DEVELOPMENT OF A SANDWICH-TYPE CARGO FLOOR FOR TRANSPORT AIRCRAFT

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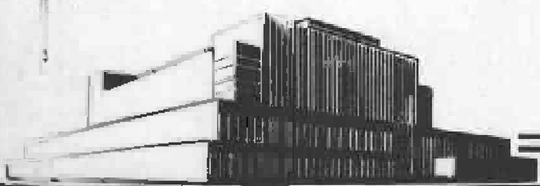

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

DEVELOPMENT OF A SANDWICH-TYPE CARGO FLOOR FOR TRANSPORT AIRCRAFT[1]

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Summary

At the suggestion of the Air Materiel Command, Army Air Forces, the Forest Products Laboratory undertook the development of a sandwich-type cargo floor having a lightweight honeycomb-type core, a strong, tough wearing surface, and a high-strength underface. In all, 16 panel types were investigated, of which 14 are described as to type of construction and performance in Appendix B. The other two experimental floors, X-15 and X-16, are the subject of this report which compares them with respect to performance under test to floors H, I, and M, which were tested previously at the Laboratory.[3, 4]

Experimental floors X-15 and X-16 both have an upper surface composed of 0.032-inch 75ST aluminum bonded to maple plywood, which is five-ply and 5/32 inch thick in floor X-15 and seven-ply and 7/32 inch thick in floor X-16. This surface in turn is bonded to a 0.625-inch resin-treated paper honeycomb core which is bonded to a sheet of 0.016-inch 75ST aluminum that forms the lower surface of the floor panels.

[1] Original report published in October 1947.

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

[3] Methods for Testing and Evaluating Cargo Flooring for Transport Aircraft. FPL Report No. 1550, April 1945.

[4] Tests of Cargo Flooring M for Aircraft. FPL Report No. 1550-B, October 1946.

Both of the floors appeared to be very satisfactory upon the basis of the test data obtained. While sandwich floor X-16 was a little heavier than aluminum floors H and M, and both sandwich floors were a little inferior to them in flexural strength and under concentrated-load tests, they equalled or exceeded the performance of the aluminum panels in the impact, rolling-load, and strip-load tests. By the comparative ratings previously established for tests of cargo flooring[3] (Appendix A), the experimental floors are superior to the aluminum floors to which they are compared, which are among the better floors previously tested.

Introduction

With the greatly increased use of aircraft for transporting heavy cargo during World War II, it was readily apparent that some standardized method for evaluating the performance characteristics of flooring materials for such aircraft must be developed. Such methods would permit comparisons of various types of cargo flooring under load conditions similar to those encountered in actual service and would indicate wherein these floors were deficient in strength. The Forest Products Laboratory, in cooperation with the Bureau of Aeronautics, Navy Department, made an investigation to develop standard test methods and to evaluate several types of flooring then in use or proposed for use.[3] Subsequently, in cooperation with the Air Materiel Command, Army Air Forces (Wright Field), the Laboratory made evaluation tests on other types of flooring and, at the suggestion of the AAF, undertook to develop a floor that would withstand the conditions imposed by service. The Laboratory proposed the development of a sandwich-type floor having a lightweight core, a strong, tough wearing surface with good load-distributing qualities, and a high-strength, lightweight underface to produce a rigid panel.

Exploratory tests were made on a number of panels, in accordance with the procedures described in FPL Report No. 1550,[3] in an attempt to determine which materials were most suitable for the purpose intended and what combinations of materials would provide the desired combination of high strength and light weight. In all, 16 sandwich-type panels were studied. Descriptions of panels X-1 to X-14, inclusive, are given in Appendix B, together with a brief account of their performance under test.

With the information obtained in tests of panel types X-1 to X-14, inclusive, as a basis, materials were selected for the fabrication of panel types X-15 and X-16. The investigation of the strength properties of these panels was more thorough than for the first 14 sandwich panels, and the test results obtained on them were compared to those on the better aluminum floors previously tested.[3,4]

Description of Floor Panels

The aluminum used in panels X-15 and X-16 was 75ST, which having a higher proportional-limit strength and less elongation and being harder than 24ST, was less likely to extrude under the action of the rolling load than 24ST.

The description of the panels being compared, from the upper or wearing surface down through the panel, is as follows:

Floor X-15. --0.032-inch 75ST aluminum; five-ply 5/32-inch maple plywood (grain direction of face ply oriented in the transverse direction); 0.625-inch paper honeycomb core; and 0.016-inch 75ST aluminum.

Floor X-16. --0.032-inch 75ST aluminum; seven-ply 7/32-inch maple plywood (grain direction of face ply oriented in the transverse direction); 0.625-inch paper honeycomb core; and 0.016-inch 75ST aluminum. An edge view of this floor is given in figure 1.

These panels were fabricated in accordance with the procedure outlined in Appendix B.

Floor H. --Floor H consisted of a flat aluminum-alloy sheet 0.064 inch thick, spot-welded to a corrugated aluminum-alloy sheet 0.051 inch thick. The corrugations were 1-1/4 inches deep, with flat tops 3/4 inch wide spaced 3 inches from center to center and with webs inclined to the vertical.

Floor I. --Floor I consisted of a flat aluminum-alloy sheet 0.064 inch thick spot-welded to a corrugated aluminum-alloy sheet 0.040 inch thick. The corrugations were square, 1-1/2 inches wide and deep, and spaced 3 inches from center to center. The open corrugations were blocked over the floor beams with Sitka spruce filler blocks. A rough-wearing surface was provided on the flat sheet by an application of nonskid material.

Floor M. --Floor M consisted of a flat aluminum-alloy sheet 0.032 inch thick, spot-welded to a dimpled aluminum-alloy sheet of the same thickness. The dimpled sheet had protrusions extending above and below the plane of the sheet about 0.08 inch to form 1/2-inch squares spaced 13/16 inch from center to center. The upper two sheets were spot-welded to a similarly dimpled sheet, of the same thickness and formed to nearly rectangular corrugations with the webs inclined slightly. The corrugations were about 1-1/8 inches deep and spaced at 1-5/8 inches center to center.

Methods of Tests

The panels were trimmed, weighed, and measured, and were then prepared, as required, for use as specimens. The following tests were made in accordance with methods specified for evaluation of this material and described in an earlier report.[3]

- Static bending: Over an 8- and 16-inch span.
- Strip loading: Under a 1-1/4- by 9-inch steel bar.
- Concentrated loading: Applied by a 1-inch-diameter steel cylinder and by a 2-1/2-inch-wide maple block shaped to a 4-inch radius.
- Impact loading: Under the drop of a 200-pound softwood box corner.
- Rolling load: Applied by an engine cradle wheel.

Presentation of Data

Complete test data are presented for experimentalfloor X-16, together with such data as were obtained for floor X-15.

Weight

Comparative weight data for floors X-15, X-16, as well as for floors H, I, and M, are given in figure 2.

Static Bending

The results of static-bending tests for floor X-16 and for the three aluminum floors are given graphically in the form of typical load-deflection curves in figures 3 and 4. The specimens were tested over two span lengths to obtain data on the effect of high shear stress in the core on the strength in flexure. Figure 5 shows typical test specimens of floor X-16 after flexure tests.

Strip Loading

The effect of strip-loading tests to simulate the action of a floor beam on the underside of a test panel is shown in figure 6. A typical curve showing the relationship between load and deformation for strip-loading tests for floor X-15 and like curves for the three aluminum panels are given in figure 7. The curve for tests on panel X-16 is similar to that for panel X-15.

Concentrated Loads

Visual evidence of damage due to the application of the concentrated loads on panel X-16 may be noted in figure 8. In figures 9 and 10 are typical load-deflection curves for panel X-16 and for the aluminum panels, which may be used together with visual evidence of damage as a measure for evaluating the resistance of the panel to loads of this type.

Impact Loading

Impact loading, simulating the effect obtained by dropping a 200-pound box on a corner from various heights above the panel, produced the effects on panel X-16 shown in figures 11 and 12. Load-deflection curves giving the relationship between load, deflection, and permanent set are presented for the several types of panels in figures 13 and 14.

Rolling Load - Engine Cradle

Wheel loads of 800, 1,000, and 1,300 pounds were used (each on a new panel) on floor panels of the X-15 type, and for each magnitude of load the number of trips or number of load repetitions required to cause failure of any sort was recorded. Similar information was obtained for panel X-16, with loads of 800, 1,000, 1,250, and 1,500 pounds. Visual evidence of damage to these panels is given in figures 15 to 23, inclusive. It should be noted that tests under the 800- and 1,000-pound wheel loads were not carried to complete failure. A semilogarithmic plot of the load-number of trips to failure for the several panel types under discussion is given in figure 24.

Analysis of Results

Weight

Floor X-16 weighed 2.19 pounds per square foot, and floor X-15 1.95 pounds per square foot. On this basis, floor X-16 is comparable in weight to floor I, while floors X-15, H, and M weigh approximately the same. It was originally proposed to develop floors weighing about 2 pounds per square foot.

Static Bending

Static-bending specimens tested over a 16-inch span failed in tension of the lower aluminum facing material at or near the center of the span at the maximum load imposed on the specimen. As a result of this type of failure, the load-carrying capacity of the specimen is sharply reduced the moment the failure takes place, as shown in figure 4. When tested over an 8-inch span, failures occurred either in tension or in shear between the core material and the plywood. It is evident from figures 3 and 4 that floor X-16 is less stiff than the aluminum floors, but the deflection is not excessive in any case, and its load-carrying capacity appears entirely satisfactory.

Strip Loading

Strip-loading tests, which simulate the reaction of floor beams on the underside of floors, showed the paper-honeycomb-core panels of the X-15 and X-16 type to be markedly stronger than the all-aluminum floors. Compression tests on samples of the core material showed it to have a compressive strength of approximately 2,000 pounds per square inch.

Concentrated Loading

Although floor X-16 has a core having a high compressive strength, its wearing surface does not add a great deal to this strength in the form of resistance to puncture from concentrated loads, as shown in figures 9 and 10. When the floor is supported as for this test, it is evident that it deflects somewhat less at loads less than the maximum than do the aluminum floors to which it is compared.

Impact Loading

Floor X-16 deflected somewhat more than floors H and I and somewhat less than floor M when loaded in impact by a 200-pound box corner dropped from heights up to 15 inches. The permanent deformation, however, compared very well to that of the better aluminum floors. None of the drop tests damaged floors X-15 or X-16 to such a serious extent that the wearing surface was punctured or dented so deeply as to constitute a hazard in placing cargo. On this test basis, therefore, the experimental floors are considered satisfactory.

Rolling Load - Engine Cradle

The data from the rolling-load test plotted in figure 24, show that the experimental floors X-15 and X-16 are equal or superior in resistance to this type of loading to the three aluminum floors, which are in turn among the better types of floors previously tested. At low loads of 800 and 1,000 pounds, the test on floor X-16 was discontinued at 5,500 and 3,500 trips, respectively, without any indication of complete failure or rupture of the wearing surface. The 75ST aluminum used in these experimental floors was much more satisfactory than 24ST aluminum in all respects, and no difficulty due to extrusion or cold working with repeated applications of the wheel load was apparent.

Conclusions

Upon the basis of the tests, experimental floors X-15 and X-16 compare favorably to three of the better floors previously tested. The sandwich combination, with a wearing surface that can distribute the load and resist concentrated and impact loads, with a lightweight core, and with a strong facing material on the underside of the panel, makes a strong, rigid cargo flooring material. If further research were undertaken, it might be directed toward the use of magnesium instead of aluminum to reduce the weight of the floor; or toward making the core of a lighter-weight paper, in order to increase stiffness by increasing the over-all height without a weight increase and without weakening the panel excessively, since such a core has adequate compressive strength. A system of ratings developed for evaluation of cargo floor panels has been used to rate panels X-15 and X-16 and is included in Appendix A.

Table 1. --Comparative ratings of air-cargo floors based on best results obtained from Forest Products Laboratory weight, impact, and rolling-load tests, according to tentative method A

Type of test	Floor				
	X-15	X-16	H	I	M
Weight per square foot......Pounds	1.95	2.19	1.93	[1]2.12	1.86
Engine-cradle rolling load sustained for 500 trips......Pounds	1,230	1,400	950	1,100	1,230
Allowable height of drop of 200-pound-box corner.........Inches	15	15	15	15	8

Criteria for satisfactory floors, based on best results

Weight = 1.42 pounds per square foot. Rolling load = 1,450 pounds.
Impact = 15 inches.

Criteria	Percentage rating of floors based on criteria				
Weight..........................	73	65	74	[1]67	76
Rolling load......................	85	97	66	76	85
Impact..........................	100	100	100	100	53
Sum............................	258	262	240	243	214
Rating..........................	86	87	80	81	71

[1]Weight of nonskid surfacing included.

Table 2. --Comparative ratings of air-cargo floors based on best results obtained from Forest Products Laboratory weight, impact, and rolling-load tests, according to tentative method B

Type of test	Floor				
	X-15	X-16	H	I	M
Weight per square foot......Pounds	1.95	2.19	1.93	[1]2.12	1.86
Engine-cradle rolling load sustained for 1,000 trips.....Pounds	1,080	1,240	750	900	1,080
Allowable height of drop of 200-pound-box corner.........Inches	15	15	15	15	8

Criteria for satisfactory floors, based on best results

Weight = 1.42 pounds per square foot. Rolling load = 1,300 pounds. Impact = 15 inches.

Criteria	Percentage rating of floors based on criteria				
Weight..........................	73	65	74	[1]67	76
Rolling load......................	83	96	58	69	83
Impact..........................	100	100	100	100	53
Sum............................	256	261	232	236	212
Rating..........................	85	87	77	78	71

[1]Weight of nonskid surfacing included.

APPENDIX A

Comparative Ratings of Floors X-15, X-16, H, I, and M

Results of Forest Products Laboratory tests and ratings by tentative methods A and B, as described in Forest Products Laboratory Report No. 1550,[3] are presented for floors X-15, X-16, H, I, and M in tables 1 and 2.

APPENDIX B

Materials, Fabrication Methods, and Exploratory Studies on Sandwich-type Cargo Floors

Description of Materials

Cargo floor panels included in this investigation consisted of a number of different combinations of plywood, papreg, aluminum alloy (either 24ST or 75ST), and either paper honeycomb core or expanded plywood core.

Descriptions of materials used in the investigation follow:

Papreg. -- A high-strength paper laminate made by treating a Mitscherlich-type paper with a thermosetting phenol resin. The impregnated sheets were assembled so that the machine direction (fiber grain) of each lamination was at right angles to that of the adjacent lamination. The assembly was molded in a hot press.

Paper honeycomb core. --The paper honeycomb used as a core material in the floor assemblies was made from paper 0.009 inch thick treated with 10 to 15 percent water-soluble phenol resin. The resin-treated paper was then corrugated on the B-flute rolls of the Laboratory's corrugating machine, after which it was cured for about 6 hours at 125° C. The nodes of the cured corrugated sheets were coated with resin, and the sheets were stacked node to node to form a block, as shown in figure 25. The assembled block was heated for approximately 3 hours at 125° C. to effect a cure of the contact resin. The process resulted in a core material of about 0.18 specific gravity. Sections of the block were cut to the desired core thickness, as shown in figure 25, with a metal-cutting saw having 4 to 4-1/2 teeth per inch and running at 4,500 feet per minute. The strips thus obtained were glued together with a phenol-resin adhesive in a high-frequency edge-gluing machine (figs. 26 and 27) to form a large panel with a meshing of the corrugations of adjacent strips. After assembly, the cores were lightly sanded to remove excess glues and surface imperfections.

Expanded plywood core. --The core for floor X-10 consisted of three-ply (1/32-, 1/60-, 1/32-inch) yellow birch plywood; for floor X-14, the plywood had face plies of 1/32-inch birch and a core of 1/40-inch yellow-poplar veneer. The plywood was assembled into the panel with grain of the face plies in the vertical direction or perpendicular to the facing of the sandwich panel.

To fabricate the expanded plywood core, a strip of three-ply resin-bonded plywood approximately 4 inches wide was laid in the assembly jig, and at 2-3/8-inch intervals a thin strip of veneer coated with hot-setting glue and air-dried was laid crosswise on this strip, as indicated in figure 28(a). By placing successive strips of plywood alternately with strips of the glued veneer in the jig, a pile was built up to a compressed thickness of about 1-1/2 inches, with the glued veneer strips offset one-half their spacing in the alternate layers. The loosely assembled panel was then taped tightly in order to hold the glued veneer strips in place and hot-pressed until the glue lines were cured. Since it was desirable to build a thicker panel in order to secure a greater expanded dimension, a procedure was devised by use of an insert ply with the glued veneer strips taped onto both its sides (fig. 28(b)), that permitted an immediate consolidation of two or more individual blocks into a single thick block. This was done as follows: Two blocks of equal thickness were hot-pressed simultaneously, and the locations of glue lines were indicated on the two surfaces to be joined to form a single block. Immediately following the end of the pressing period, the press was opened, the insert ply was laid on the surface of one block, and then the other block was placed above it in such a way that the alternate spacing of the glued veneer strips was maintained throughout the entire block. Paper tubes were used to keep the hot surfaces of the assembled blocks from contacting the glued veneer strips of the inserted ply until pressure was applied. The press was then closed upon the double-thickness block, and the retained heat within the recently pressed blocks was adequate to cure the layer of inserted glued veneer strips. In this stepwise manner it is feasible to develop a consolidated block of considerable thickness.

After the block of the desired thickness was pressed and allowed to cool, strips of the desired thickness or core depth were cut from it with a band saw. Although the particular core constructions desired had a high percentage of end grain, it was still practical to finish the sawed strips on the joiner and single-head planer.

The strip of compact machined material was then placed in a hot-water soaking bath until thoroughly soaked. Then cord loops were placed through each edge opening, and the panel was prepared for expansion, as shown in figure 29. Since an appreciable length of time was required to insert the cords, the strip with loops and expansion bars in place was again placed in the soaking bath for several minutes and then removed, and the panel was then expanded while still in the hot, wet condition. After expansion to the desired degree, the expansion bars were clamped in place and the expanded panel allowed to dry. Figure 30 shows the expanded dried panel in the drying rack.

Plywood.--The plywood made from yellow-poplar or maple veneers was all resin-bonded in a hot press with the grain direction of adjacent plies at right angles to each other.

Aluminum Alloy.--Aluminum alloys 24ST or 75ST were used in several thicknesses.

Fabrication of Cargo Flooring Panels

The identification marks printed on the sheet aluminum were removed by washing with acetone. This was followed by cleaning and etching the sheets in a sulfuric acid-sodium dichromate bath (10 parts by weight of concentrated sulfuric acid, 1 part of sodium dichromate, and 30 parts of water) for 20 minutes at 145° F. or 8 to 10 minutes at 160° F. The sheets were etched for a time sufficient to obtain a smooth, unbroken water film when they were subsequently rinsed with water. The sheets were then placed in a wood rack to dry.

After the sheets dried over night, one side of each was sprayed with a hot-setting, modified thermoplastic resin. This cement was applied in six spray coats with 30 minutes drying time allowed between each coat and a 24-hour drying period after the final coat. The cement was then cured in a press at 325° F. for 30 minutes. The surface was sanded with fine sandpaper to remove slight irregularities caused by spraying and wiped with a clean cloth moistened with methyl alcohol. The aluminum sheets were then ready for gluing.

The only preparation necessary for the plywood was to sand the surfaces lightly to obtain a clean surface for gluing.

The adhesive used to fabricate the cargo flooring panels was a phenolic resin adhesive. This adhesive was applied to the surfaces to be glued with a rubber roller. The weight of the spread used for the various components was as follows:

(1) Top aluminum sheet -- 8 grams per square foot.
(2) Plywood (face to aluminum) -- 8 grams per square foot.
    Plywood (face to paper honeycomb) -- 20 grams per square foot.
(3) Paper honeycomb core -- 4 grams per square foot on each side.
(4) Bottom aluminum sheet -- 20 grams per square foot.

The spread components were air-dried for 1 to 24 hours before they were assembled, to allow the escape of volatile solvents from the adhesive. The panels were then assembled in the order shown above, cured in a press at a temperature of 220° F. and a pressure of 40 pounds per square inch for 1-1/4 hours, with two sheets of heavy paper on each side of the panel for cauls, and removed from the press while hot. The panels were then trimmed to size and were ready for tests.

Description of Floor Panels

To facilitate the presentation of data, each type of floor was given the general identification letter X, followed by a number. Unless otherwise indicated, the "core" will refer to paper honeycomb core, and the corrugated sheet will run in the long direction of the panel. The description of each floor will start at the upper or wearing surface and continue down through the panel.

Floor X-1. --1/16-inch papreg; nine-ply 9/32-inch yellow-poplar plywood (grain of face plies in the transverse direction); 1-inch core; and 0.012-inch 24ST aluminum.

Floor X-2. --1/16-inch papreg; 1/4-inch end-grain yellow-poplar; 0.012-inch 24ST aluminum; 1-inch core; and 0.012-inch 24ST aluminum.

Floor X-3. --0. 040-inch papreg; 1/32-inch birch veneer (face grain placed in the transverse direction); seven-ply 7/32-inch yellow-poplar plywood; 1/32-inch birch veneer, 0. 012-inch 24ST aluminum; 1-inch core; and 0. 012-inch 24ST aluminum.

Floor X-4. --1/16-inch papreg; 0. 012-inch 24ST aluminum; seven-ply 7/32-inch yellow-poplar plywood; 1-inch core; and 0. 012-inch 24ST aluminum.

Floor X-5. --1/16-inch papreg; seven-ply 7/32-inch yellow-poplar plywood; 1-inch core; and 0. 020-inch 24ST aluminum.

Floor X-6. --0. 040-inch papreg; 0. 032-inch 24ST aluminum; five-ply 5/32-inch plywood (birch faces - yellow-poplar interior); 1-inch core; and 0. 012-inch 24ST aluminum.

Floor X-7. --0. 032-inch 24ST aluminum; 1/16-inch maple veneer, placed with the direction of grain in the longitudinal direction; 1/16-inch maple veneer placed with direction of grain in transverse direction; 1-1/8-inch core; and 0. 012-inch 24ST aluminum.

Floor X-8. --0. 012-inch 24ST aluminum; 0. 040-inch papreg; and seven-ply 7/32-inch yellow-poplar plywood mounted on a heavy solid-wood base not considered a part of the floor assembly.

Floor X-9. --0. 032-inch 24ST aluminum; seven-ply 7/32-inch maple plywood; 0. 625-inch core; and 0. 012-inch 24ST aluminum.

Floor X-10. --0. 032-inch 24ST aluminum; seven-ply 7/32-inch maple plywood; 0. 625-inch expanded plywood core; and 0. 012-inch 24ST aluminum.

Floor X-11. --0. 020-inch 24ST aluminum; 0. 030-inch papreg; five-ply 5/32-inch maple plywood; 0. 625-inch core; and 0. 020-inch 24ST aluminum.

Floor X-12. --0. 030-inch papreg; seven-ply 7/32-inch maple plywood; 0. 625-inch core; and 0. 012-inch 24ST aluminum.

Floor X-13. --0. 020-inch 24ST aluminum; seven-ply 7/32-inch maple plywood; 0. 60-inch core (corrugated sheet running in the transverse direction); and 0. 012-inch 24ST aluminum.

Floor X-14. --0. 032-inch 24ST aluminum; seven-ply 7/32-inch maple plywood; 0. 60-inch expanded plywood core; and 0. 012-inch 24ST aluminum.

Methods of Test

The tests were conducted according to the methods described in FPL Report No. 1550.[3] Unless otherwise indicated, the rolling-load test was conducted with a weight of 800 pounds on the engine cradle wheel, and the impact test with the 200-pound softwood box corner dropped from the indicated heights.

Description of Test Results

Floor X-1

Floor X-1 weighed 2.32 pounds per square foot. Initial failure, crushing in the core, was observed after 75 trips of the rolling load, and the papreg wearing surface began to delaminate after 100 trips. Complete failure occurred after 491 trips. The floor was badly damaged by drop tests from heights of 8 and 15 inches, but did sustain a concentrated load on a 1-inch-diameter steel cylinder, before failure, of 2,170 pounds.

Floor X-2

Floor X-2 weighed 2.42 pounds per square foot. End-grain yellow-poplar was placed between papreg and aluminum in an attempt to provide a wearing surface having greater compressive strength. Initial failure at 200 trips of the rolling load was noted as a separation between the papreg and the yellow-poplar as well as a crushing of the core in the path of the wheel. The ultimate failure at 512 trips showed the end-grain yellow-poplar to be sheared into small pieces in the area covered by the wheel. Impact tests from heights of 8 and 15 inches severely fractured the wearing surface. The floor withstood a concentrated load of 2,090 pounds on the 1-inch-diameter cylinder.

Floor X-3

Floor X-3 weighed 2.13 pounds per square foot. It was similar in construction to floor X-1, with the exception of the replacement of the outer plies of the yellow-poplar plywood with birch veneers and the addition of a sheet of aluminum between the plywood and the core to strengthen the wearing surface. The initial rolling-load failure occurred after 128 trips as a cracking of the papreg. As the test continued, the papreg tended to separate from the plywood, the plywood became crushed and delaminated, and the core crushed. The floor failed at 1,050 trips of the rolling load. The impact test from 8- and 15-inch heights caused failure of the wearing surface and crushing in the core. The floor held a concentrated load of 1,990 pounds.

Floor X-4

Floor X-4 weighed 2.11 pounds per square foot. It was similar to X-3 in construction, but had the sheet of aluminum directly under the papreg on the wearing surface. Crushing in the core was observed after 200 trips of the rolling load. At 480 trips, the papreg surface began to crack, and after 794 trips, failure of the panel occurred. A 1,680-pound concentrated load did not puncture the wearing surface, but did rupture the panel, possibly because of the small undamaged area available for this test.

Floor X-5

Floor X-5 weighed 1.97 pounds per square foot and was built with a heavier aluminum sheet on the underside of the floor panel. The fact that it withstood only about 50 trips of the rolling load before failure, showed that increased tensile strength of the underside of the panel did nothing to increase its resistance to rolling and impact loads.

Floor X-6

Floor X-6 weighed 2.52 pounds per square foot and was the heaviest floor tested. The use of a thicker sheet of aluminum underneath the papreg and a heavier paper with a high resin content in the core brought about the considerable weight increase. While exceptionally heavy, this floor was much more satisfactory in the rolling-load and impact tests. After 700 trips of the rolling load, the initial failure, a slight crushing of the core, was observed. The plywood began to crush and delaminate after 1,300 trips, and cracks appeared in the papreg at 1,770 trips. After 2,600 trips, the test was stopped without showing any evidence of complete failure. Drop tests from heights of 8 and 15 inches did not puncture the wearing surface, but did cause some failure in the core.

Floor X-7

While the tests of floor X-6 were generally satisfactory, the floor was much too heavy, and efforts were directed at means for reducing the weight while maintaining the desired strength characteristics. Floor X-7 weighed 2.30 pounds per square foot and had an aluminum wearing surface over two plies of 1/16-inch maple veneer. After 945 trips of the rolling load, the aluminum cracked along the edge of the wheel track; while this did not cause complete failure, the core had by that time failed in shear. The impact tests did not rupture the wearing surface, but they caused failure in the core, an indication that additional material above the core to distribute the applied loads was necessary.

Floor X-8

Floor X-8 was made to check the suitability of aluminum for the upper surface. When the panel was rigidly supported, 1,000 trips of a rolling load of 1,300 pounds did not cause delamination and caused only a small amount of extrusion of the aluminum. The yellow-poplar plywood did crush and was eliminated from further consideration as a part of the wearing surface.

Floor X-9

Floor X-9 weighed 2.21 pounds per square foot and was fabricated with maple plywood instead of yellow-poplar plywood in the wearing surface. The floor was fairly satisfactory under the rolling-load and impact tests, although after 1,000 trips of the rolling load the aluminum began to separate from the plywood, possibly due to the extrusion of the aluminum under the load. The floor was still in good condition after 3,000 trips. The wearing surface was undamaged in the drop tests, and only slight damage was evident in the core.

Floor X-10

Floor X-10 was similar to X-9 except for the expanded plywood core replacing the paper honeycomb core. It weighed 2.11 pounds per square foot. Initial failure under the rolling load was observed as a slight delamination between the plywood and aluminum after 800 trips and as a bulging of the lower aluminum surface under the wheel track. After 1,400 trips, the lower aluminum surface began to separate from the core, but no final failure was evident after 3,000 trips, when the test was stopped. Examination of the floor after test revealed that the portion of the core under the path of the wheel had failed vertically in shear at the junctures between the cells. The drop test did not damage the wearing surface from 8- and 15-inch heights, but did tend to cause slight shear failure in the core.

Floor X-11

Floor X-11 weighed 2.10 pounds per square foot. It had a thinner aluminum upper surface than did panel X-9 and had a five-ply plywood replacing the seven-ply. After 400 trips of the rolling load, a bond failure between the papreg and the plywood began. Further separation of the papreg and plywood took place as the test continued, and after 1,200 trips, crushing of the core became evident. Failure along one edge of the wheel track took place after 2,000 trips, at which time the test was stopped. While the 8-inch drop had little effect on the panel, the 15-inch drop caused a failure in the core but without rupture of the wearing surface.

Floor X-12

Floor X-12, weighing 1.98 pounds per square foot, was tested to determine if papreg over maple plywood produced an acceptable wearing surface to eliminate the separation effects due to cold working or extrusion when aluminum was used. This was not a satisfactory construction. The papreg had completely separated from the plywood after 1,600 trips of the rolling load, and the drop test from both 8- and 15-inch heights caused failure of the wearing surface.

Floor X-13

Floor X-13 weighed 2.15 pounds per square foot and, except for a thinner aluminum upper surface and a transverse orientation of the corrugated sheet in the core, the panel was similar to X-9. Three thousand trips of the rolling load did not seriously damage the floor except for extrusion of the upper surface, and the impact test did not rupture the wearing surface.

Floor X-14

An expanded plywood core of slightly different plywood construction than that of panel X-10 was used in the construction of floor X-14 to produce a floor weighing 2.04 pounds per square foot. No serious damage was caused by either 3,000 trips of the rolling loads or the drop tests from 8- and 15-inch heights. The panel did deflect more under load than did X-13, and the core was somewhat damaged in the drop test.

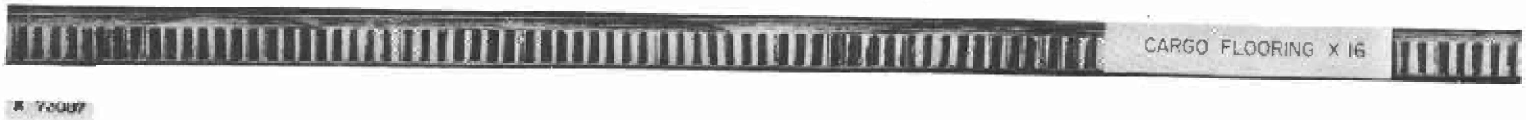


Figure 1.--Edge view of experimental cargo floor test panel X-16.

ZM 78643 F

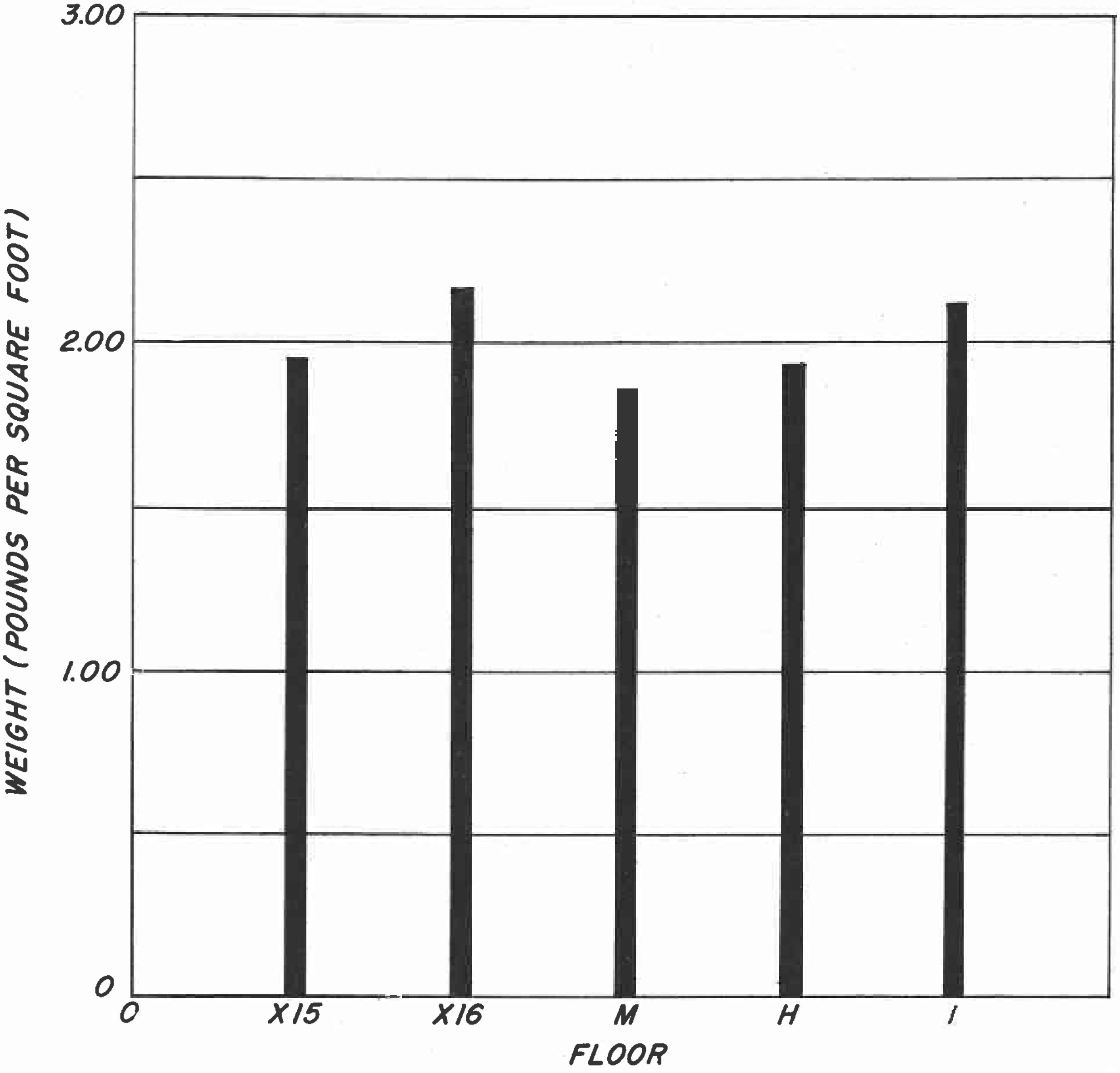


Figure 2.--Weight per square foot of floors X-15, X-16, M, H, and I.

Z M 74788 F

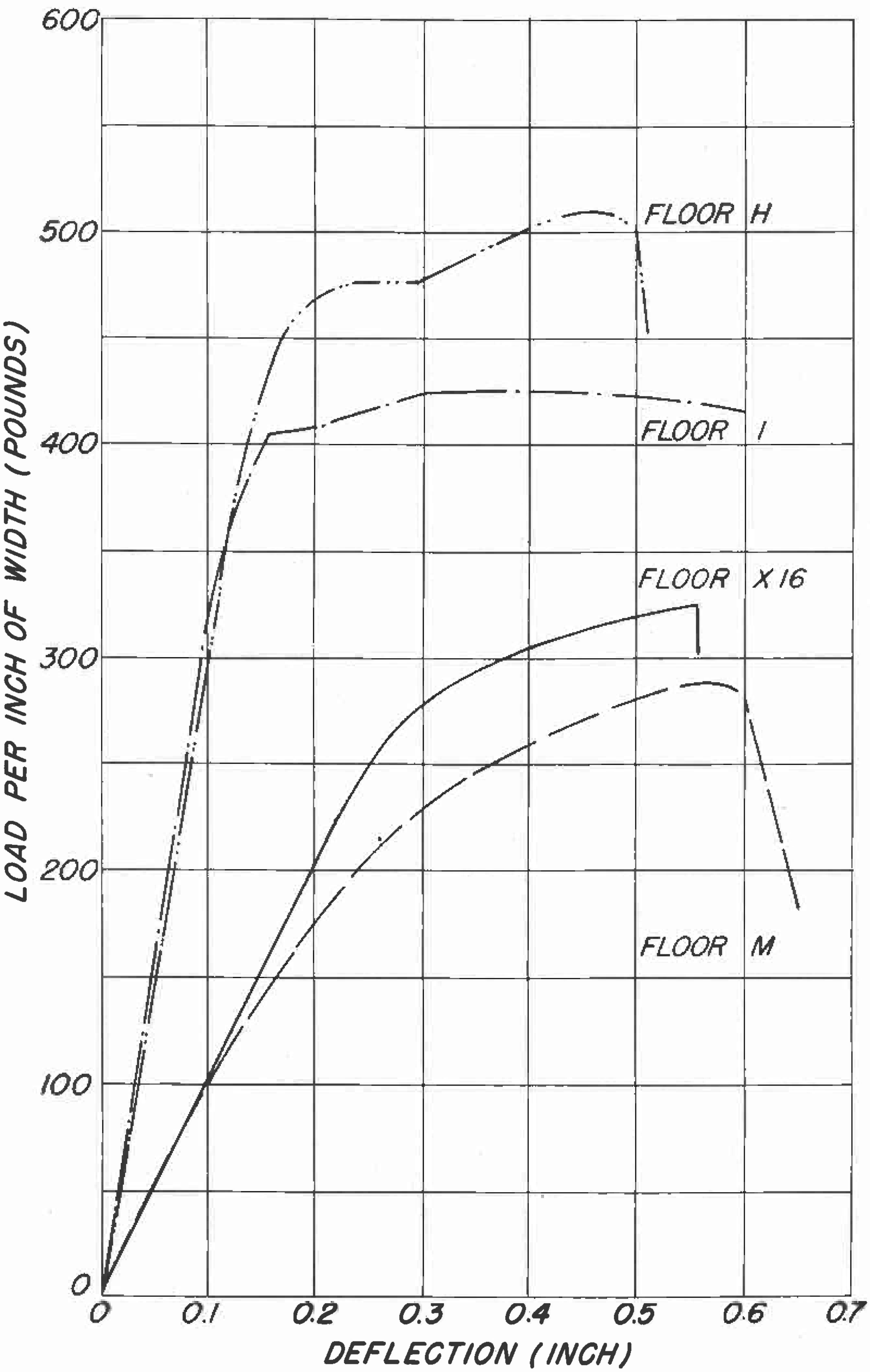


Figure 3.--Typical load-deflection curves from static-bending tests of floors X-16, H, I, and M over an 8-inch span.

ZM 74789 F

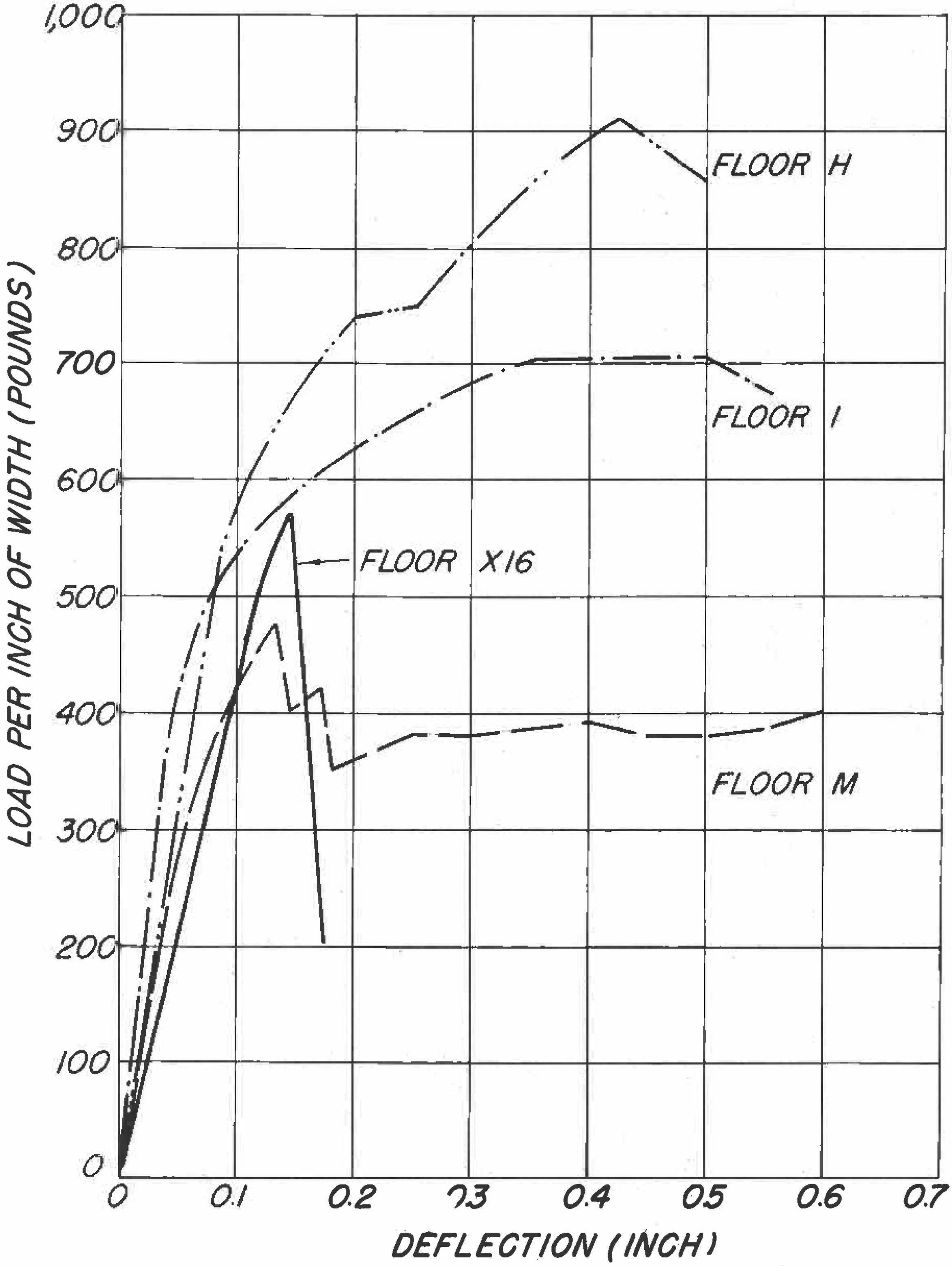


Figure 4.--Typical load-deflection curves from static-bending tests of floors X-16, H, I, and M over a 16-inch span.

Z M 74790 F

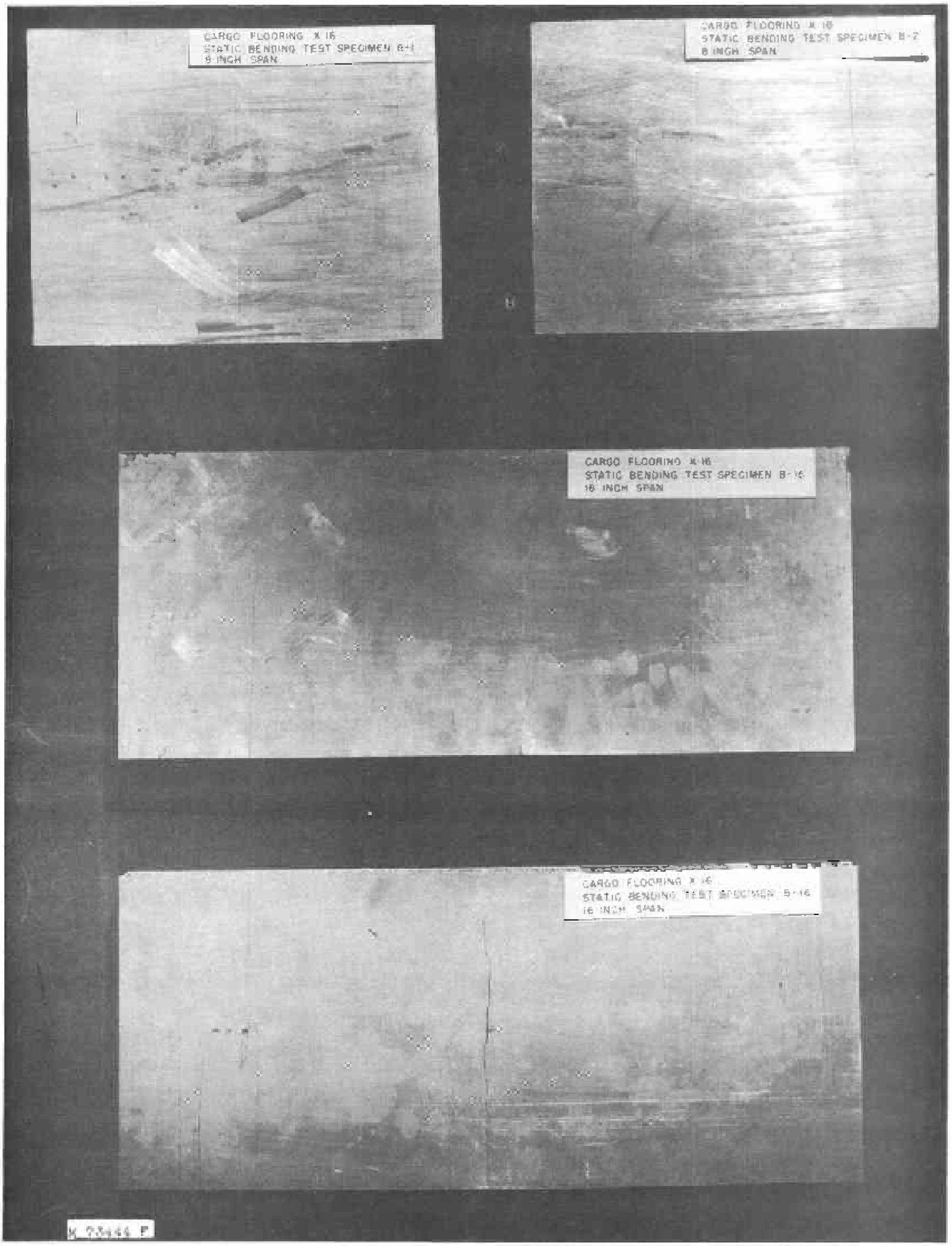


Figure 5.--Static-bending test specimens (8- and 16-inch spans) showing appearance of lower (tension) surfaces after test. Note: tensile failure in aluminum face.

Z M 78644 F

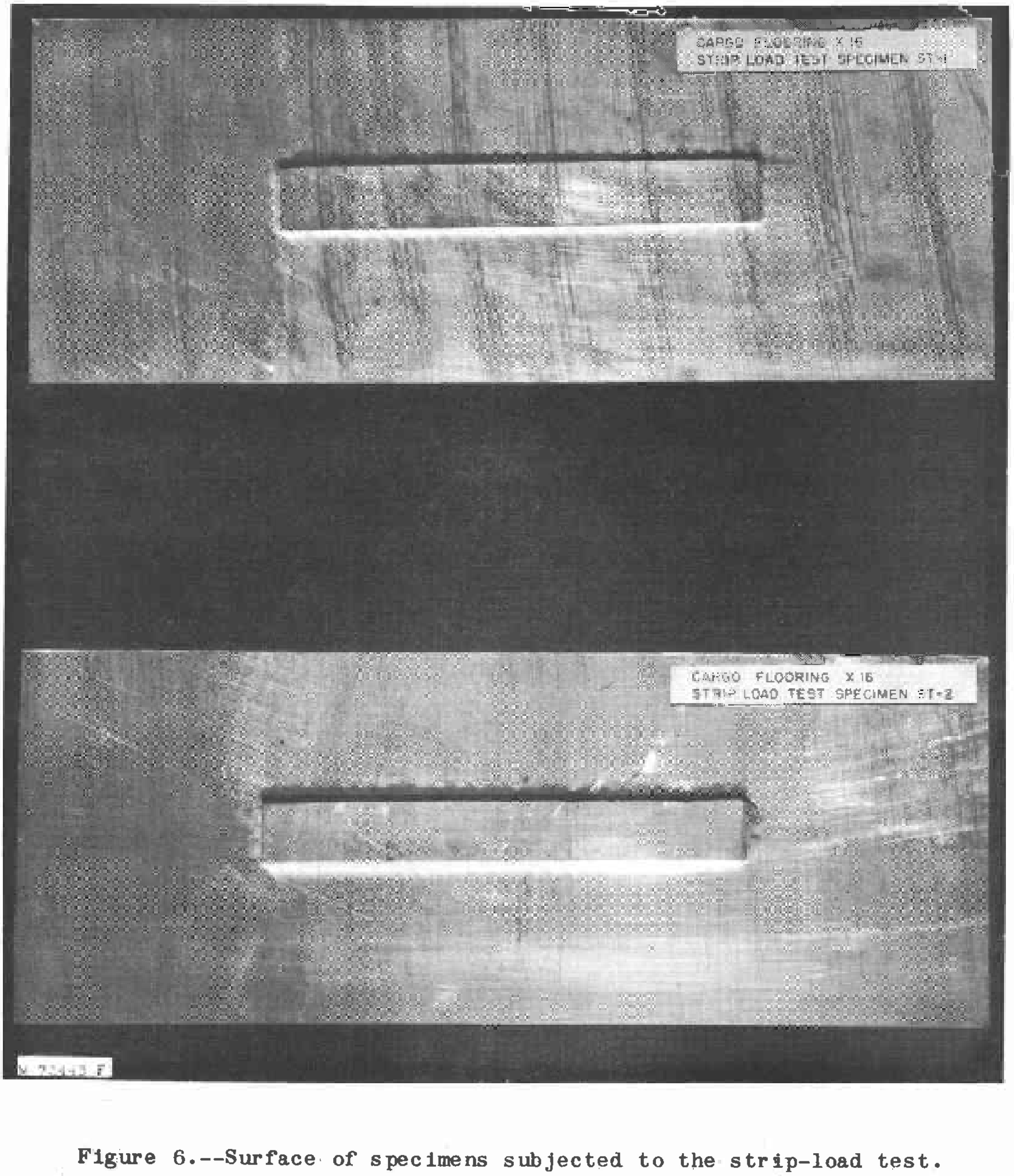


Figure 6.--Surface of specimens subjected to the strip-load test.
ZM 78645 F

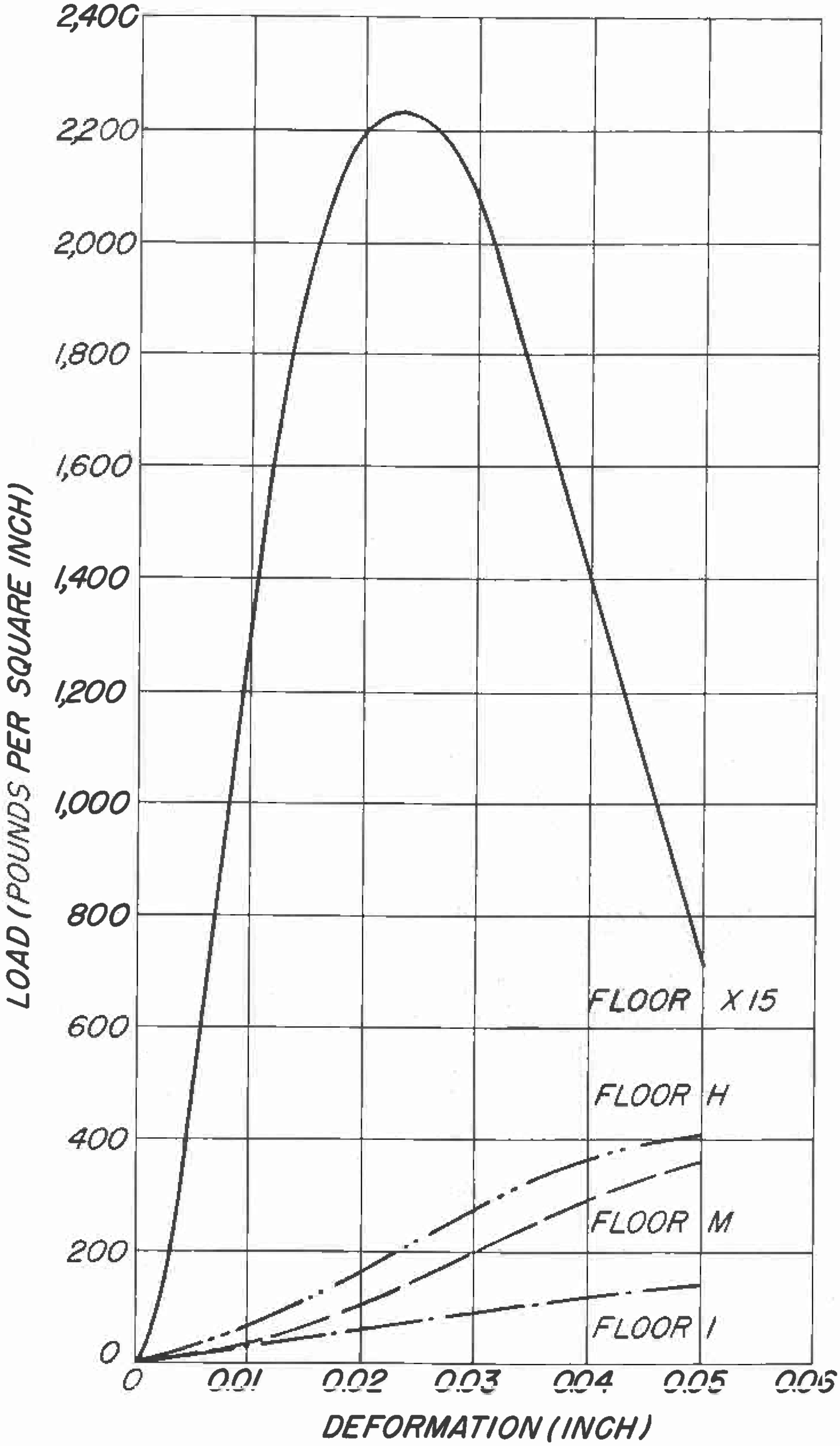


Figure 7.--Typical load-deformation curves from strip-loading compression tests simulating the crushing effect of floor beams on cargo floors X-15, H, M, and I.

Z M 74791 F

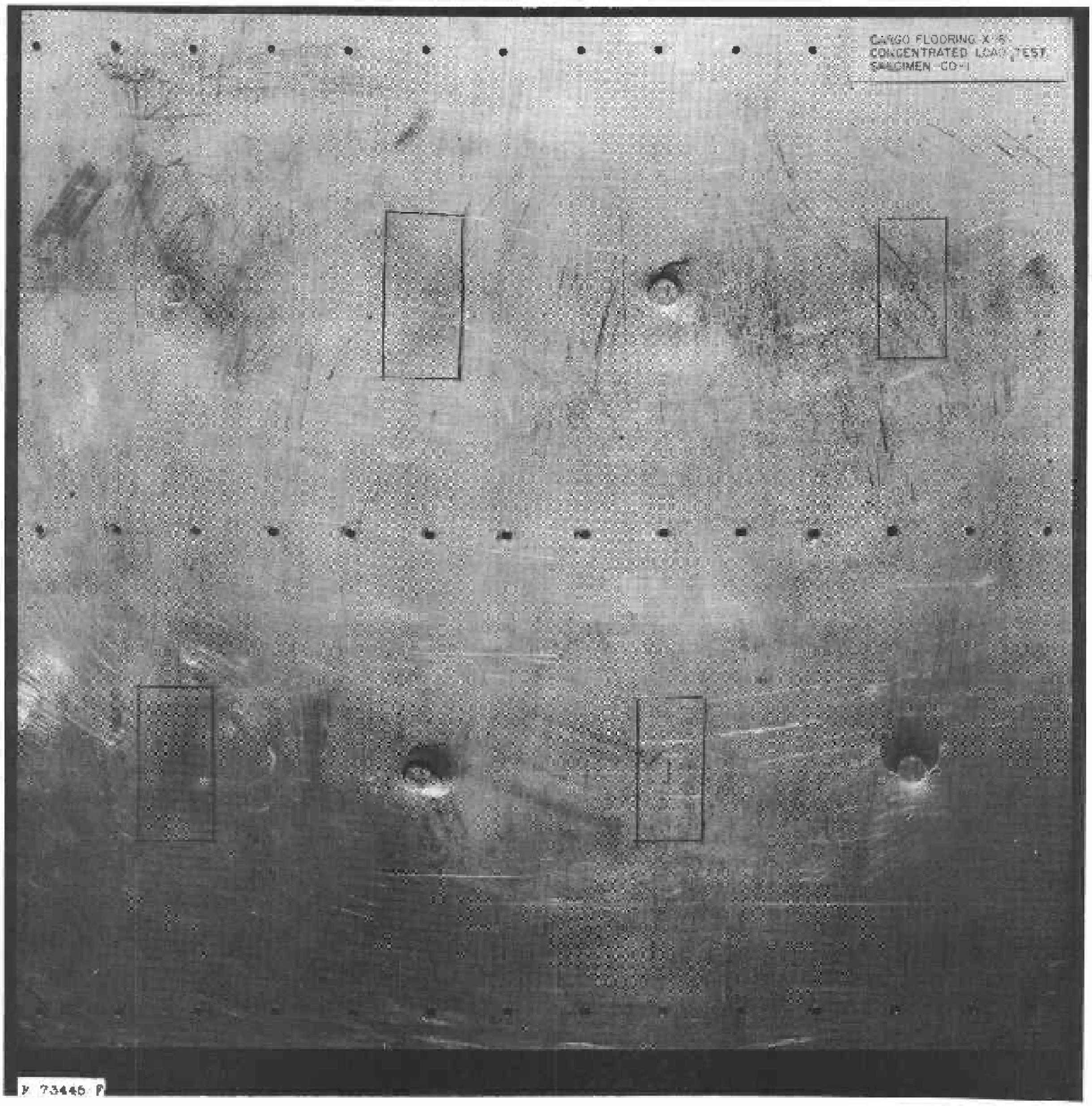


Figure 8.--Test specimen showing the place of application and the effect of concentrated loads on panel X-16.

ZM 78646 F

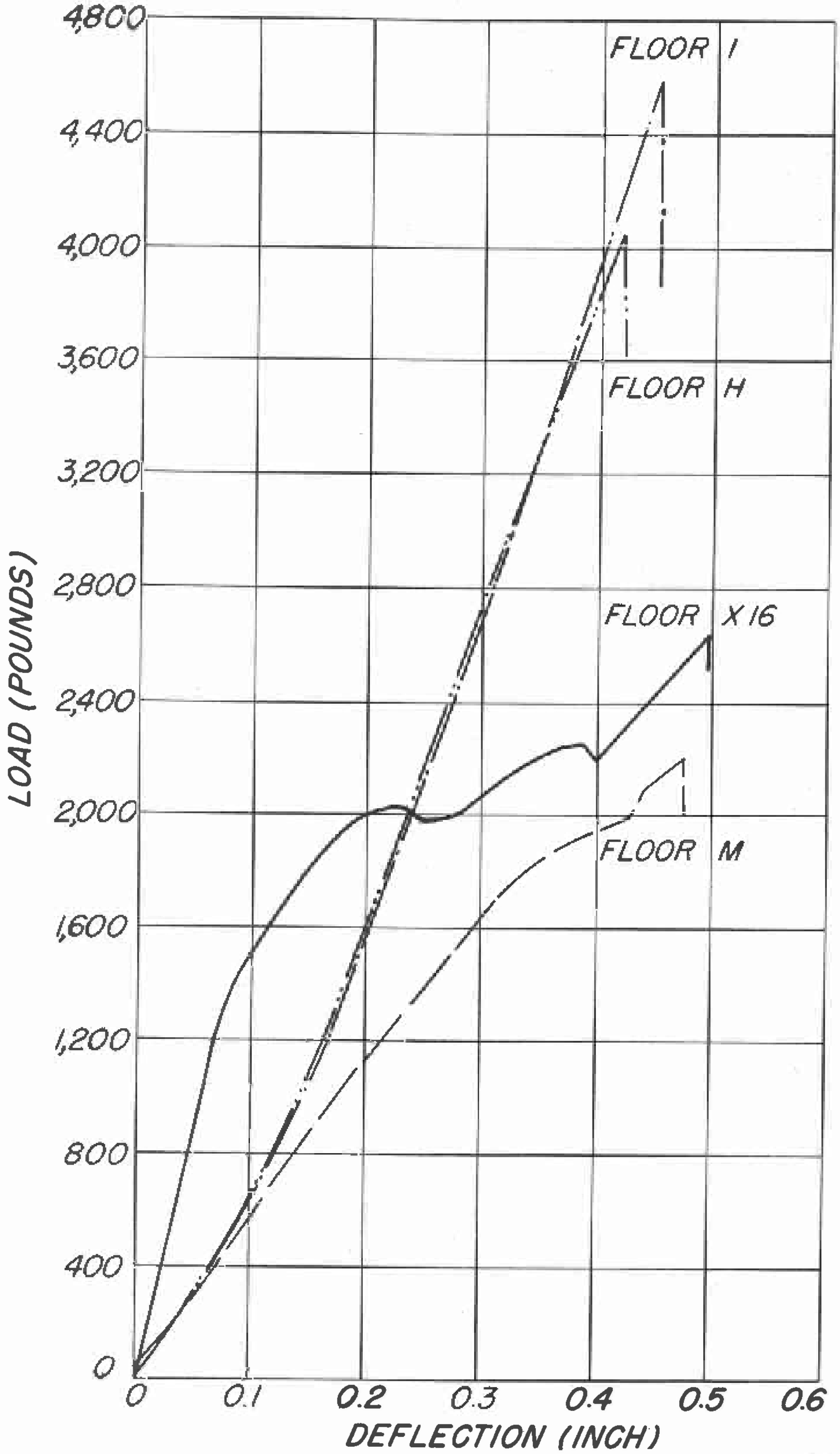


Figure 9.--Load-deflection curves from concentrated load tests on floors X-16, I, H, and M. Specimen loaded at midspan with a 1-inch diameter steel cylinder.

Z M 74792 F

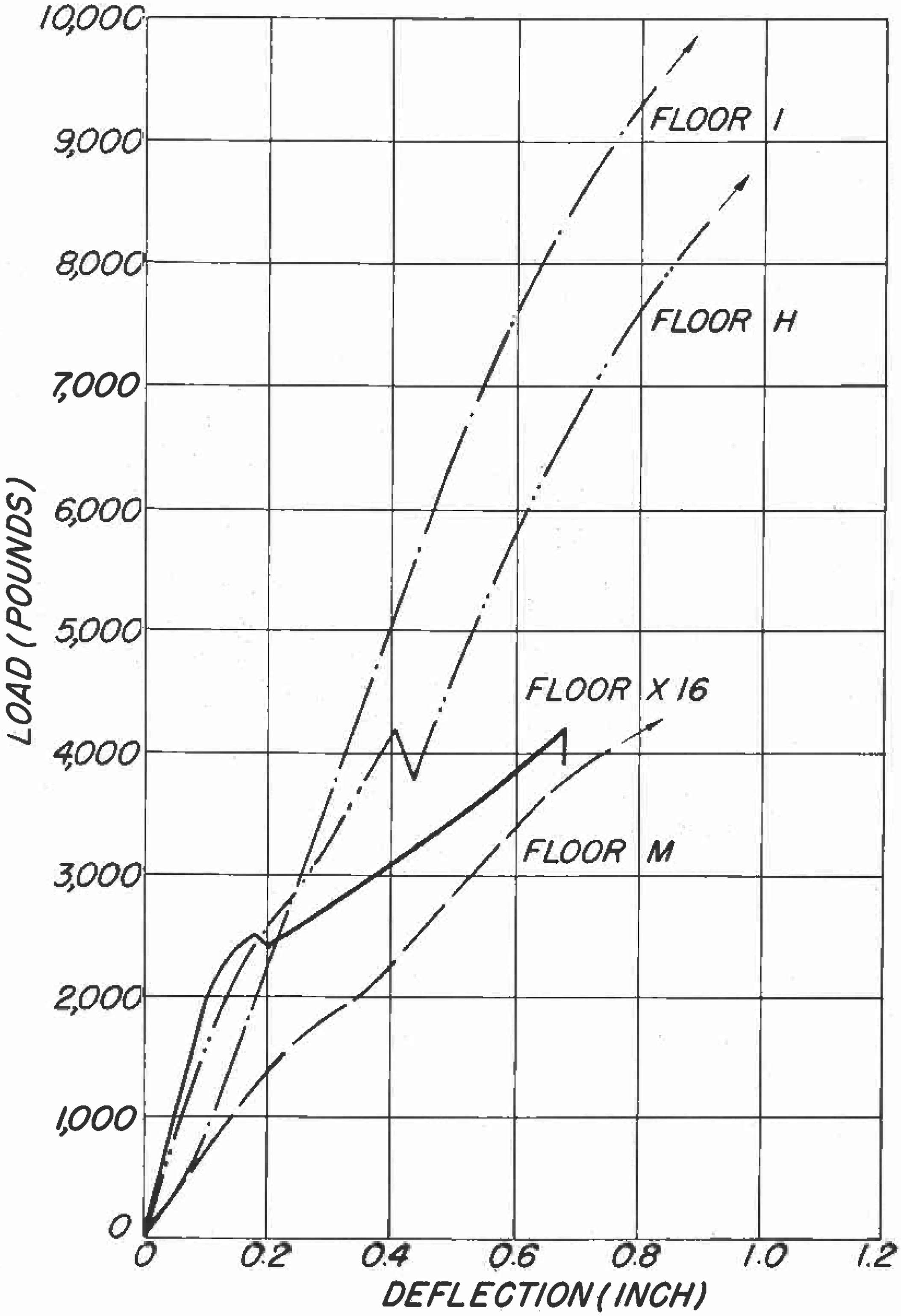


Figure 10.--Load-deflection curves from concentrated load tests on floors X-16, I, H, and M. Specimen loaded at midspan with a maple block simulating an engine cradle wheel 2-1/2 inches wide, shaped to a 4-inch radius.

Z M 74793 F

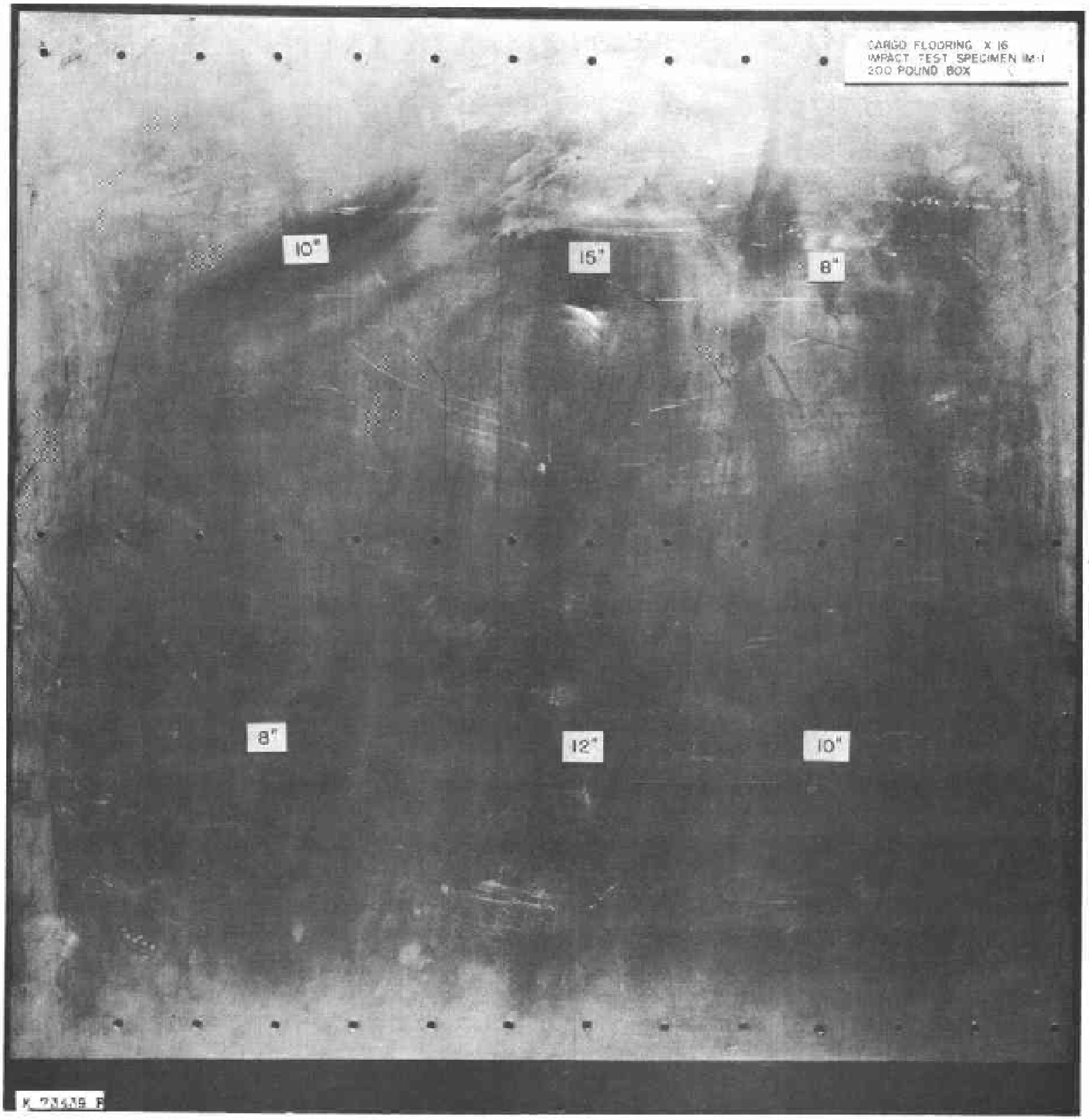


Figure 11.--Upper surface of cargo flooring X-16 impact-test specimen, showing heights and effects of drop of 200-pound-softwood-box corner on this panel.

Z M 78647 F

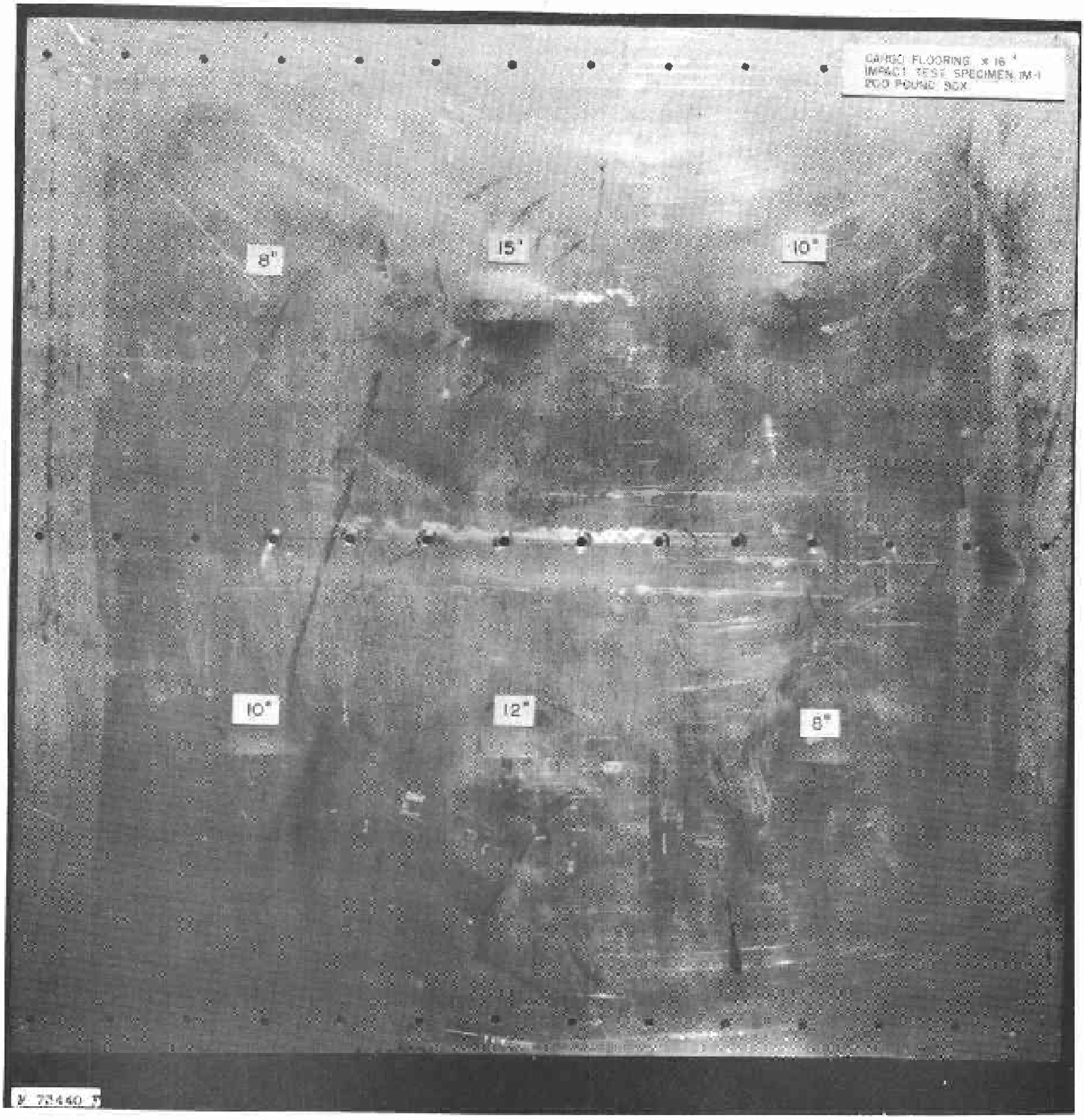


Figure 12.--Lower surface of X-16 impact-test specimen showing heights and effects of drop of 200-pound-softwood-box corner on this panel.

Z M 78648 F

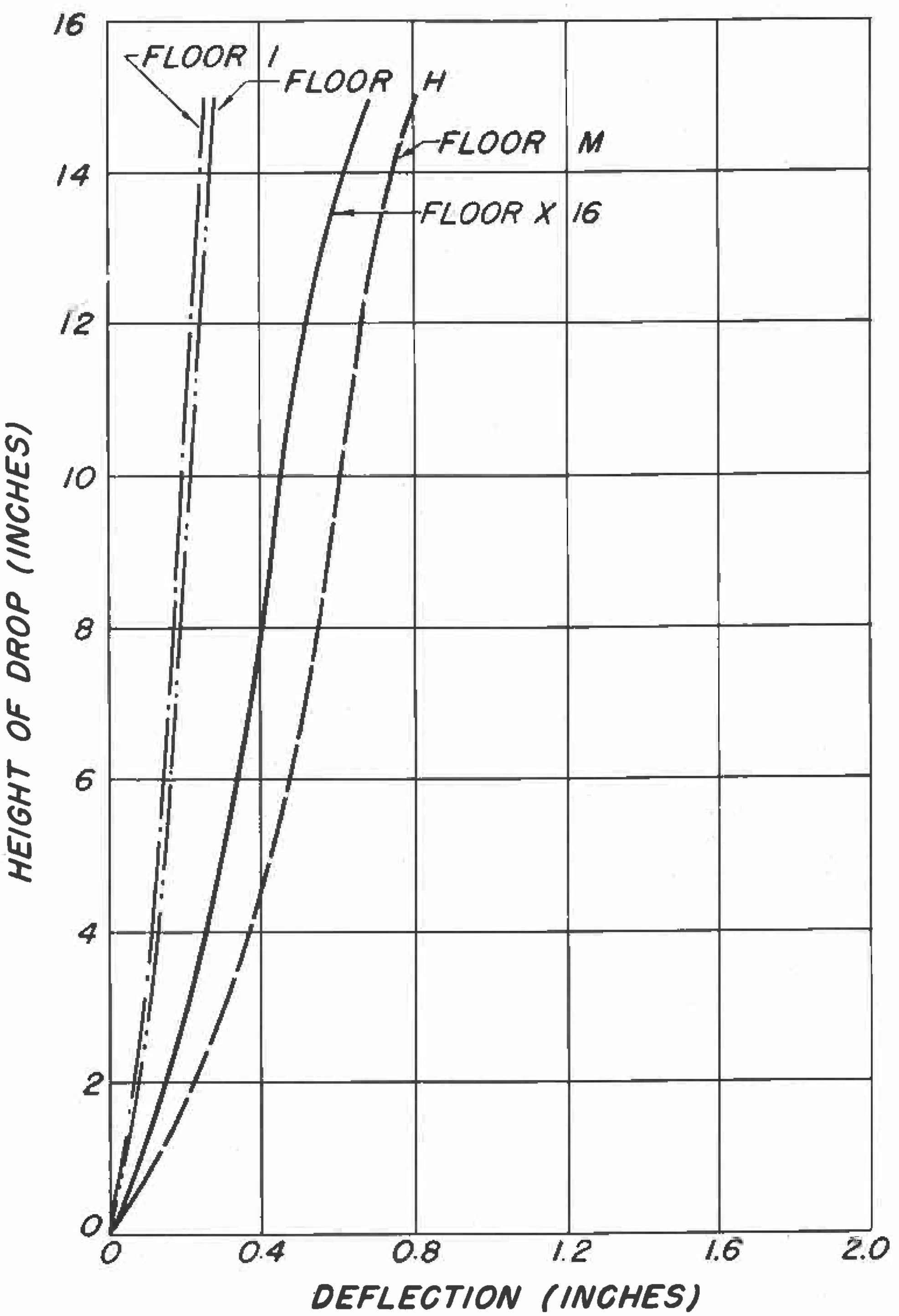


Figure 13.--Relation between height of drop of a 200-pound-softwood-box corner and the deflection under the load point for floor panels X-16, I, H, and M.

Z M 74794

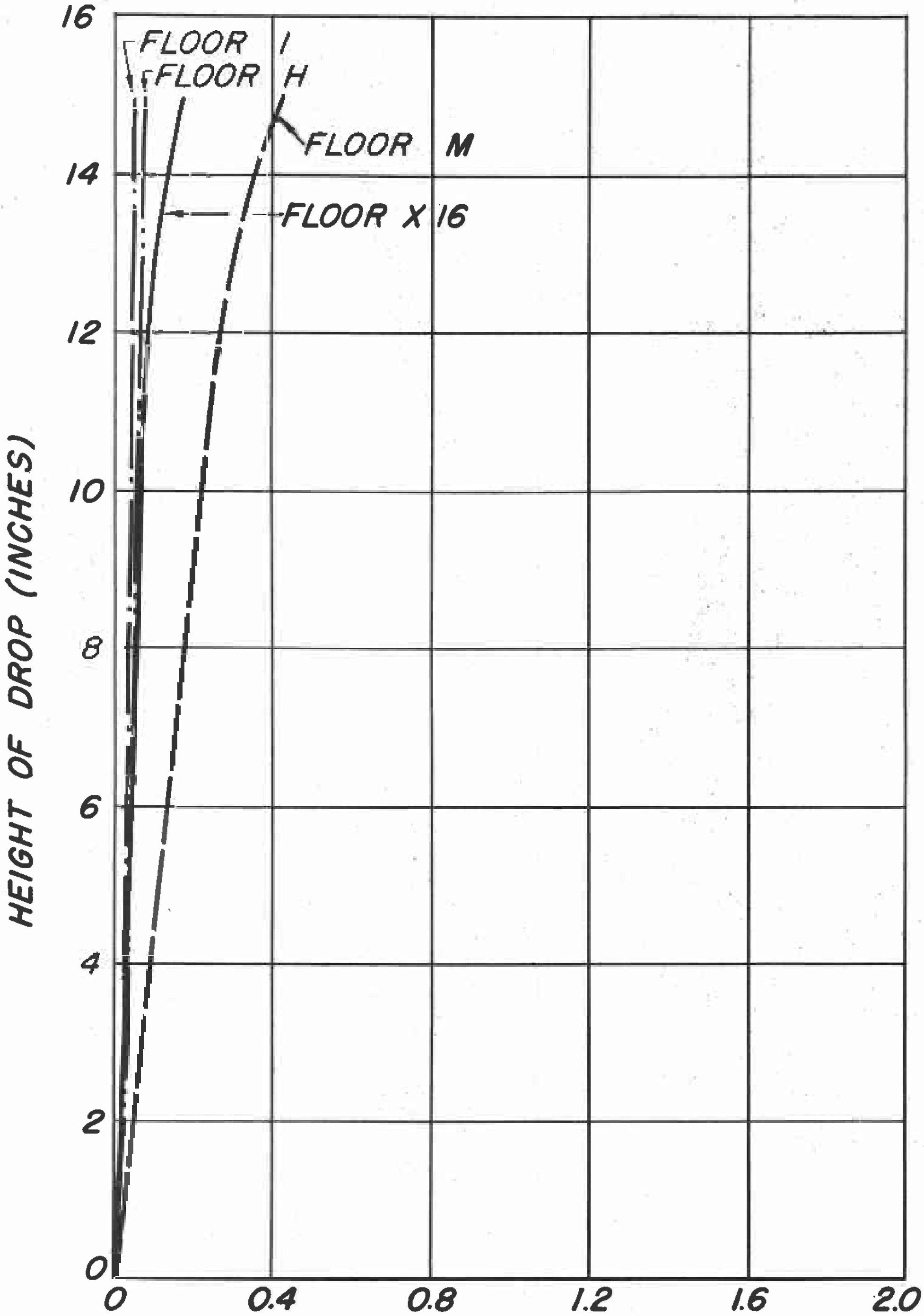


Figure 14.--Relation between height of drop of a 200-pound-softwood-box corner and the permanent deformation under the load point for floors X-16, I, H, and M.

Z M 74795 F

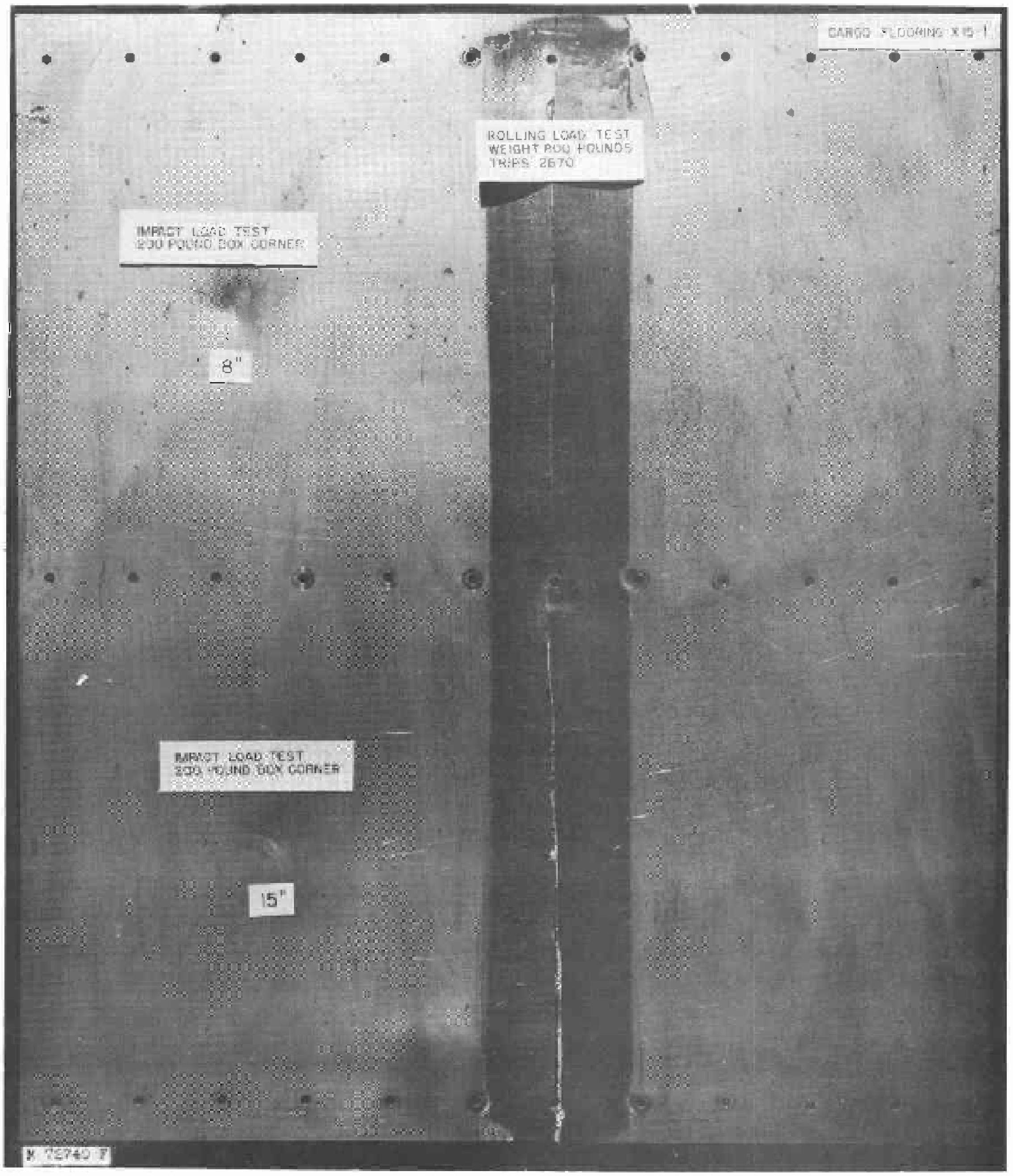


Figure 15.--Upper surface of cargo floor X 15-1 rolling-load specimen, showing effect of rolling an 800-pound engine-cradle wheel load over the panel 2,670 trips and the effect of drop of 200-pound-softwood-box corner from heights of 8 and 15 inches.

Z M 78649 F

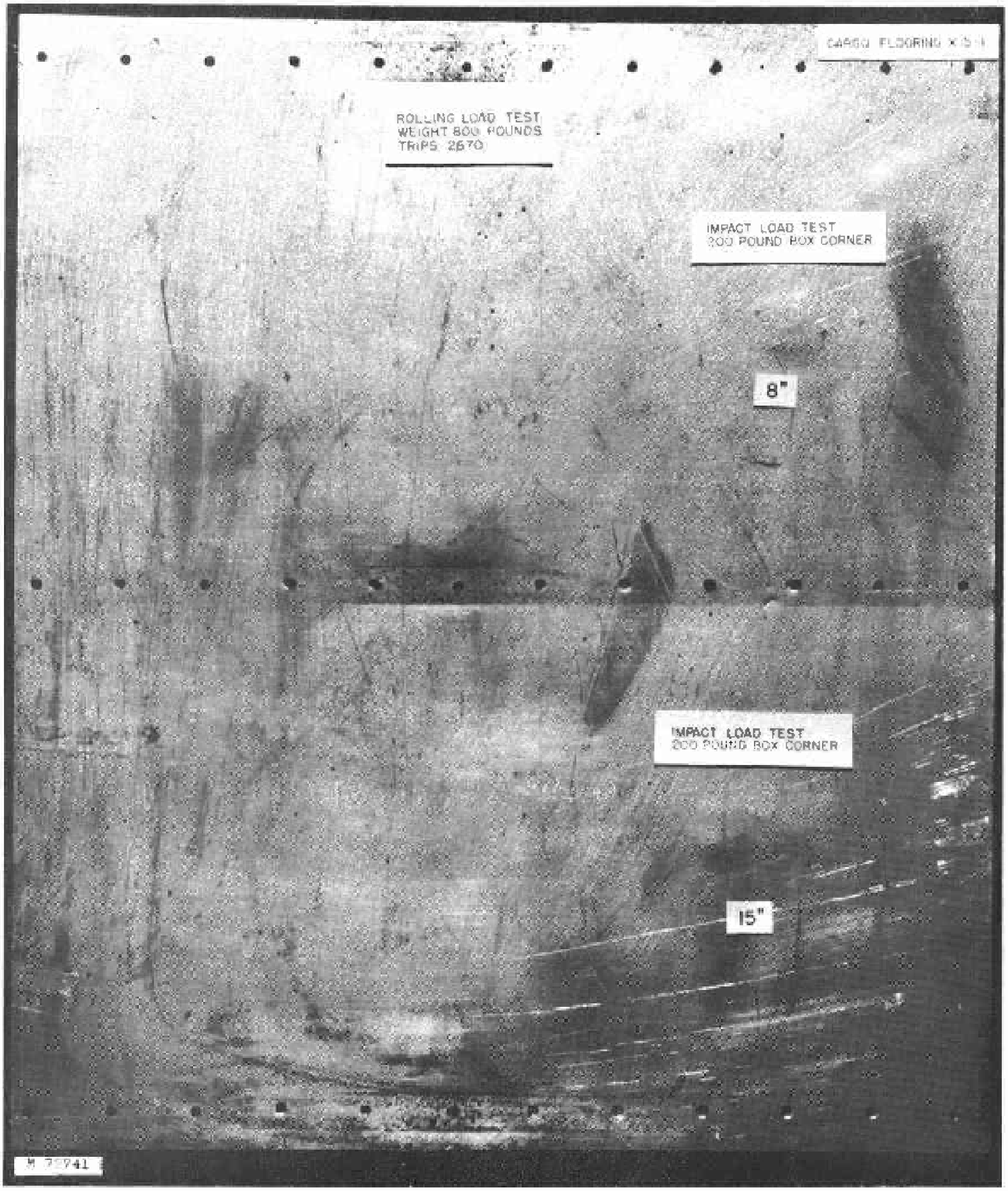


Figure 16.--Lower surface of cargo floor X 15-1 rolling-load specimen, showing effect of rolling an 800-pound engine-cradle-wheel load over the panel 2,670 trips, and effects of drop tests of 200-pound-softwood-box corner from heights of 8 and 15 inches.

Z M 78650 F

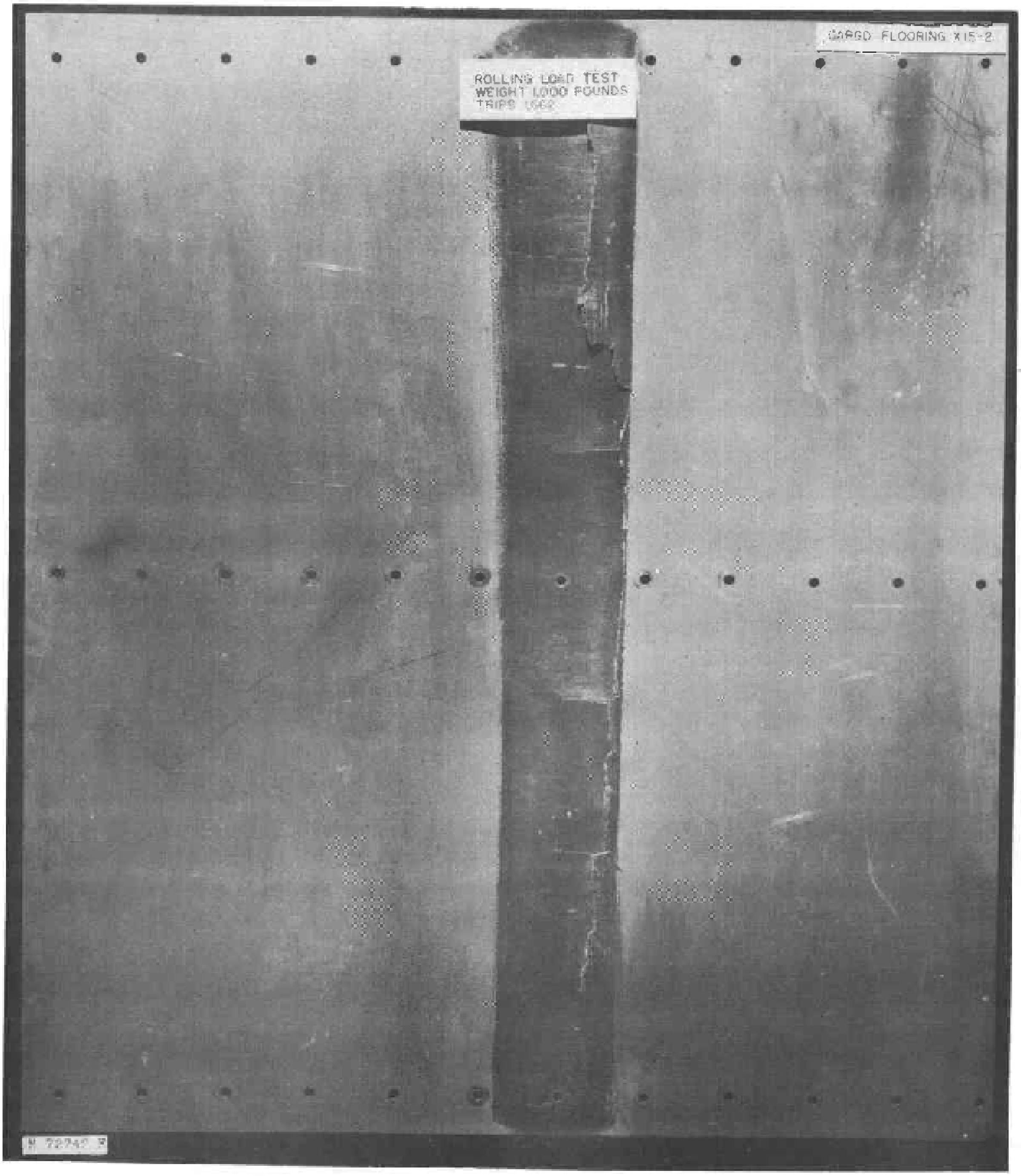


Figure 17.--Upper surface of cargo floor X 15-2 rolling-load specimen showing effect of rolling a 1,000-pound engine-cradle-wheel load over the panel 1,662 trips.

Z M 78652 F

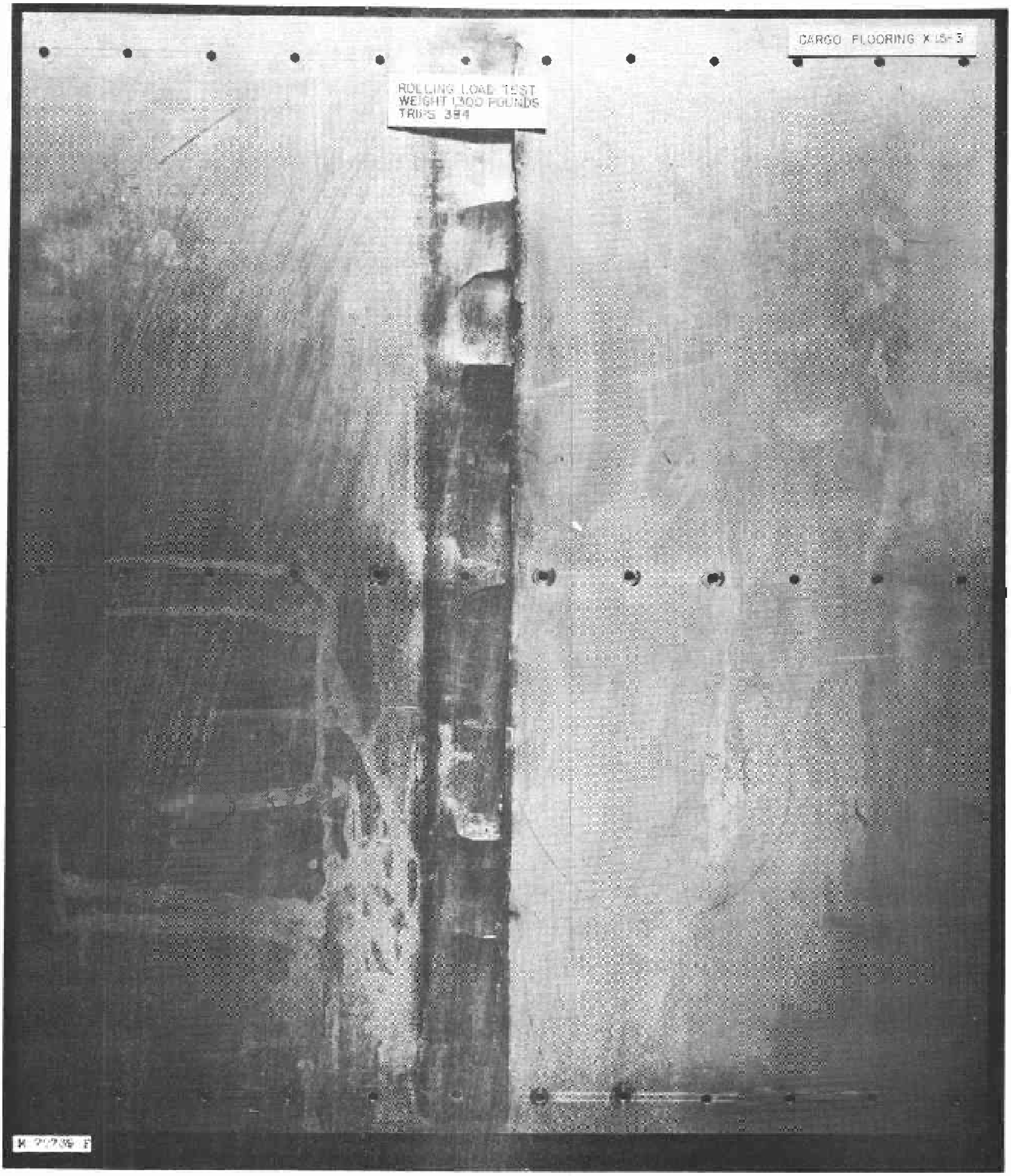


Figure 18.--Upper surface of cargo floor X 15-3 rolling-load specimen showing effect of rolling a 1,300-pound engine-cradle-wheel load over the panel 384 trips.

Z M 78651 F

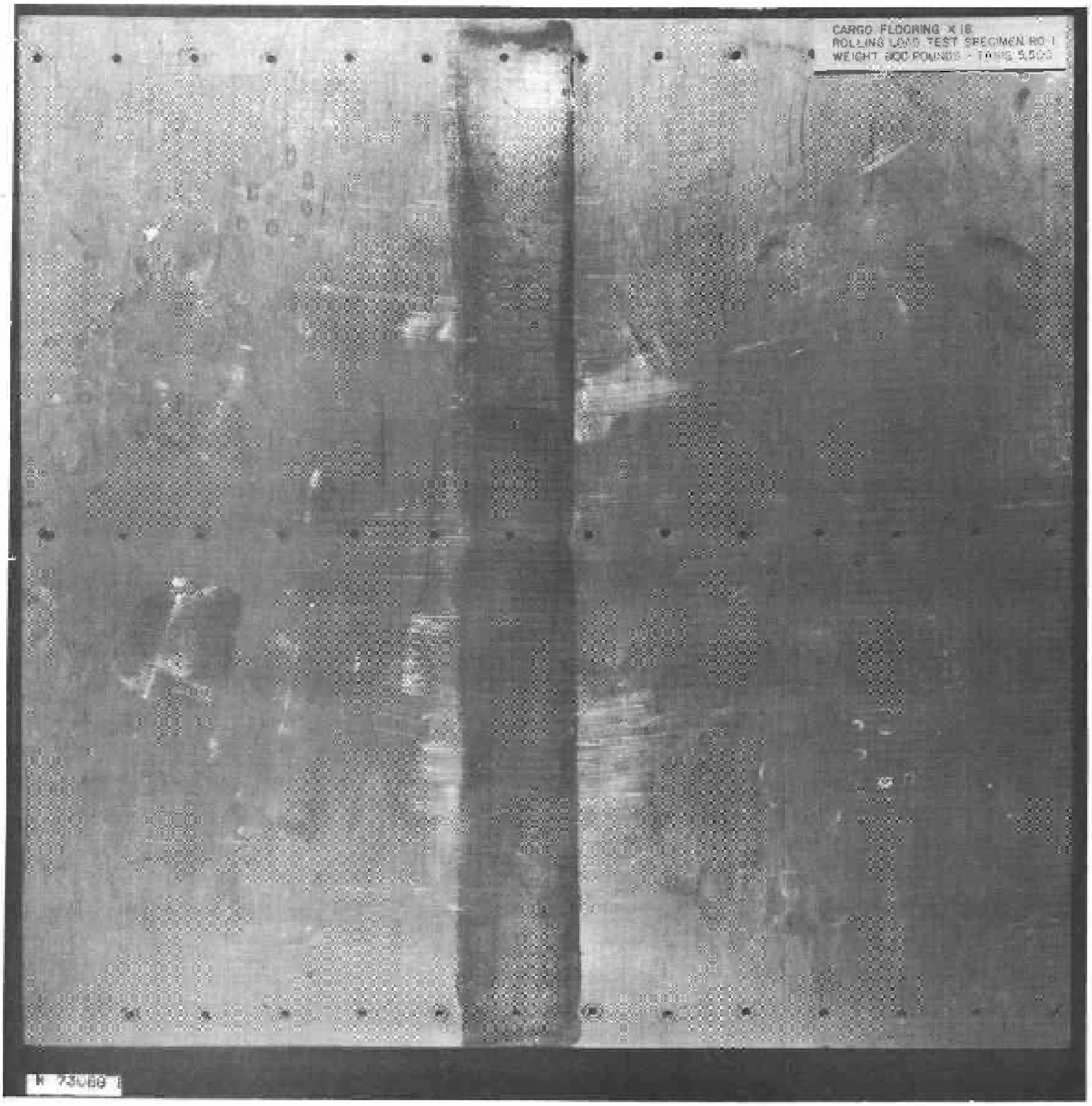


Figure 19.--Upper surface of cargo floor X 16 rolling-load specimen RO-1, showing effect of rolling an 800-pound engine-cradle-wheel load over the panel 5,500 trips.

Z M 78653 F

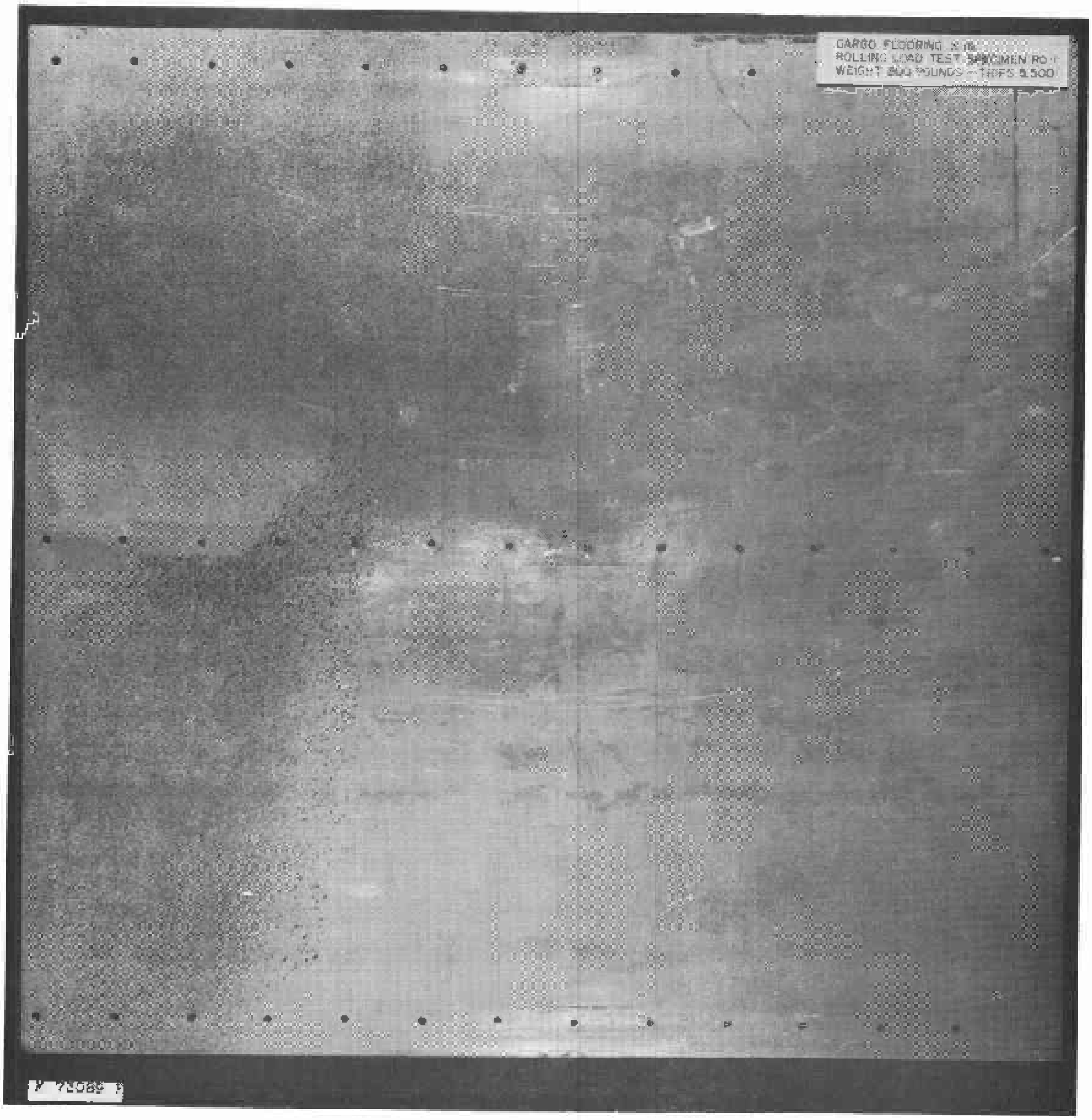


Figure 20.--Lower surface of cargo floor X 16 rolling-load specimen RO-1, showing effect of rolling an 800-pound engine-cradle-wheel load over the panel 5,500 trips.

Z M 78654 F

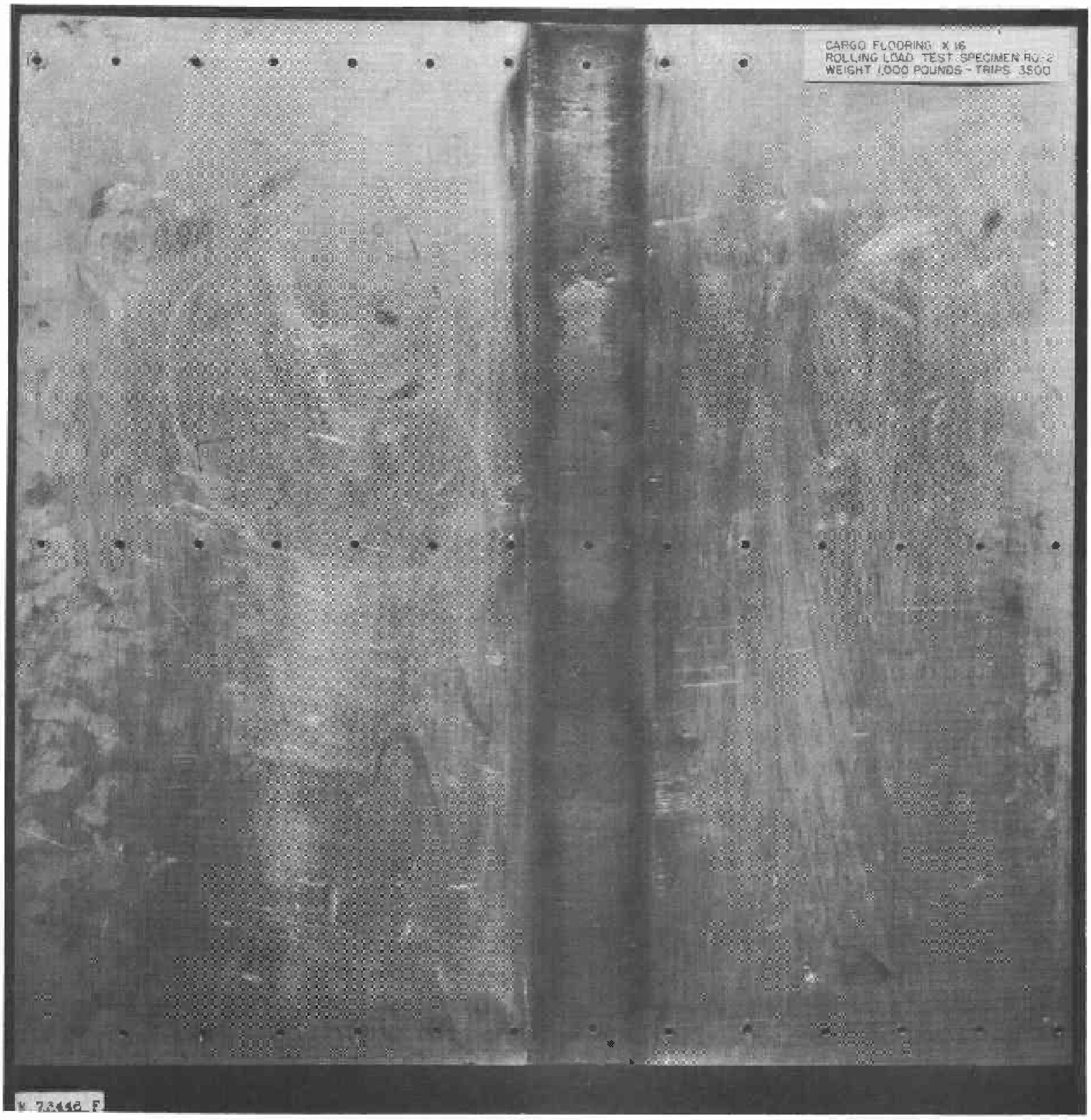


Figure 21.--Upper surface of cargo floor X 16 rolling-load specimen RO-2, showing effect of rolling a 1,000-pound engine-cradle-wheel load over the panel 3,500 trips.

Z M 78655 F

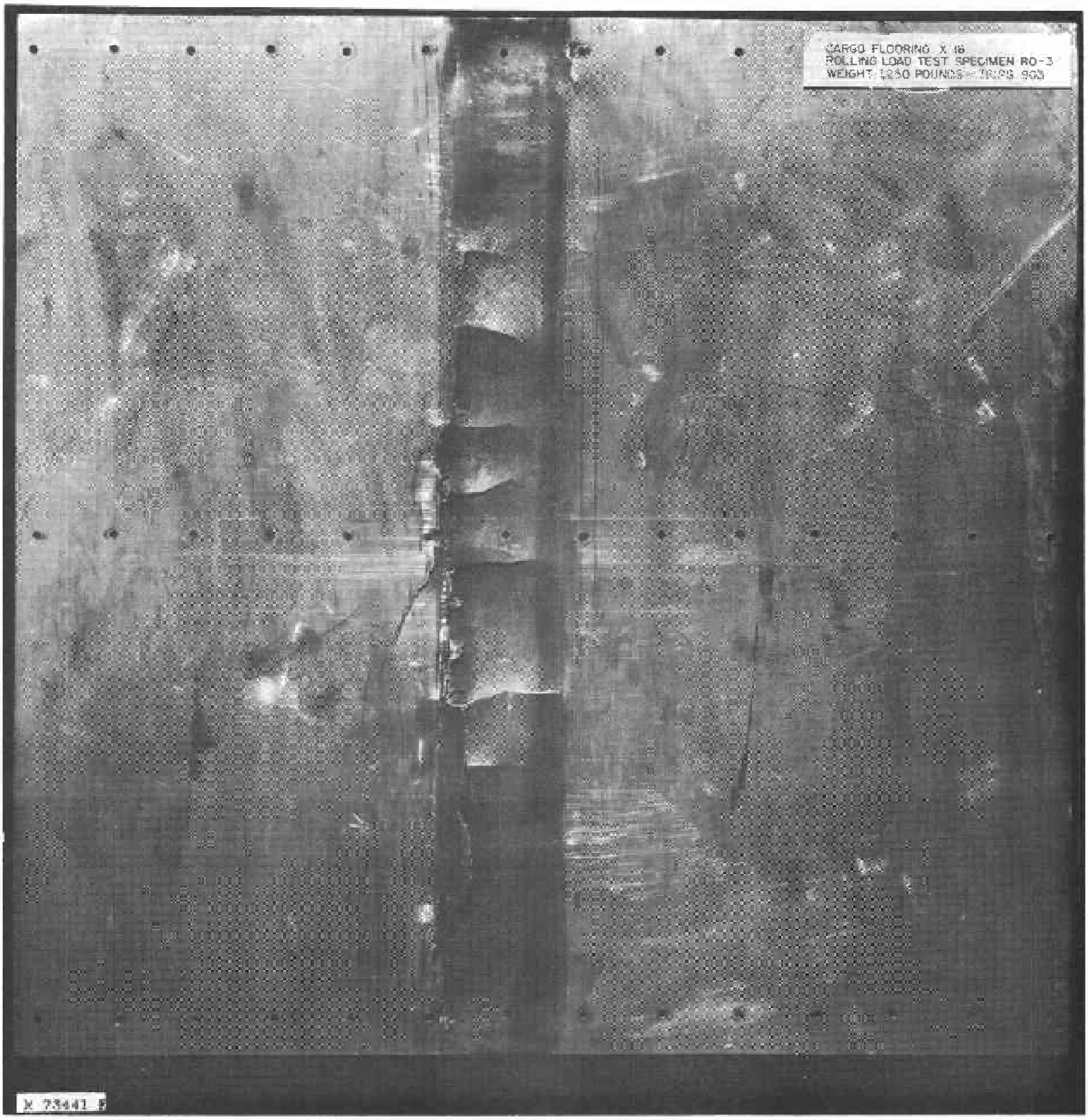


Figure 22.--Upper surface of cargo floor X 16 rolling-load specimen RO-3, showing effect of rolling a 1,150-pound engine-cradle-wheel load over the panel 903 trips.

Z M 78656 F

Figure 23.--Upper surface of cargo floor X 16 rolling-load specimen RO-4, showing effect of rolling a 1,500-pound engine-cradle-wheel load over the panel 352 trips.

Z M 78657 F

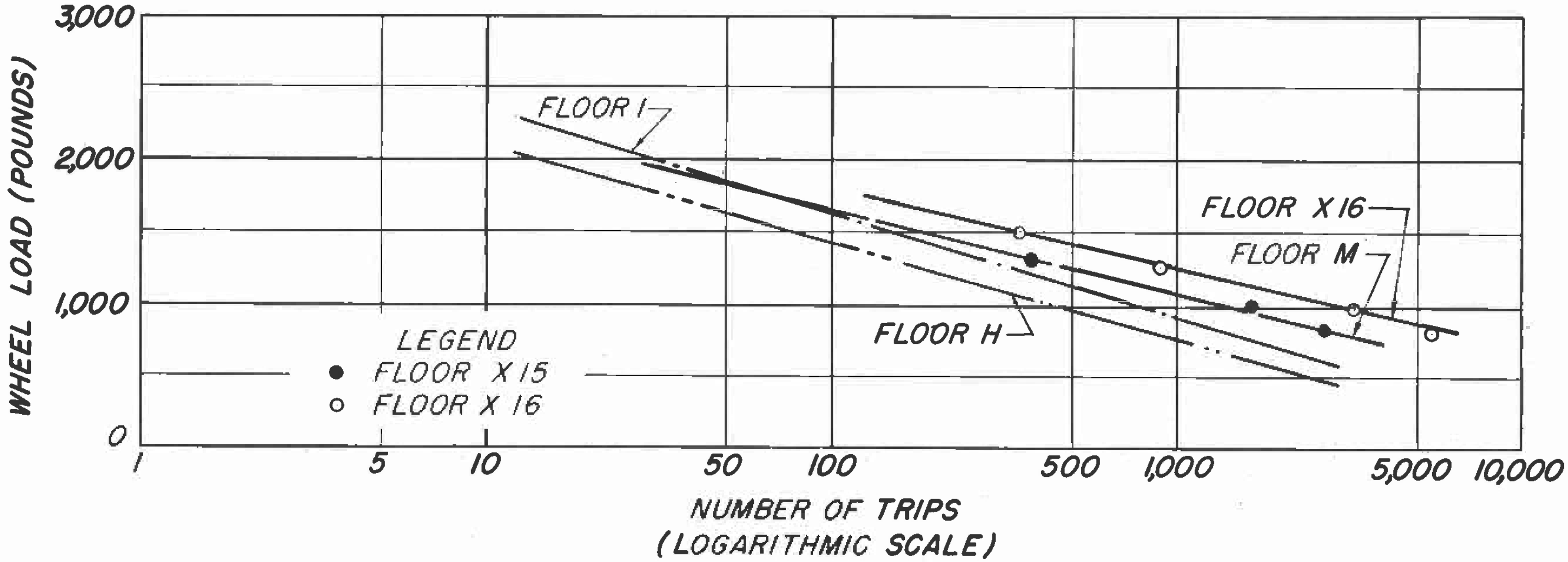


Figure 24.--Relation of wheel load to number of trips required to produce failure of floors X-15, X-16, I, M, and H. The points of curve X-15 approximately coincide with those of curve M.

Z M 74796 F

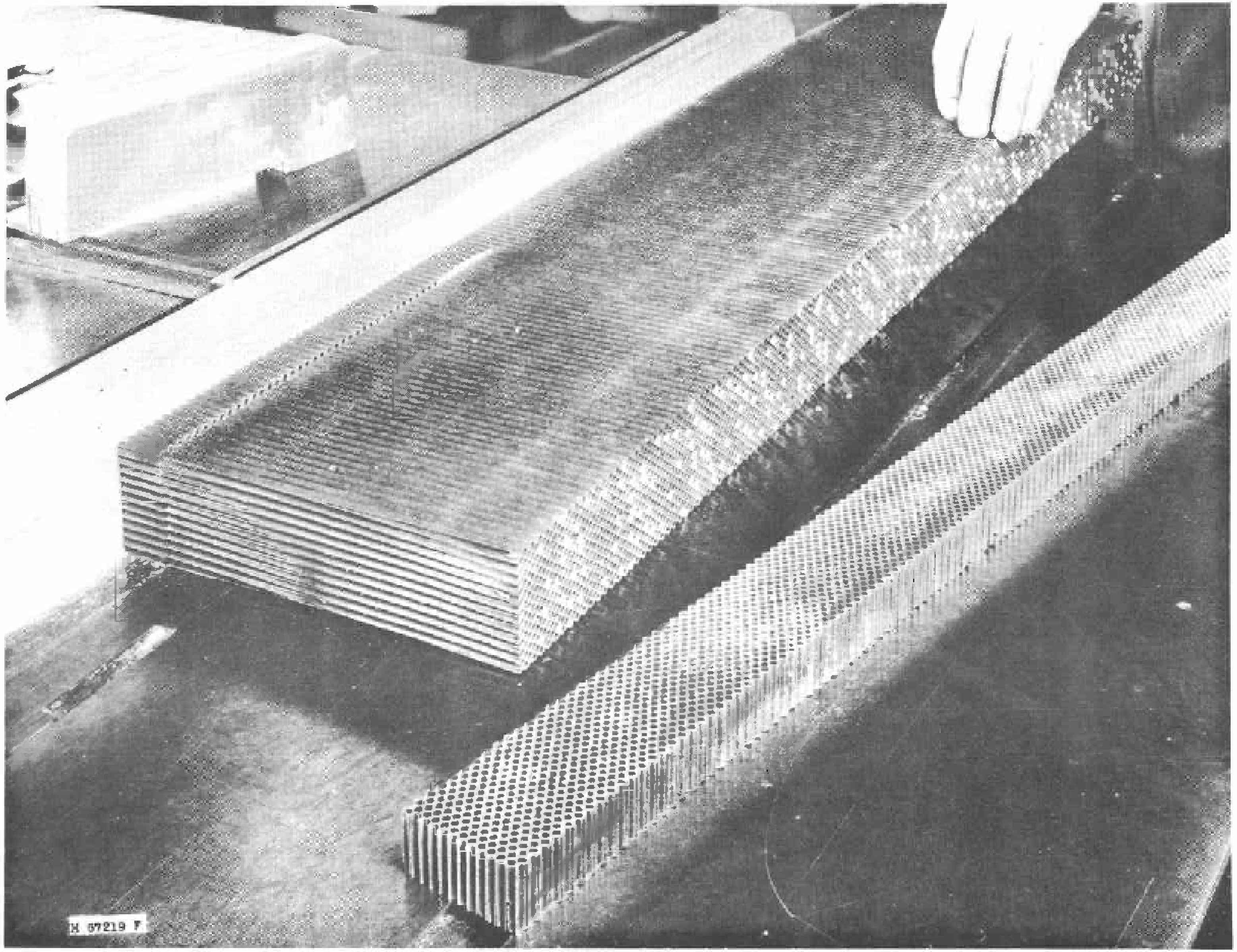
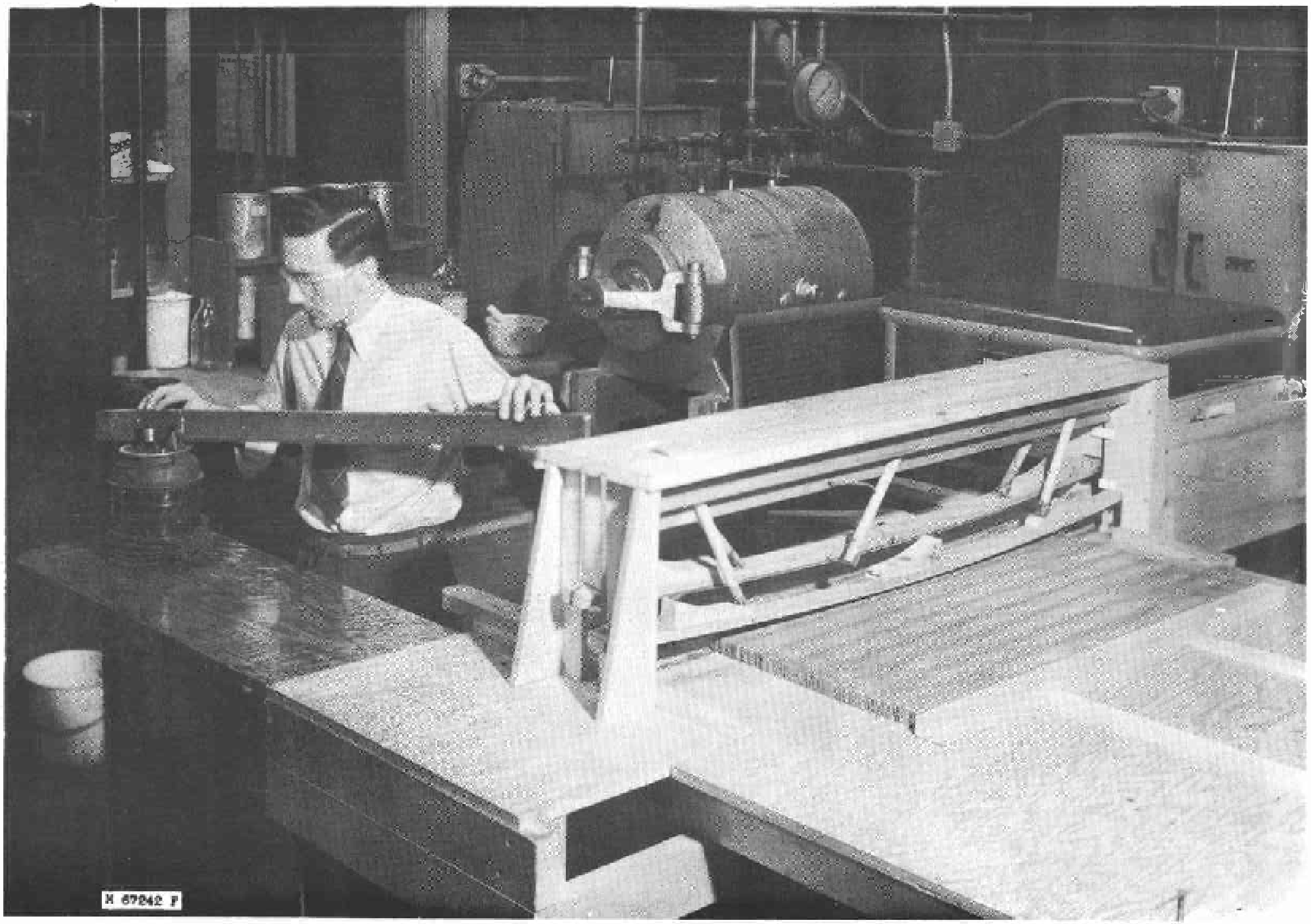


Figure 25.--Sawing the paper honeycomb block into the desired thickness for core material. The paper tubes used to position the individual corrugated layers properly can be seen on the end of the large block.

Z M 78658 F



Z M 78659 F

Figure 26.--Applying the adhesives to the edge of a strip of paper honeycomb core.

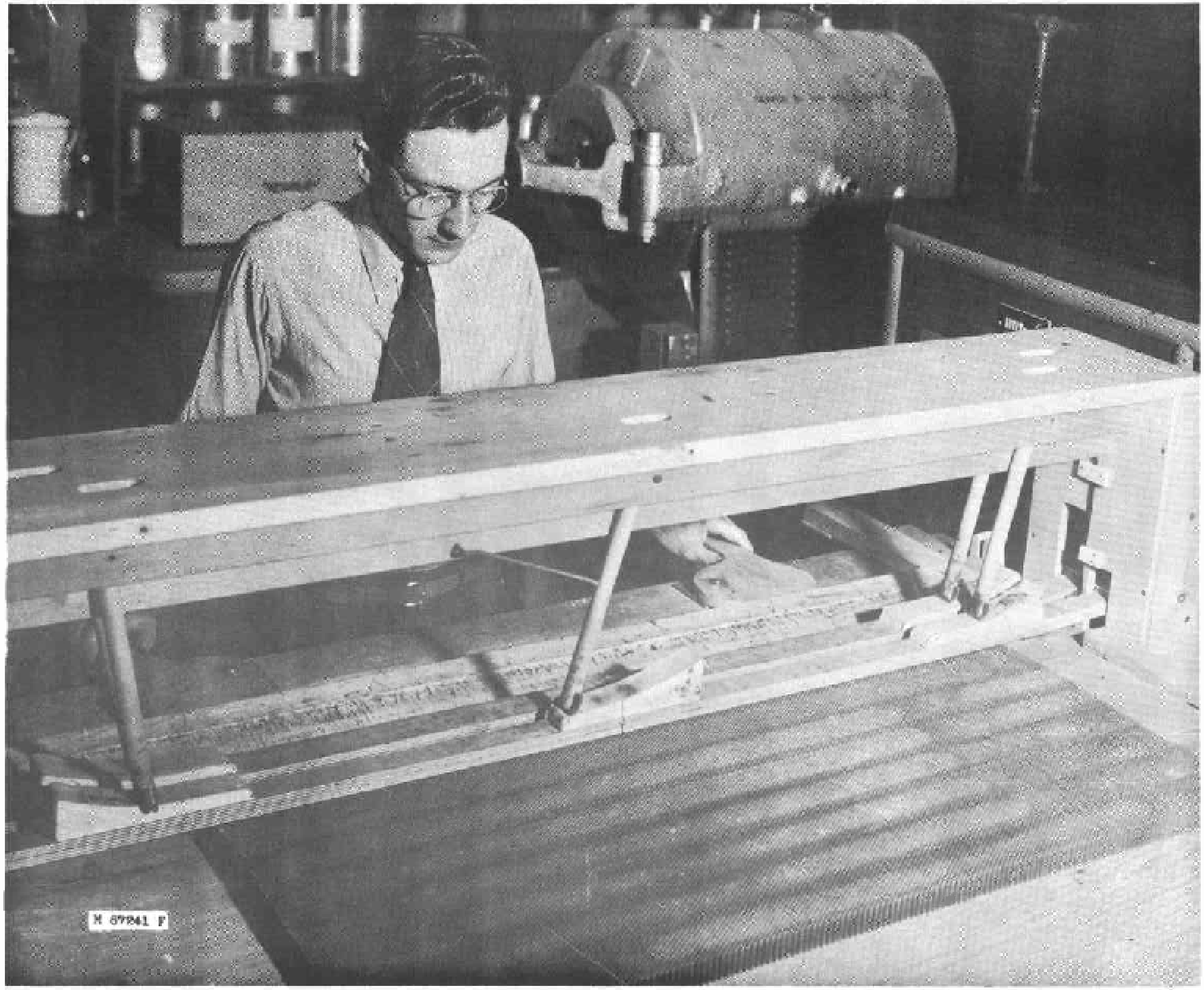


Figure 27.--Gluing the strips of paper honeycomb into a panel, in the high-frequency edge-gluing machine.

Z M 78660 F

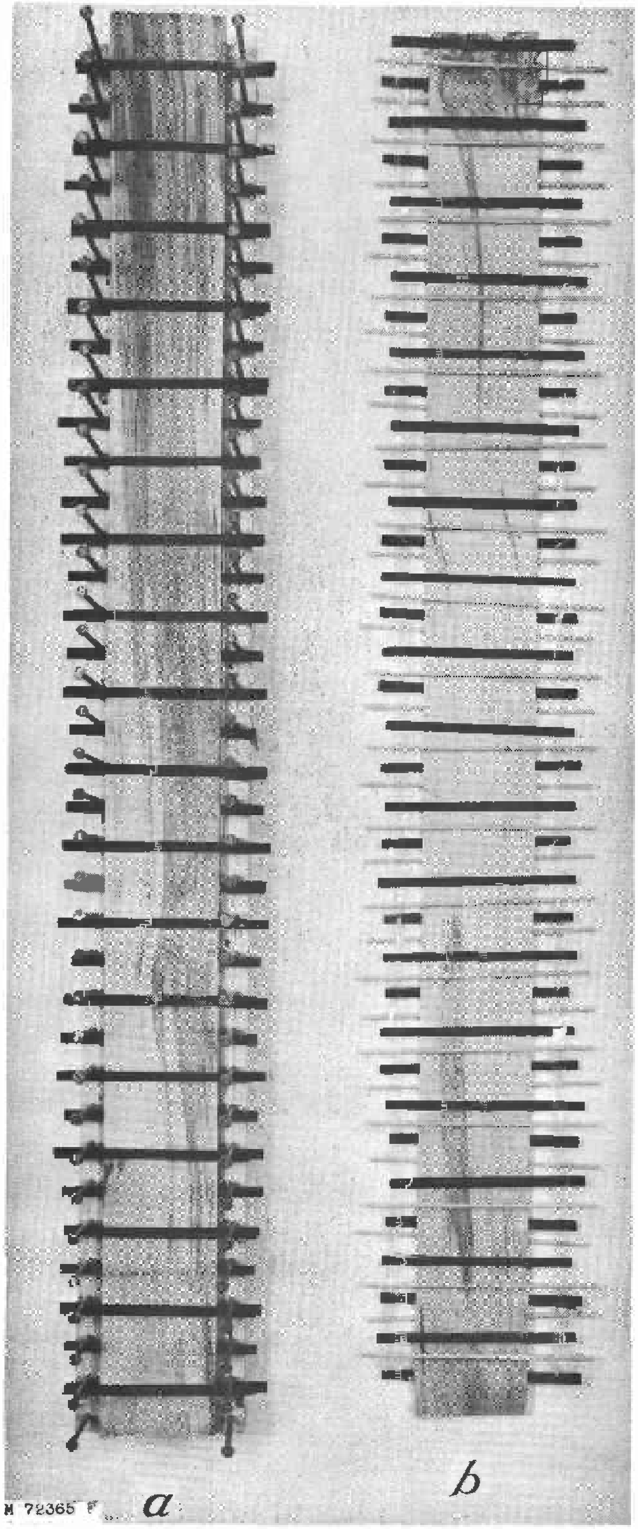


Figure 28.--(a) Method of assembling plywood with glue-coated strips of veneer. (b) Insert ply with attached glue strips and separation tubes employed in making multiple-thickness blocks.

Z M 78661 F

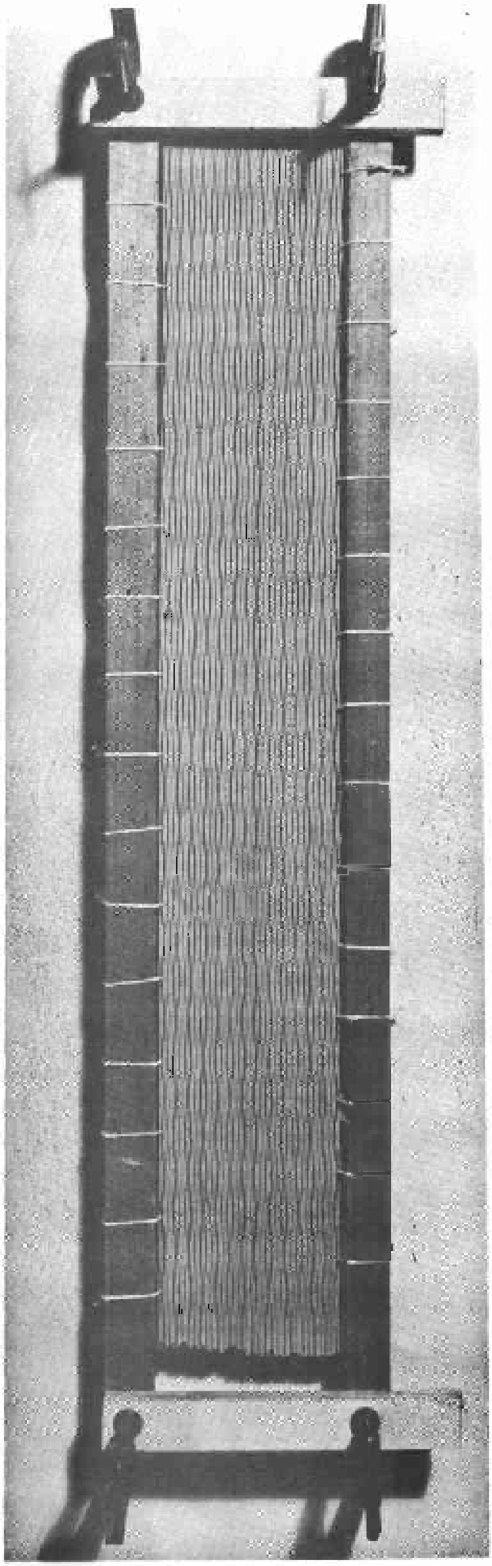


Figure 29.--Strip cut from assembled block with expansion bar and cord loops attached just prior to expansion.

Z M 78662 F

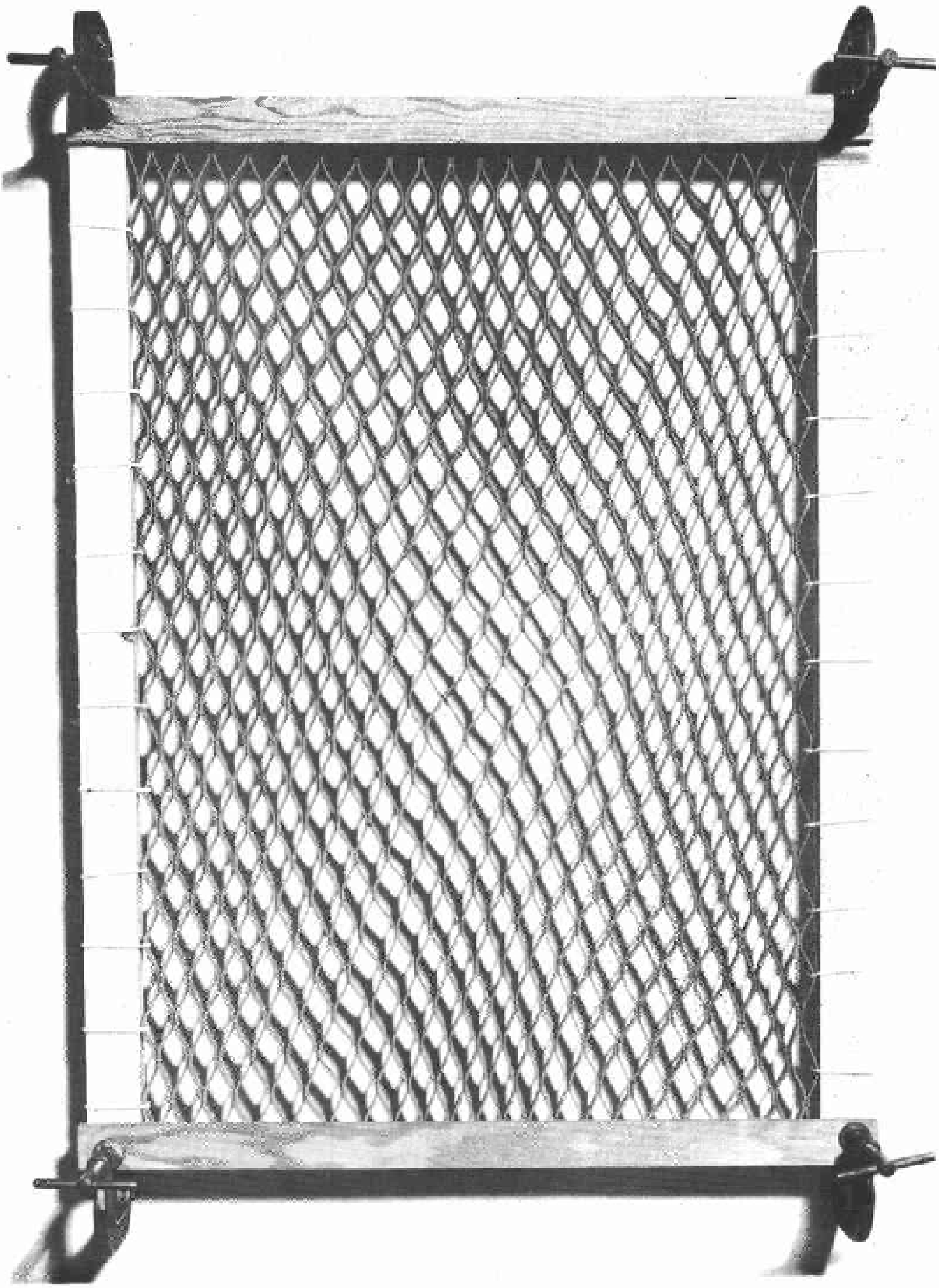


Figure 30.--Expanded plywood in expansion and drying rack.

Z M 78663 F