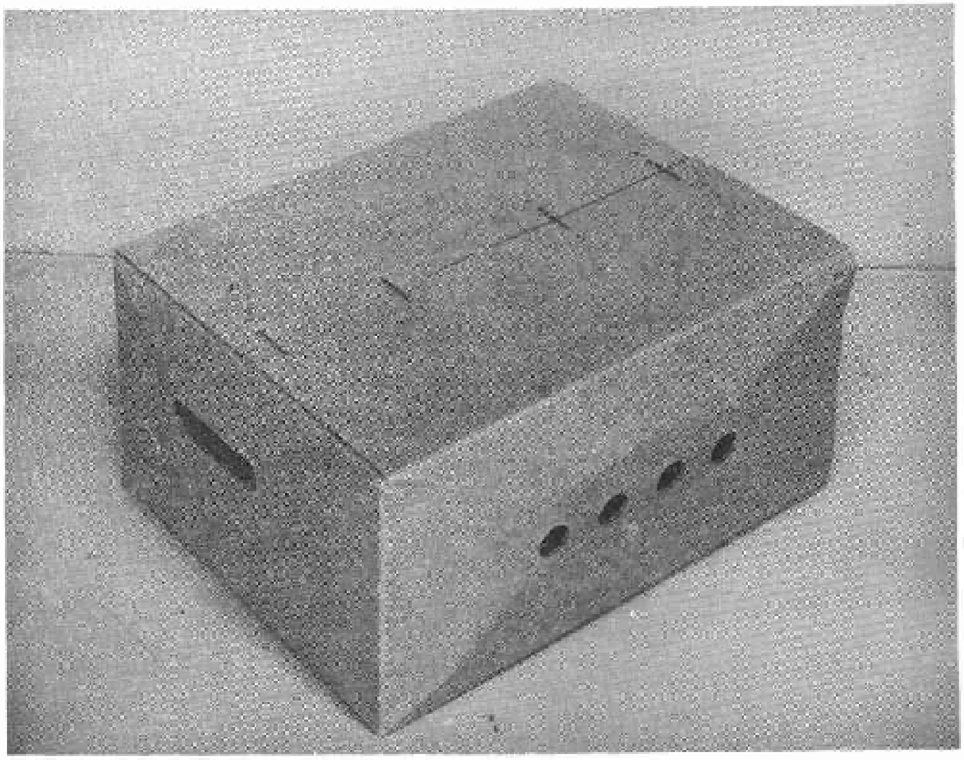

Figure 7.--Handholes in end panels and four holes on a horizontal line in each side panel of group 12 boxes caused stress lines as shown during compression test.

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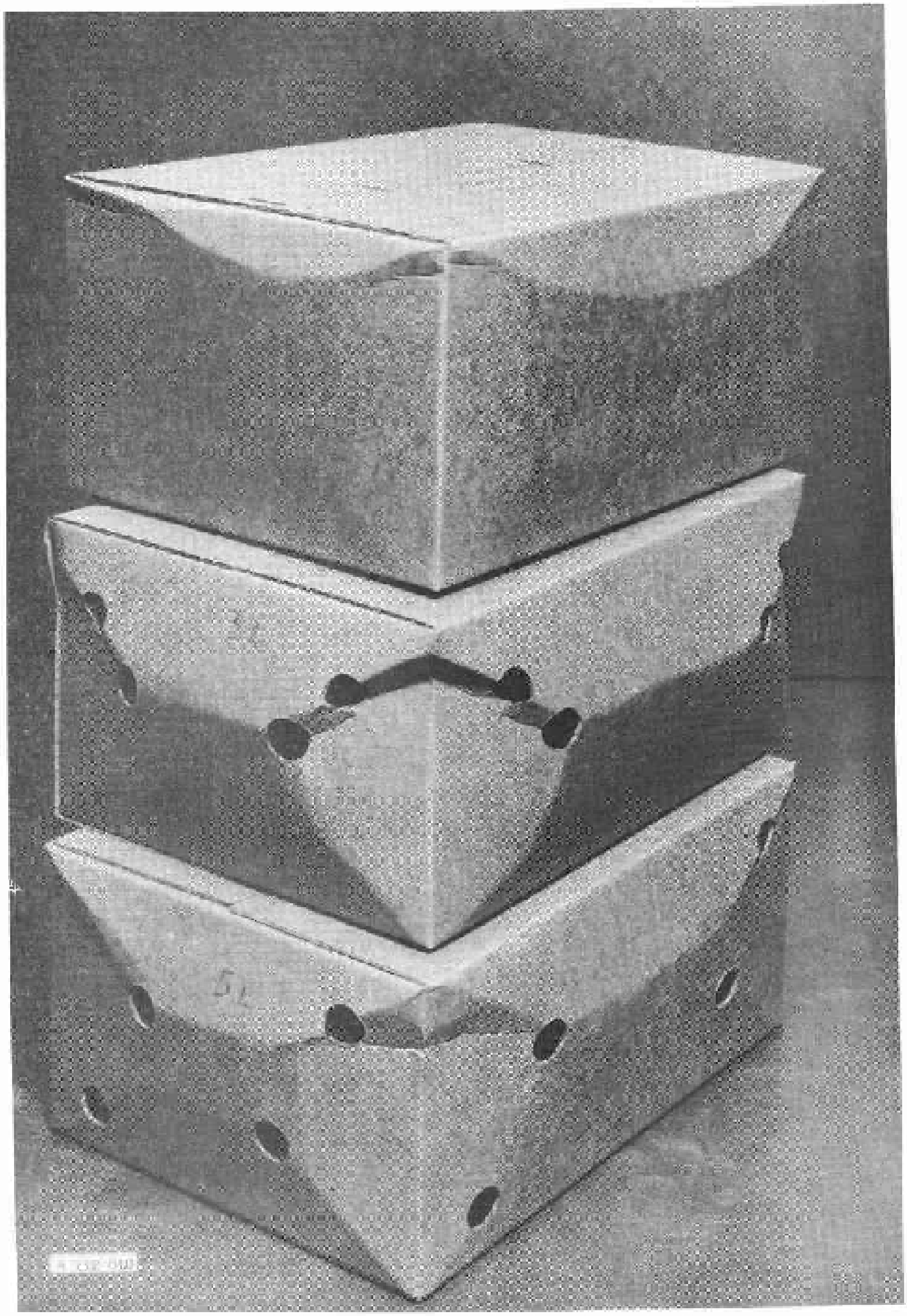

Figure 8.--Effect on strength reduction when holes are located on lines of concentrated stress is shown in these boxes. Upper, control box without holes. Center and bottom boxes had holes critically close to edge corners.

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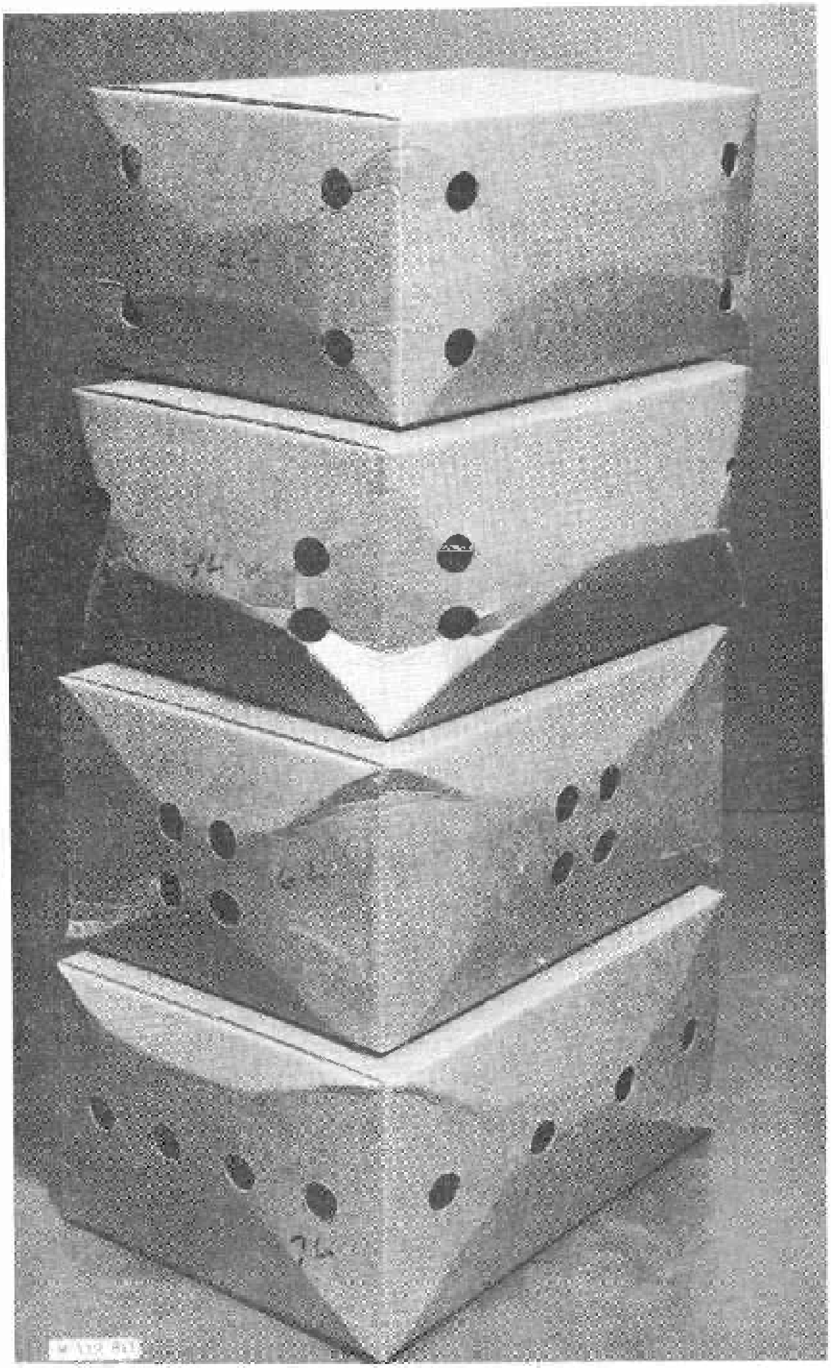

Figure 9.--Effect of hole location as a critical factor in strength reduction is shown in these boxes from, top to bottom, groups 2L, 4L, 6L, and 7L.

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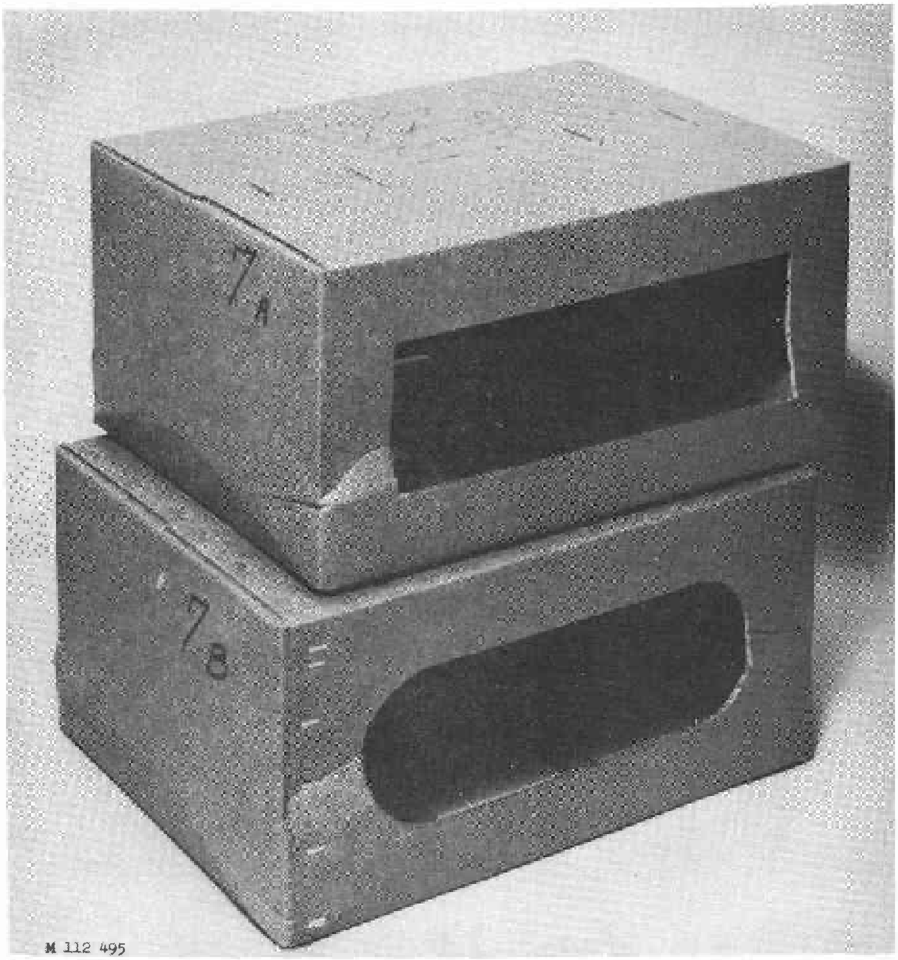

Figure 10.--Effect on strength reduction of large cutouts in panels of groups 7A and 7B fiberboard boxes tested in compression. Cutouts were also made on the opposite panels.

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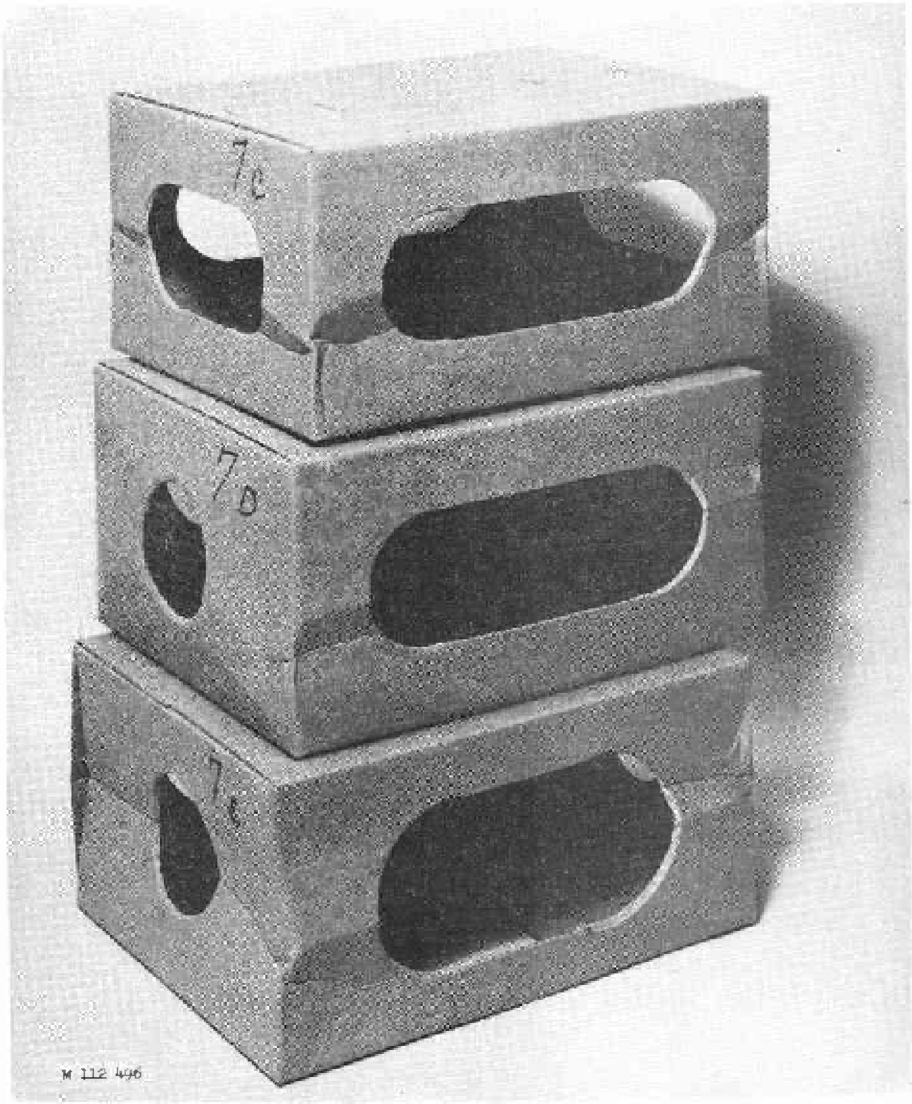

Figure 11.--Large cutout areas in boxes from groups 7C, 7D and 7E show that the removal of 24.8 percent of the panel area reduced the strength only 23 percent when the holes were relatively far from corner areas.

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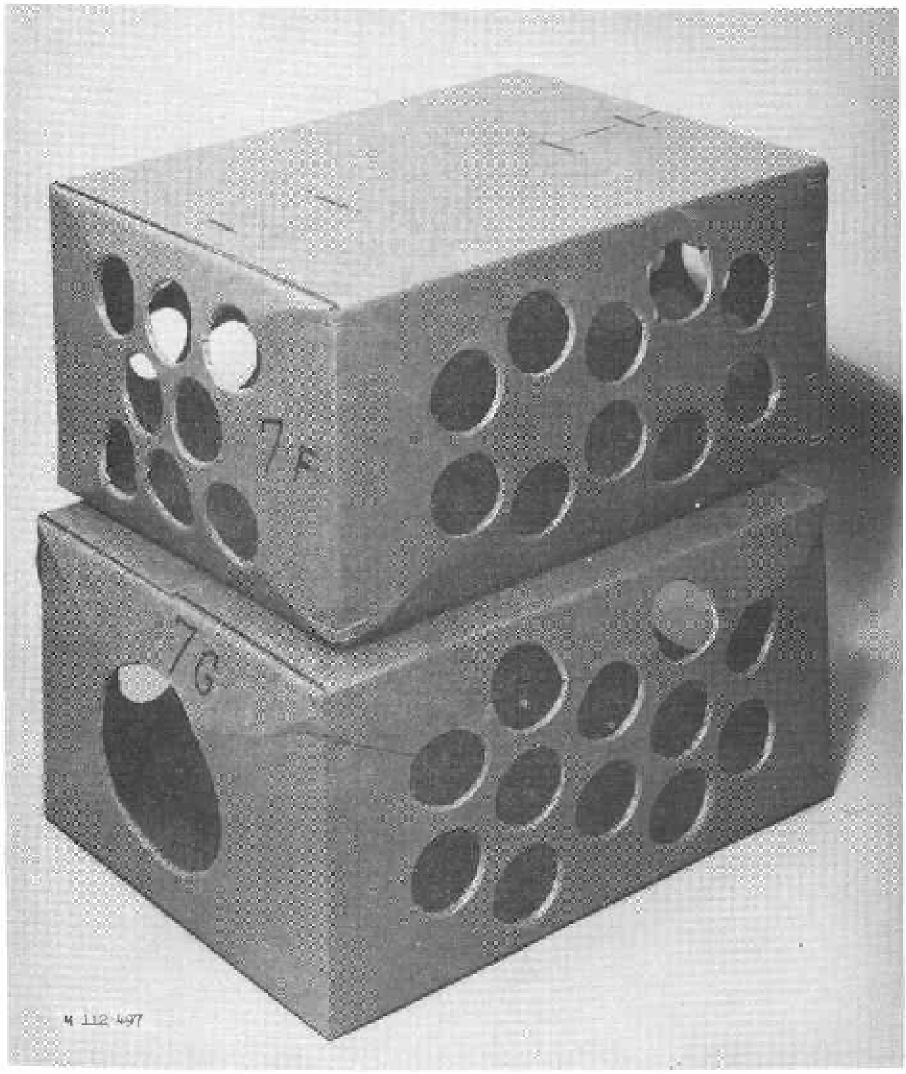

Figure 12.--Large cutout areas in boxes from groups 7F and 7G show that the removal of 25.3 percent of the panel area reduced the strength 51.3 percent when the holes were close to the critical corner areas.

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