

# **METHODS FOR TESTING AND EVALUATING CARGO FLOORING FOR TRANSPORT AIRCRAFT**

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# METHODS FOR TESTING AND EVALUATING CARGO

## FLOORING FOR TRANSPORT AIRCRAFT

By

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### Summary

This report presents the results of an investigation made for the purpose of developing methods of testing and evaluating cargo flooring used in transport aircraft.

The methods of test used are described in detail, and the results for 10 types of flooring are shown.

### Introduction

The greatly expanded use of aircraft for transporting heavy cargo in wartime has emphasized the need for studies of flooring for transport aircraft. Considerable developmental work and testing of various materials has been carried out by those associated with this problem. The methods currently employed, however, have not been coordinated to produce comparable results and to allow an exchange of information and data. Unnecessary duplication of effort has resulted, and criteria for a satisfactory flooring have not been established.

In an effort to develop and standardize methods of test and evaluation, the Bureau of Aeronautics, Navy Department, financed an investigation by the Forest Products Laboratory, which was carried out in cooperation with the Technical Subcommittee on Air Cargo Transport (Joint Aircraft Committee). Manufacturers of cargo aircraft and cargo flooring also cooperated by supplying samples of flooring.

The specific purpose of the investigation was to develop methods for testing the physical and structural properties of air cargo flooring under simulated service conditions, and to evaluate by these tests several types of flooring, some of which are now in use and whose behavior in service has been observed.

## Material

The cargo flooring employed in this investigation consisted of representative types in general use. An effort was made to confine the selection to those floors on which service records are available.

To facilitate the presentation of data, each type of flooring was designated by a letter. The letter designations and descriptions of the various materials follow:

Floor A.---Five-ply Douglas-fir plywood, 1/2 inch thick. Commercial grade; water resistant. Grain of face plies was parallel to long dimension of the panel. Moisture content at time of test was 9.5 percent (based on weight when oven dry).

Floor B.---Five-ply Douglas-fir plywood, 3/4 inch thick. Commercial grade; water resistant. Grain of face plies was parallel to long dimension of the panel. Moisture content at time of test was 9.5 percent (based on weight when oven dry).

Floor C.---Sandwich construction having 13/32-inch solid basswood core with outer faces of parallel-laminated paper plastic arranged with the grain of both the core and the surfacing parallel to the axis of the plane. Nominal thickness, 1/2 inch. The wearing surface was roughened in molding to provide resistance to slipping. Moisture content at time of test was 6 percent (based on weight when oven dry).

Floor D.---Five-ply Douglas-fir plywood, 1/2 inch thick, reinforced with two extruded aluminum skid strips and a 24 ST 0.064-inch aluminum-covered treadboard, and equipped with tie-down rings. Face grain of plywood was parallel to long dimension of the panel. Moisture content at time of test was 9.0 percent (based on weight when oven-dry).

Floor E.---Flat 0.032-inch aluminum alloy sheet riveted to a corrugated 0.040-inch aluminum alloy base. The corrugations were 1-1/4 inches center to center and 3/4 inch deep and extended in the fore and aft direction. A 1/4-inch three-ply Douglas-fir plywood panel with face grain perpendicular to the corrugations was attached to the flat sheet to serve as a replaceable wearing surface.

Floor F.---Flat 0.032-inch aluminum alloy sheet covering fabricated transverse and longitudinal beams, and all forming an integral part of the airplane. The wearing surface was a replaceable 1/4-inch three-ply Douglas-fir plywood attached to the aluminum floor with the grain of the face plies parallel to the axis of the airplane.

Floor F (Task Force).---Wood floor consisting of panels 27 inches wide, 66 inches long, and 1-1/2 inches thick. Constructed with outside faces of 1/4-inch three-ply Douglas-fir plywood glued to inner yellow-poplar transverse stiffeners 3/4 inch wide spaced at 2-1/4-inch centers

along the 66-inch dimension. Outside edges were reinforced by a continuous inserted rail. The wearing surface was roughened by application of a nonskid material. Face grain of plywood was parallel to the 27-inch dimension. This floor was made to be used on floor F on top of the 1/4-inch plywood.

Floor G.--Sandwich construction having 13/32-inch seven-ply cross-banded yellow-poplar core with outer faces of cross-laminated paper plastic. Nominal thickness, 1/2 inch. Wearing surface had "morocco" finish, slightly irregular. Grain of the face ply of the core was parallel to the long dimension of the panel. Moisture content at time of test was 6 percent (based on weight when oven dry).

Flooring H.--Flat 0.064-inch aluminum alloy sheet spot-welded to a corrugated 0.051-inch aluminum alloy base. The corrugations had flat "heads" 3/4 inch wide, spaced at 3-inch centers, and were 1-1/4 inches deep with webs of the corrugations inclined to the vertical. The wearing surface was provided by the plain flat sheet.

Flooring I.--Flat 0.064-inch aluminum alloy sheet spot-welded to a corrugated 0.040-inch aluminum alloy base. The corrugations were square, 1-1/2 inches wide and 1-1/2 inches deep, formed on 3-inch centers. The open corrugations were blocked over the floor beams with Sitka spruce fillers. A rough wearing surface was provided on the flat sheet by an application of nonskid material.

Flooring J.--Sandwich construction having a three-ply 3/8-inch yellow-poplar cross-banded plywood core placed with the grain of the face plies longitudinal and with the upper surface of 0.025-inch and the lower surface of 0.016-inch 24 ST aluminum alloy. Maple skid strips were placed at 10-inch centers and in direct contact with the plywood core. The aluminum covering was made continuous over them. The wearing surface was treated with nonskid material.

### Methods of Test

#### Weight

Each type of flooring was weighed in the condition received, except flooring F, which is an integral part of the airplane structure. In this instance, the total weight was adjusted to remove the weight of transverse floor beams and miscellaneous pulleys and brackets attached to the floor structure.

Flooring D includes the weight of cargo tie-down fittings, which were not attached to the other types.

The weights of the several floors are shown in figure 1.

## Absorption

The absorption of water during immersion for a period of 48 hours is shown in figure 2. The tests were performed on specimens approximately 18 by 32 inches in size. In all instances, at least two edges were unprotected from free entrance of water. The results of this test are expressed as a percentage of the weight when air dry of the sample before immersion.

## Abrasion

Abrasion tests of the flooring in both the wet and dry condition were performed on a commercial-type abrasion machine. Small samples, approximately 4 inches in diameter, were cut from the flooring and tested with standard abrasion wheels under 1,000 grams pressure. Measurements of thickness were made before test and again following 10,000 cycles of abrasion. The loss in thickness of the specimen was considered an index of resistance to abrasion. The results, shown in figures 3 and 4, are expressed as a ratio of the loss of thickness of the specimen to the loss of thickness of 24 ST aluminum alloy. This material, following 10,000 cycles, showed a reduction in thickness of 0.0004 inch.

Tests for resistance to abrasion in the dry condition were performed on specimens maintained in air having a relative humidity of 65 percent and a temperature of 74° F. Tests in the wet condition were made by submerging air-dry specimens in water at room temperature while on the turntable of the abrasion machine. The time required for each test was approximately 140 minutes.

## Coefficient of Friction

Tests of the coefficient of friction between Douglas-fir plywood or rough sole leather and the various types of flooring were made in the air-dry condition, with water as a lubricant following the absorption test, and with SAE 30 oil as a lubricant.

The tests were made by pulling a 12-inch square of Douglas-fir plywood or rough sole leather, mounted on a suitable wood plate, along the surface of the flooring. The 12-inch square was backed by a metal plate on which was placed a weight of 200 pounds, thus giving a normal component of that magnitude. The entire assembly was pulled along the flooring by a chain attached to the plate and the tension head of a testing machine. In all instances, the face grain of the Douglas-fir plywood was parallel with the direction of motion.

The equipment is shown in figure 5.

The tangential load was measured by the testing machine and the coefficient of friction was calculated from this value and the normal

load. The static coefficient was obtained by pulling at a rate of 0.05 inch per minute until the maximum tangential force was measured at the time of impending movement. Dynamic coefficients were measured at a speed of 2 inches per minute, which allowed a more uniform motion than was obtainable at the lower rate.

Tests in the air-dry condition were made on material stored in air having a relative humidity of 65 percent and a temperature of 74° F. Tests in the wet condition were made on flooring specimens and Douglas-fir plywood or rough sole leather that had been submerged in water for a period of 48 hours. Free water was placed on the surface of the flooring prior to each test. Tests of the effect of SAE 30 oil on the coefficients were made on material in the air-dry condition. A sufficient quantity of oil was brushed on each surface to satisfy the demand of absorption, and prior to test a quantity of free oil was placed on the flooring before assembly of the apparatus. The results of the tests for coefficient of friction obtained under these conditions are shown in figures 6, 7, and 8.

### Corrosion

The effect of corrosion induced in specimens of flooring covered with loose salt and placed in air having a relative humidity of 97 percent and a temperature of 80° F. was tested during an exposure period of 2 weeks. At the end of the test, there were no indications of corrosion damage to any of the various types of flooring. Because of the high moisture condition, some evidence of delamination at the edges of the plywood types and warping of flooring C were noted.

### Static Bending

Tests of ultimate strength and work to maximum load were made on specimens 8 inches wide and 10 or 18 inches in length over spans of 8 or 16 inches, respectively. The specimens were simply supported on knife-edges equipped with roller-bearing blocks. Deflection at the center of the span was measured by a dial gage graduated to 0.001 inch. Load was applied at the center of the span by a maple block 9 inches long shaped to a 4-inch radius at a constant rate of deflection of 0.05 inch per minute in a hydraulic testing machine.

The test equipment is shown in figure 9. Figures 10 and 11 present the results of tests made with 8- and 16-inch spans. Figures 12 and 13 are typical load-deflection curves for each type of flooring.

### Uniform Loading

Tests of strength under uniform loading were made on 18- by 32-inch panels supported on a steel fixture. The floor was fastened to the floor beams along two edges by 1/4-inch cap screws at 2-1/2- or 3-inch

centers. The span, measured between centers of the beams, was 16 inches. The width of the flanges of the beams supporting the floor was 1-1/4 inches, and no support was given the floor on the edges not fastened down. Figure 14 shows a panel mounted on the floor fixture.

Load was applied to the floor by compressed air confined in an inelastic rubber bag mounted in a heavy wood case, which could be placed over the floor fixture. (Details of the design of fixture and case are shown in figure 15.)

Compressed air was passed into the bag through a diaphragm-type regulator in an amount sufficient to load the specimen at a rate of about 0.1 inch of deflection per minute. Deflection at the center of the panel was measured by a dial gage graduated to 0.001 inch. The gage, supported below the test fixture, was in contact with the tension face of the specimen.

The entire assembly was placed on the lower platen of a testing machine, and the compression head was located about 1/8 inch above the wood case containing the rubber bag. Air, passing into the bag, raised the case into contact with the compression head, and the load imposed on the floor panel was transmitted to the testing machine where it was measured in the conventional manner.

Figure 16 shows the apparatus assembled and ready for test. Figure 17 presents the results of the tests on the various types of flooring. Typical load-deflection curves for each floor appear in figure 18.

### Strip Loading

The effect of strip loading, such as obtains between the flooring and floor beams when heavy boxed or crated cargo is placed over a beam, was investigated. Specimens 8 inches wide and 18 inches long supported top down on the platen of a testing machine were loaded by a metal bar 1-1/4 inches wide by 9 inches long. The bar was placed across the specimen in the same position as that occupied by a floor beam for the particular floor being tested. Load was applied at a rate of 0.01 inch of head movement per minute. Deformation of the flooring under the bar was measured by two dial gages mounted on each side of the bar and touching the flooring outside of the deformed area. In addition, floors A, B, and C were tested with the bar placed parallel to the 18-inch dimension with no significant difference in results. Figure 19 shows the test equipment. The results of the tests expressed in terms of the stress per unit area that was developed at a deformation of 0.05 inch appear in figure 20. Load-deflection curves appear in figure 21.

### Concentrated Loading

The strengths of floor panels were tested by three methods of concentrated loading. All of the tests were performed on a single panel, although several panels were included for each type of flooring.

The panels were 32 inches wide by 34 inches long, supported on a steel fixture providing edge support along two sides and a center support over which the flooring was continuous. The panels were fastened to the fixture at the edges and center by 1/4-inch cap screws placed at 2-1/2- or 3-inch centers along each support. The distance between supports, measured from the center of floor beams, was 16 inches. Flanges at the top of the floor beams were 1-1/4 inches wide. Figure 22 shows the details of construction for the floor fixture.

Concentrated loads were applied by a steel bar 1 inch in diameter placed at midspan and at locations 4 or 12 inches from an unsupported edge. The panels were also loaded in similar positions by a maple block simulating the size and shape of an engine-cradle wheel. The block was 2-1/2 inches wide and shaped to a 4-inch radius. Tests were made with the block positioned as for travel in the direction of the span or at right angles to the span. The 1-inch diameter steel bar or maple cradle wheel was attached to a solid maple block supporting deflectometer arms that held two dial gages bearing on the panel at the floor beams. The deflection at the load point was taken as the average of the observations of the two gages. The gages were graduated to 0.001 inch. Figures 23 and 24 show the loading devices and deflectometer in position for test of a floor panel. Load was applied to the panel by a gear-driven testing machine at the rate of 0.10 inch of machine head movement per minute.

In addition to the loads previously described, the panels were loaded by an 8.25- by 20-inch heavy-duty ten-ply truck tire inflated to 90 pounds per square inch placed in positions with the longitudinal center line of the tire at 4 or 12 inches from an unsupported edge. The tire and rim were mounted in a heavy wood frame which served to transfer load from the testing machine to the rim. In all cases, the tire was placed on the panel in a position as for spanwise movement. The rate of loading was maintained at 0.20 inch per minute on a gear-driven testing machine. Deflection at the point of load was measured by a 0.001-inch dial gage mounted below the panel and touching the tension face of the flooring. Figure 25 shows the method of test.

Figures 26, 27, and 28 present the results from the three types of concentrated loading. Ultimate loads are shown for tests made on interior or exterior portions of the panel, depending on whether the load was placed 12 or 4 inches from an unsupported edge. Typical load-deflection curves appear in figures 29, 30, and 31.

### Impact Loading

The methods of test used for evaluating resistance to impact were developed to provide types of loading simulating conditions causing floor failures in transport operations. Handling of such items as wood crates and boxes and gasoline drums was reported as contributing to many structural failures. The tests used in this investigation, therefore, were designed to study the effect of dropping on the flooring from various

heights a 200-pound softwood box on its corner or a 365-pound gasoline drum on its edge.

Floor panels 32 inches wide by 34 inches long were mounted on the steel fixture described under "Concentrated Loading" and are shown in figure 32. Deflections at the point of impact were determined from the measured displacement of a steel pin, 1/4 inch in diameter and 5-1/4 inches long, supported by a transverse wood beam (2 by 3 inches in cross section) mounted 2 inches below the floor panel at midspan. The pins, set in a vertical position and passing through the beam, were in contact with the flooring at time of test. Sufficient friction from a set screw in the beam prevented the pin from exceeding the movement caused by deflection of the floor. At termination of a test, the pin remained in the position of maximum deflection and measurements of the length of pin below the wood beams made by a 0.001-inch dial gage before and after an impact blow determined the maximum deflection. The pin could then be returned to a position against the flooring and a reading taken to obtain the amount of permanent deformation. Space for three tests was provided in each span, and six tests were performed on each panel. Figure 33 shows the essential features for the construction of the wood beam and steel pin deflectometer.

Impact loads were applied by a gravity device consisting of a metal container, mounted in open side rails, which could be supported at selected heights above the floor panel. Corners, sawn from soft pine blocks, or the edge of a gasoline drum were attached to the bottom of the container to form the tup. The container, free to slide in the outer rails, was supported by clevises of varying lengths and a quick-release latch attached to a cross member between the outer rails. The entire assembly was placed in position over the floor panel by use of a hoist. The device was then clamped in the desired position and the latch released, allowing the tup to strike the floor. The softwood tups were used for one drop and then replaced. A single drop from a measured height was made for each position on the floor. A sufficient number of panels was tested to obtain reasonable average values of deflection and permanent deformation for each height of drop. Figures 34, 35, and 36 show the details of construction of the impact machine and striking heads. Figures 37, 38, and 39 present views of the impact machine in positions for test. Figure 40 presents an estimate of the height of drop that caused incipient failure in each type of flooring. The relationship between height of drop, or head, to deflection or permanent deformation is shown in figures 41 and 42.

#### Rolling Load -- Engine Cradle

Rolling loads are imposed on the floors of transport aircraft by the wheels of cradles used for supporting and moving airplane engines and are a severe test of any floor. The effect of this type of load was tested by rolling a cast steel wheel, 8 inches in diameter and 2-1/2 inches wide, across panels of cargo flooring. The cast steel wheel was

mounted on a steel frame so constructed that two outrigger wheels could help support the frame, but would not pass over the test panel. A box mounted on the frame was filled with steel weights in an amount to provide the desired wheel load. A detailed drawing of the three-wheeled cradle is shown in figure 43. A photograph of the equipment appears as figure 44.

Wheel loads of several intensities were applied, and the number of repetitions of load, or trips, required to cause failure was recorded. These data were plotted on semilogarithmic paper with load intensity plotted on the arithmetic scale. Fatigue curves were drawn on the data from which the life expectancy corresponding to a given cradle-wheel load could be determined.

The flooring for the rolling-load test was 32 inches wide and 34 inches long supported on the steel fixture as described for concentrated loading. The fixture with floor installed was placed in position and heavy approach panels were provided to allow the cradle wheel to pass over the entire test specimen at a uniform rate of speed. The cradle was pushed along the approach panel at about 3 feet per second, then over the test panel onto another approach panel where the motion was stopped and the direction reversed.

Maximum deflection at the center of each span under the rolling load was recorded and measured by the method described in "Impact Loading." A view of the floor fixture and pin-type deflectometer is shown in figure 45.

The results of the rolling-load tests are shown in figure 46. The single-trip ultimate wheel load and 10-, 100-, and 1,000-trip fatigue limits, all as taken from the graphs of figure 46, appear in figure 47.

The effect of cut-outs for tie-down fittings was tested by rolling loads passing over the tie-down plates and adjacent areas not affected by the installation.

Resistance to rolling load applied by an engine cradle equipped with rubber-tire casters was tested on floor A. The tests were conducted in the manner previously described, except that the wheel was 12 inches in diameter and had a rubber tread 2 inches wide. Four tests were made on floor A.

#### Rolling Load -- 1,000-pound Bomb

The effect of severe abrasion contributing to final structural failure was tested by rolling a 1,000-pound general-purpose bomb equipped with rings over floor panels. The method of test and type of specimen were the same as described for engine-cradle rolling loads. A wood frame was attached to the casing of the bomb to enable two operators to push or pull the bomb over the flooring at a speed of approximately 3 feet per

second. The bomb was pushed in a straight path, except on alternate trips, where an effort was made to induce a sidewise twisting motion to simulate handling and stowing.

Observations of the character of surface deterioration were made as the test progressed. The criterion for structural failure was a condition that prevented further movement of the bomb by two operators, or damage of a nature that would seriously affect the floor beams.

The test equipment is shown in figure 48. The results of the tests expressed in terms of number of trips causing structural failure and trips to cause surface deterioration severe enough to contribute to ultimate failure of the floor appear in figure 49.

### Analysis of Results

#### Weight

The weight per square foot of the several types of flooring, shown in figure 1, does not include allowance for floor beams or other supporting structure transferring floor loads to the belt frames or fuselage. Floor D includes tie-down fittings, which were installed by the manufacturer. In general, the total weight of floor F will be the sum of ordinates marked (plain) and (plywood), while the total weight of areas protected for task force loading will be the sum of ordinates marked (plain) and (task force).

#### Absorption

The results of absorption tests presented in figure 2 are based on the total weight of flooring, without floor beams, except for floor F. The absorption for floor F (plywood) is based on the weight of the plywood only. Likewise, for floor F (task force) the absorption is based on the weight of the treadboards alone.

#### Abrasion

The results of abrasion tests, shown in figures 3 and 4, can be duplicated only by the equipment described in the method of test.

Floor A and floor B show widely divergent values of surface wear when tested in the air-dry condition. The difference in results can be explained when the relative amounts of summerwood are considered. The sample for floor A had about 65 percent of the exposed area composed of summerwood, while floor B had only 45 percent. Since summerwood is more dense and harder than springwood, the material having most summerwood content would be expected to show the best resistance to wear and abrasion. Tests on a wet surface, however, indicated that the difference in

wear owing to summerwood is not critical. In this instance, the direction of motion of the abrading agent in reference to direction of grain is more important. The mean wear values for floors A and B are about equal when wet, but the rate of wear is greater when the abrasion is along the grain than when it is across the grain.

In general, this method of testing abrasion resistance of cargo flooring is easily reproduced. The results, however, must be correlated with operational experience ratings.

### Coefficient of Friction

The results of tests of coefficients of friction on dry surfaces, figure 6, require no comment, except in the case of floor D (skid strips). Contrary to expectation, the resistance to slipping of a Douglas-fir panel pulled along the skid strips was higher than that obtained without strips. The difference was probably due to local indentation of the plywood by the strips and a resulting change in surface characteristics. It is likely that, after long use of a floor, the coefficient for skid strips would remain more or less unchanged, while an increase in the value obtained on flooring without strips could be expected.

Coefficients of friction for a wet surface were, in general, greater than for a dry surface. The reason for an increase, regardless of the lubricating qualities of a water film, is attributed to the treatment of the specimens and the Douglas-fir panel or rough leather. These materials were soaked 48 hours previous to test and the resulting changes in surface texture, hardness, and contour could offset the small benefit gained by the lubricating effect of a water film.

Tests made on an oily surface of air-dry material showed the effect of a good lubricant on the coefficient of friction. A marked decrease in the values for all materials except floor C and floor F (task force) was noted. In these instances, the rough surface finish was sufficient to offset the lubricating effect of SAE 30 oil. The results of tests with oil were variable. The thickness of the oil film greatly influenced the magnitude of the coefficients, and the results are open to question from the standpoint of dependable reproduction.

### Corrosion

No serious deterioration of the various floors due to the effect of salt corrosion was apparent during an exposure period of 2 weeks.

### Simple Bending

The results of bending tests presented in figures 10 and 11 show the relative flexural strengths and energy absorbed by each type of floor

material. Two different spans, 8 and 16 inches, were selected in order to make evident any possible effect of shear on the ultimate strength. Only floor F (task force) indicated a weakness in shear resistance. In this floor, the ultimate loads were proportional to the areas resisting horizontal shear rather than inversely proportional to the span.

Special tests were made on floor D to determine the reinforcing effect of skid strips or treadboard. Specimens 9 inches wide with two skid strips attached at 7-inch centers on the underlying plywood, and specimens 8 inches wide with a 6-1/2-inch treadboard attached to the plywood were tested. For a span of 16 inches, the strength of two skid strips and included plywood was about three and one-half times as great and that of a treadboard and plywood about five times as great as for the plywood alone on the basis of load per inch of width.

Work to ultimate load serves as an indication of the resistance to impact by loads uniformly distributed across the width. It does not, however, accurately reflect resistance to localized impacts as in the box-corner and drum-edge impact tests.

### Uniform Loading

The results of tests for ultimate uniform load appearing in figure 17 indicate that all these types of flooring are satisfactory insofar as ability to withstand uniform load is concerned. The ultimate strengths of all floors greatly exceeded any requirement that has been considered for uniform loading. Floors E, H, and I were loaded to 7,000 pounds per square foot without visible damage. The tests were discontinued at that load.

It appears that a test for resistance to uniform load can be omitted in the evaluation of flooring for heavy cargo, since the requirements for concentrated load are more severe and control the floor design.

### Strip Loading

Strip loading tests were performed to determine the resistance of floors to crushing over the floor beams. Floors of solid and rigid construction usually were not seriously affected by this loading. Cellular-type floors, or those using shell construction or light corrugations, sometimes showed weakness under this test.

### Concentrated Loading

Resistances of the various floors to puncture by a 1-inch cylindrical steel bar are shown in figure 26. Results are shown separately for tests at an interior position 12 inches from an unsupported edge, and for tests at an exterior position 4 inches from the unsupported edge.

All tests were made at the center of the span. All floors, with the exception of floors F, were supported on a steel fixture providing two equal 16-inch spans 32 inches wide. Floor F was tested with the support provided by the actual floor substructure, and floor F (task force) was tested while in position on floor F. Tests at the 4-inch position were not made for these two types because of limited material.

Tests of strength under loads applied through an engine-cradle wheel are presented in figure 27. The wheel was placed at midspan and was oriented for travel in a direction along the span or across the panel. It was found that the differences in ultimate load between the two directions were not significant, so the results were pooled in computing the average strengths. Floors D and F were tested at locations free from the supporting action of the tread strips, as well as on the treadboard provided to accommodate engine-cradle wheels. Tests at the 4-inch point were not made on floors F and F (task force) for reasons stated previously.

The ultimate loads obtained from tests by a heavy-duty truck tire are shown in figure 28. Floor D was loaded adjacent to skid strips or treadboards. Floors E, F, F (task force), H, and I did not fail at a load of 8,000 pounds, and the tests were discontinued at this value.

For purposes of evaluation, tests on exterior panels are of small value, since magnitude of the ultimate load depends upon the distance to the free edge. The use of this test would be desirable only for floors installed without edge support.

### Impact Loading

Interpretation of the results of impact tests, shown in figure 40, was made by consideration of head-deflection curves, head-deformation curves, and visual examination of the test specimens. The values of critical height of drop chosen are such that serious damage will result if these values are exceeded.

The height of drop shown for floors E, H, and I does not represent the maximum value that could be sustained. The equipment used in these tests limited the available head to 15 inches, which was not sufficient to cause serious damage to floors E, H, or I.

Values for floor F (task force) are for tests in which the drop was on those areas backed by interior stiffeners. Areas not thus supported offered little resistance to impact, and for these the critical height would be 1 inch or less.

Floor J performed well under these tests and could be considered reasonably satisfactory. Failures from impact by the 365-pound drum were in the core material.

## Rolling Load --- Engine Cradle

Results of the test simulating action of a rolling steel engine-cradle wheel are shown in figure 47. The data are taken from fatigue curves constructed for each type of flooring. Floors D and F were tested on the tread strip especially provided for this type of loading.

Visual examination of the specimens during and after test was of value in studying the abrasive effect of rolling loads. In wood-surfaced floors (Douglas-fir plywood), failure was preceded by a progressive deterioration caused by high compressive stresses perpendicular to the grain and shearing stresses at the edge of the cradle wheel. Peeling of the surface was rapid and resulted in a condition that would seriously impede moving and stowing of strap- or wire-bound boxes. Floors C and G (impregnated paper surfacings) suffered little surface abrasion under combinations of loads or number of trips that cause internal structural damage. This internal break-down was not usually evident until failure occurred.

Floor D performed satisfactorily while the protective aluminum strip remained in place on the treadboard. It was not securely attached, however, and failed to provide continuous protection. It was necessary to exercise care to guide the cradle wheel along the strip, since the 1/2-inch plywood panel alone did not have adequate strength to support heavy concentrated loads.

Initial failure in floors E and H was a collapse of the corrugations over the floor beams. Distortion of the floor panel, owing to failure in the corrugations, was apparent upon removal from the test fixture.

Floor F performed satisfactorily until the tread strips became roughened because of crippling and loosening of the small angles connecting the web of the longitudinal beam to the strip. The roughness was sufficient to increase the rolling load factor considerably, bringing about rapid failure of the floor.

Floor I was reinforced by small Sitka spruce blocks placed in the open corrugations over the floor beams. This construction prevented initial failure by crushing. The square shape of the corrugations contributed to improved strength, but final failure of the upper surface was by shear along the edge of the vertical leg of a corrugation.

Floor J showed the best results under the rolling load test. Deflection at midspan was somewhat greater than for floors D, E, H, and I, but was not sufficient to impede the handling of an engine cradle. The nonskid coating applied to this floor appears to resist abrasion satisfactorily.

In the tests to determine the effect of tie-down fittings on resistance to rolling load, the panels were prepared by making a circular cut-out 2-1/2 inches in diameter and covering each of the resulting holes

with two 16-gage steel plates 4 inches in diameter fastened together by six 1/4-inch bolts. The results of this limited number of tests indicate that tie-down fittings installed in 1/2- and 3/4-inch Douglas-fir plywood do not reduce the strength significantly.

Special rolling-load tests of floor A, using a steel wheel with rubber tread, showed that surface abrasion was less severe than with the wheel used in the other tests, but no significant change in the fatigue curve was indicated. Results from two tests were in agreement with the established curve (fig. 46), while two additional tests gave results slightly better than the curve would indicate.

#### Rolling Load --- 1,000-pound Bomb

The results of the rolling-load test by a 1,000-pound bomb equipped with rings are shown in figure 49. Ultimate operational use is the number of trips causing a structural failure of such a character as to make replacement of flooring necessary. Limit for surface wear is that number of trips at which the surface shows deterioration of a nature contributing to ultimate structural failure. At this stage, moving and stowing of strap-bound boxes or crates would become difficult.

The abrasion and structural failures resulting from bomb handling were similar to those caused by the engine-cradle wheel. In fact, the number of trips before failure was, in many instances, very close to the number that would be read from the diagrams of figure 46 for a load of 500 pounds, the weight on one bomb ring. For floors D and F, the bomb rings did not travel in the same path as the engine-cradle, since special tread strips are provided for wheel loads. From tests to determine the effect of raised tie-down rings when traversed by a rolling load such as a 1,000-pound bomb, it was found that such rings may be punched through the flooring. Indications are that flush type tie-down rings should be used where rolling loads of this nature are expected.

Floors H and I provide a plain aluminum surface to resist abrasion, and neither floor exhibited serious wear following 3,000 trips of the bomb.

#### Variability of Results

The strength of any structural member is a function of the material of which it is composed, the manner in which it is assembled, and the conditions under which it is tested. Similar members, as alike as is physically possible, will exhibit different strengths. The most that can be expected of tests is to establish an average strength and a measure of the deviations of individual values from this average.

In the present instance, the number of tests of any one floor or of any one quality was too few to fix these quantities with accuracy.

Whenever similar tests were found to give results of much variability, however, an effort was made to obtain additional data, and thus more surely fix the average or expected value. It is felt, therefore, that the results here presented will, within limits, be found reasonably representative of experience.

### Conclusions

A wide variety of tests were used in this investigation. In some instances, the property measured by one test was measured also by others. The tests necessary for proper evaluation of flooring depend on several factors, such as method of support in the airplane, conditions causing failures in service, ease of duplicating test procedures, and desirability of obtaining comparable results for a diversity of construction.

The methods employed were in some instances adapted from earlier procedures, while others were developed especially for tests of floors used for heavy cargo, such as crates, boxes, bombs, and engine cradles. The data and observations of tests lead to the conclusion that the relative value of several floor types may be secured from consideration of weight per square foot, number of trips, and magnitude of a rolling load simulating an engine-cradle wheel, and behavior under impact of a 200-pound box. The weightings assigned to these tests can be adjusted to bring the results into agreement with experience records.

Evaluation of floors not intended for support of heavy cargo may be secured by substituting the results of other tests, such as resistance to static concentrated and uniform loads, and weight per square foot.

## APPENDIX I. IMPACT AND ROLLING-LOAD TESTS OF FLOOR K

### Purpose

The purpose of this extension of the foregoing program was to evaluate maple plywood as a flooring material for transport aircraft.

### Material

The material, prepared especially for these tests, consisted of maple plywood composed of seven cross-laminated plies having a total thickness of approximately 0.54 inch, and weighing 2.17 pounds per square foot. The grain of the face plies was parallel to the long dimension of the panel. Moisture content at time of test was approximately 7 percent (based on weight when oven dry). This construction is designated as floor K.

### Methods of Test

Impact tests simulating the action of a 200-pound box, or a 365-pound steel gasoline drum, dropped from various heights, and a rolling load simulating the effect of a steel wheel mounted on an aircraft engine cradle were used.

### Analysis of Results

#### Impact Test

The results of impact tests on maple plywood flooring are shown in figure 50 as typical graphs of height of drop versus deflection or permanent deformation. A study of these curves in conjunction with visual examination of the specimens indicated that the floor should sustain a 7-inch drop of a 200-pound box or a 3-inch drop of a 365-pound gasoline drum without showing a visible failure in either face of the material. In all instances, a splintering tension failure of the lower face preceded penetration of the upper face, which occurred only at the highest heads.

#### Rolling-load Test

The results of the rolling-load test are shown in figure 51, which may be compared to figure 46. The relationship of wheel load and number

of trips causing failure is indicated by the line drawn through the data. The specimen tested by a 1,300-pound load was in good condition after 3,000 trips, and it is believed that up to 6,000 trips could be sustained before failure. Surface abrasion and wear under the cradle wheel were not apparent.

All failures were in the tension face but with a tendency to start near the center floor beam. Surface abrasion and wear were not factors in the failure of floor K.

### Conclusions

The performance of floor K was similar to that of floor B. The greatest difference in the qualities of these materials was in the superior resistance to wear and abrasion shown by floor K, as evidenced by the improved performance under rolling load.

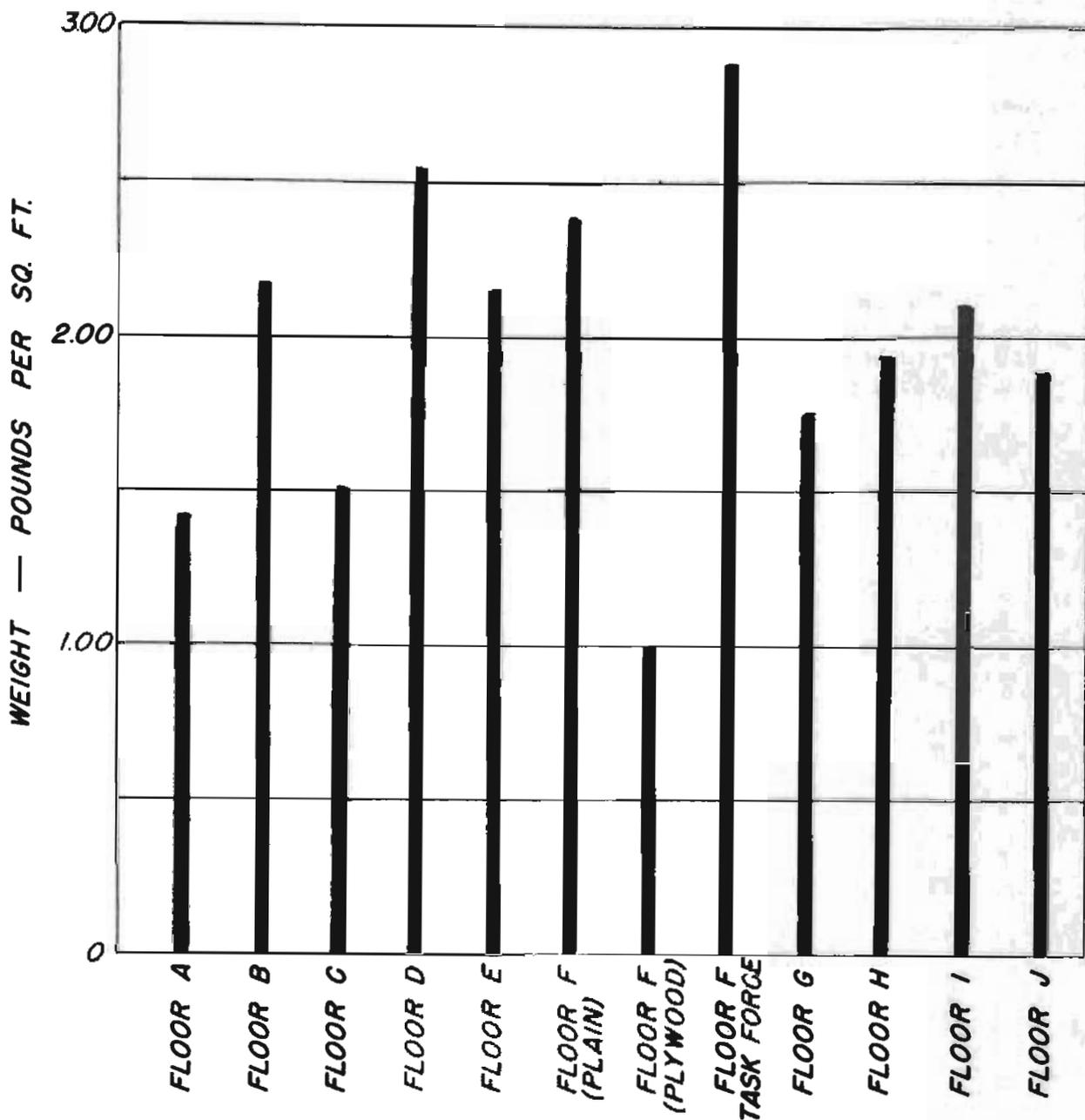


Figure 1.--Weight per square foot of the flooring as received. Floor D has tie-down rings attached. Floor J is equipped with skid strips on 10-inch centers. The weight of floor F as installed is the sum of ordinates marked (plain) and (plywood). The additional weight marked (task force) applies only to areas so protected.

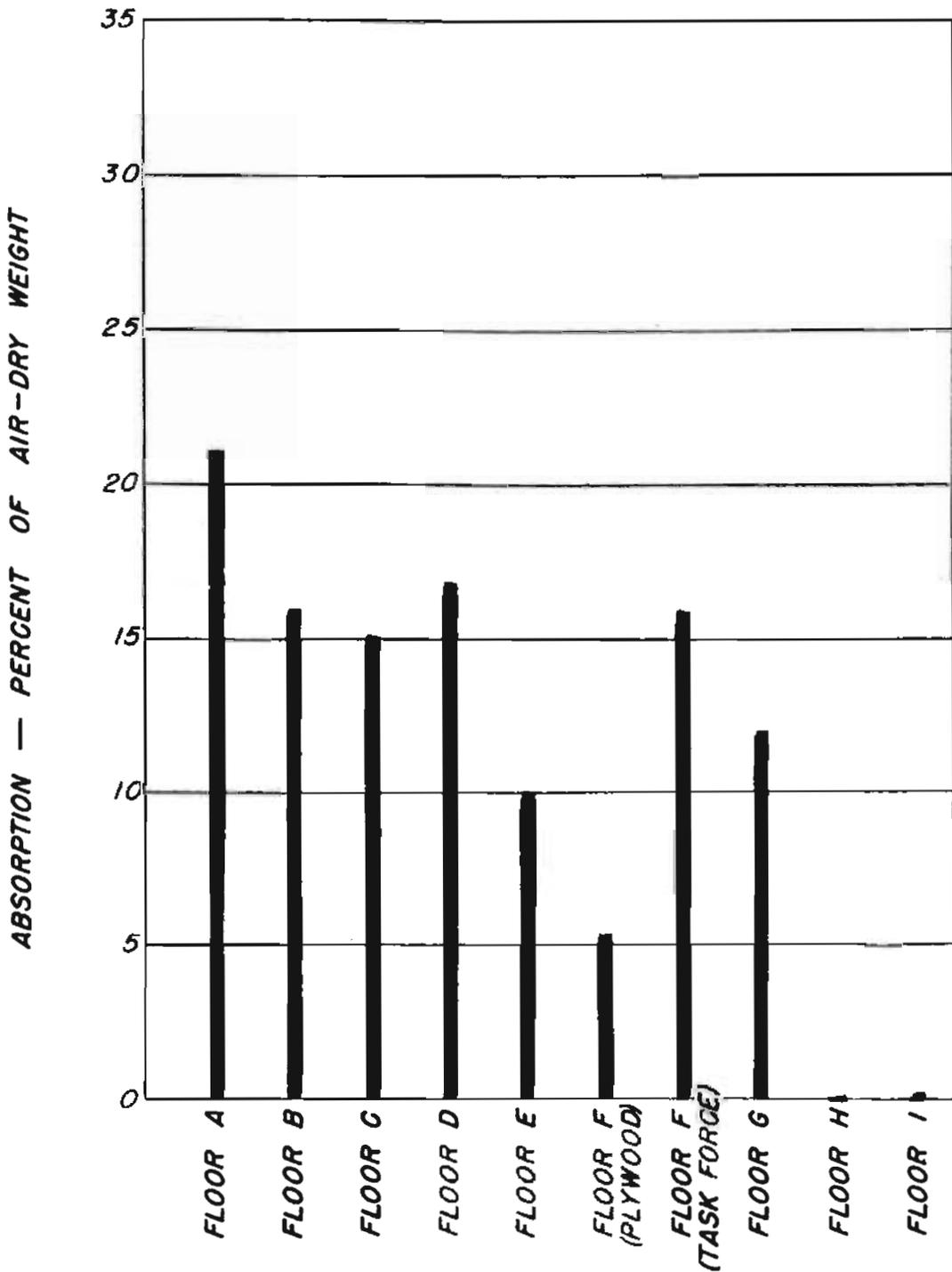


Figure 2.--Results of tests to determine absorption during immersion in water for a period of 48 hours. Specimens were 18 inches wide and 32 inches long. Absorption for floors E and F was based on the weight when air dry of the protective plywood cover or task force treadboards.

RATE OF WEAR - BASED ON 24 ST. ALUMINUM ALLOY

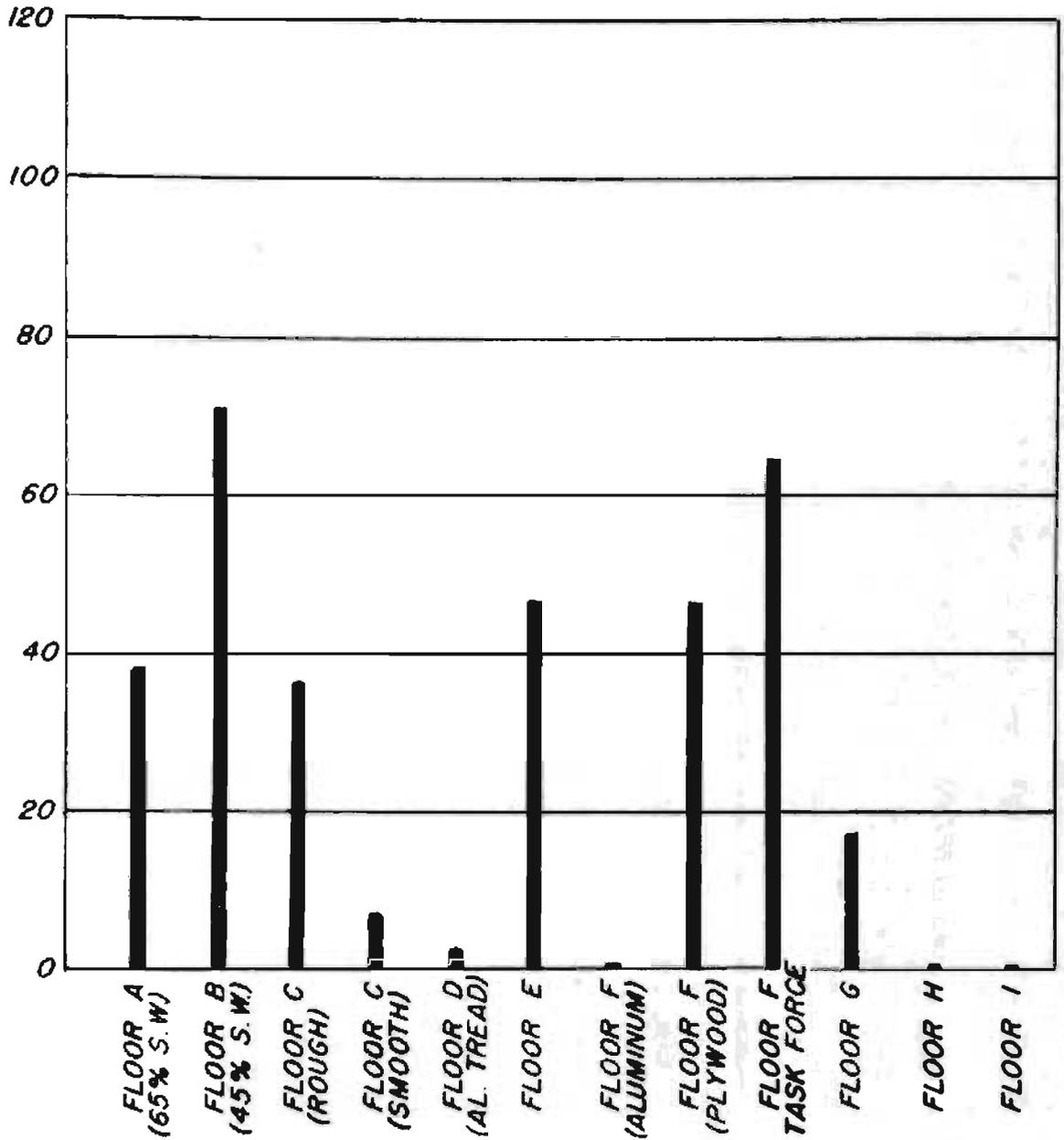


Figure 3.--Ratio of thickness loss of floorings to thickness loss of 24 ST aluminum under abrasion tests on air-dry specimens. The surfaces of floors A and B had 65 percent and 45 percent, respectively, of the area composed of summerwood.

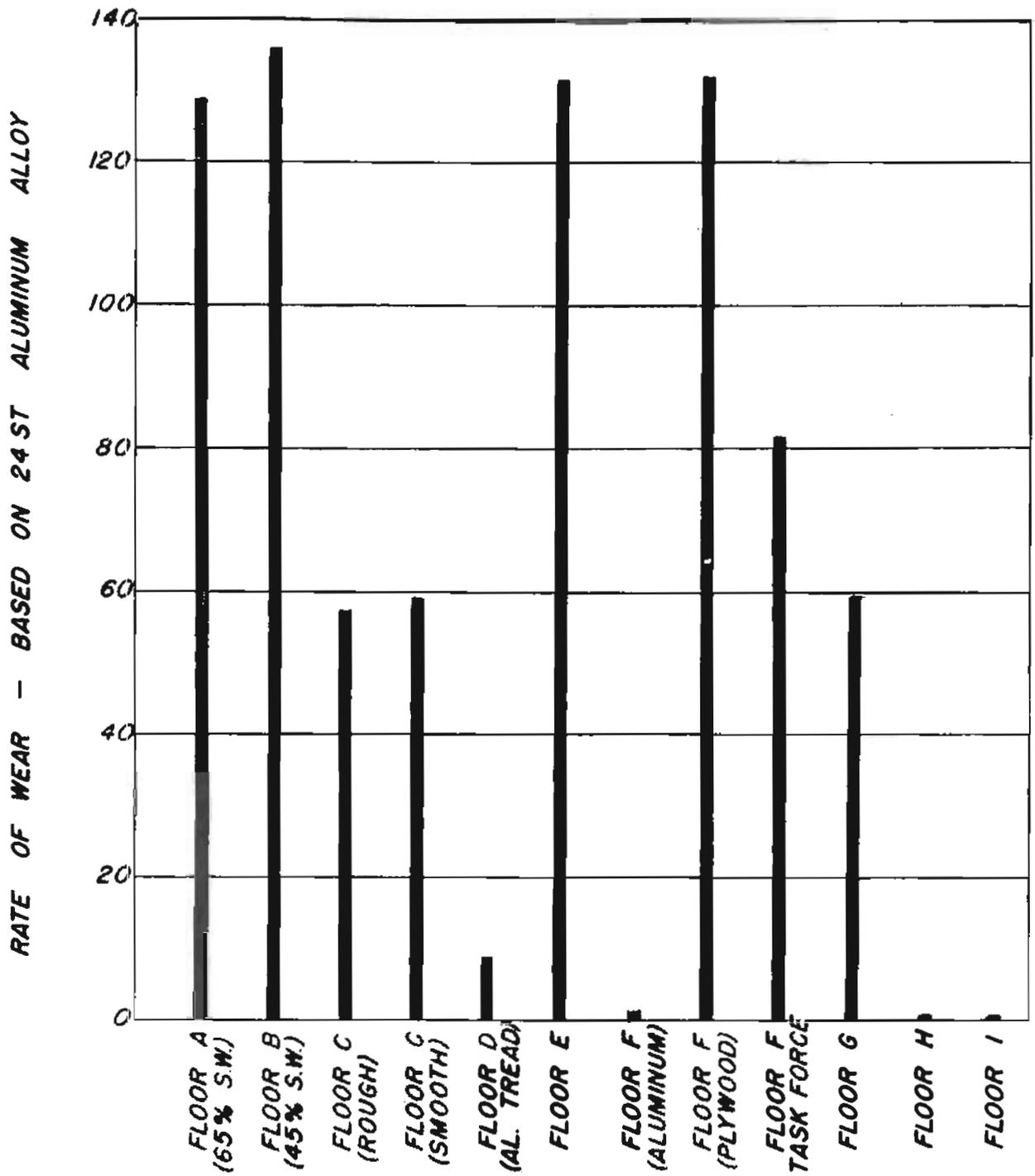


Figure 4.--Ratio of thickness loss of floorings to thickness loss of 24 ST aluminum under abrasion tests on specimens immersed in water. The effect of summerwood on rate of wear for floors A and B is not as apparent in the wet test as it is when tested dry.

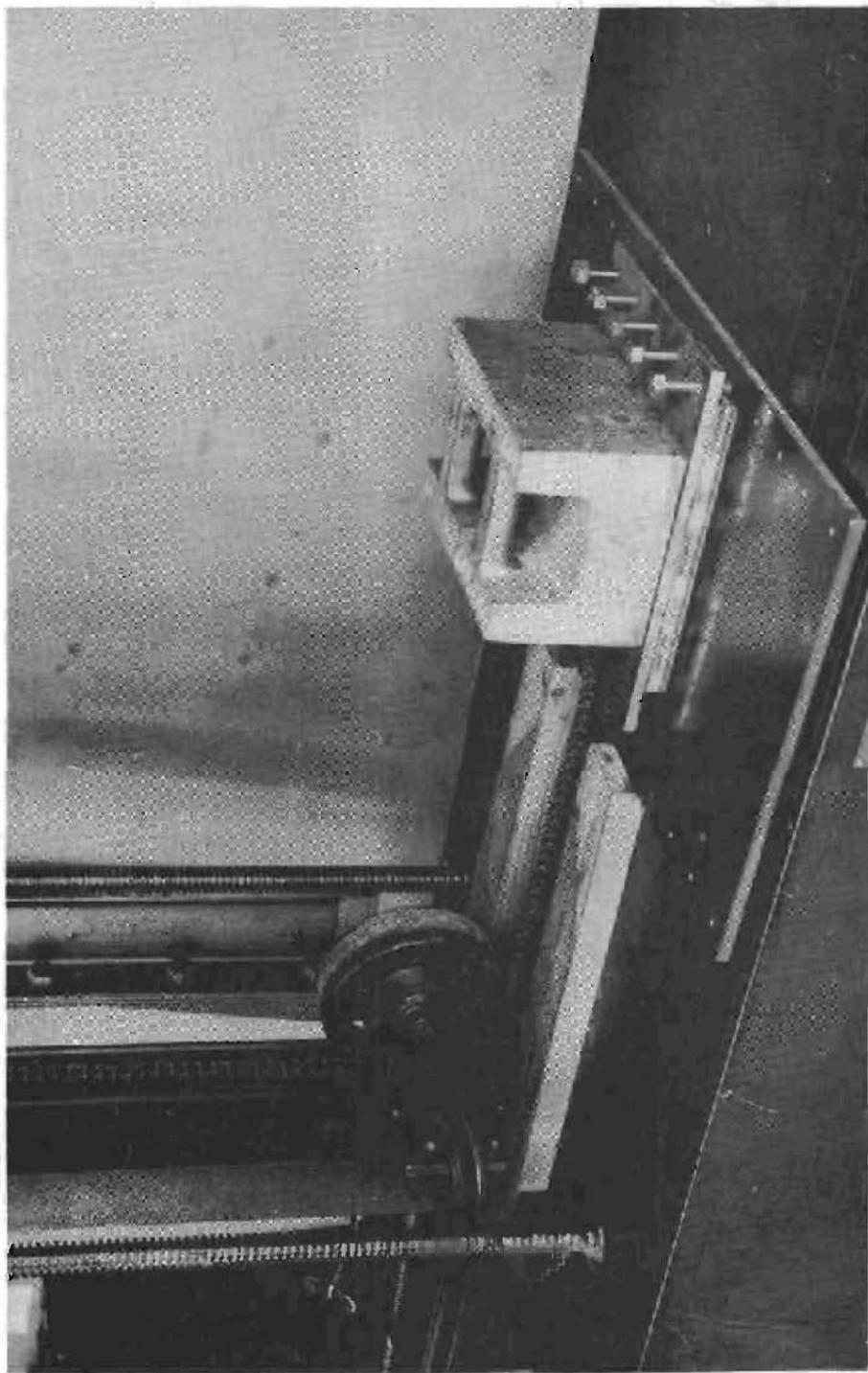


Figure 5.--Apparatus used for determining frictional resistance. The Douglas-fir panel is in place on the flooring with the normal load in position. The weighted panel is pulled across the floor by a chain appearing at the left of the panel. Tangential load is measured through the upper head of the testing machine.

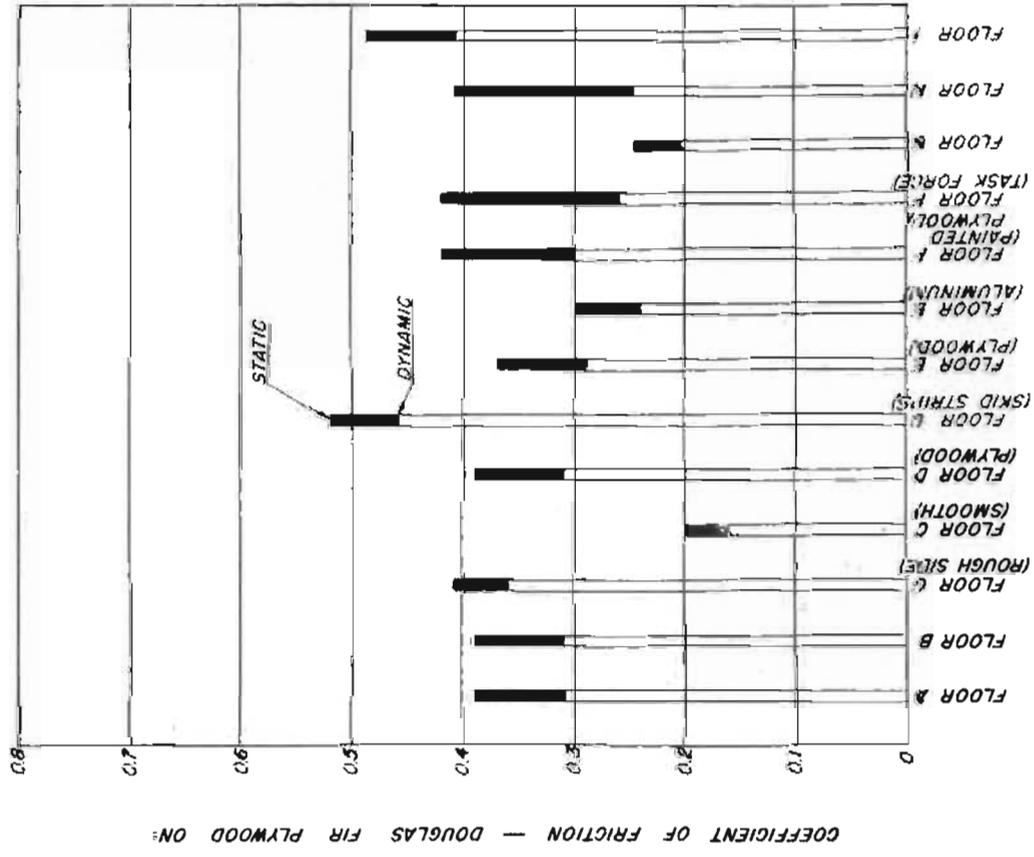
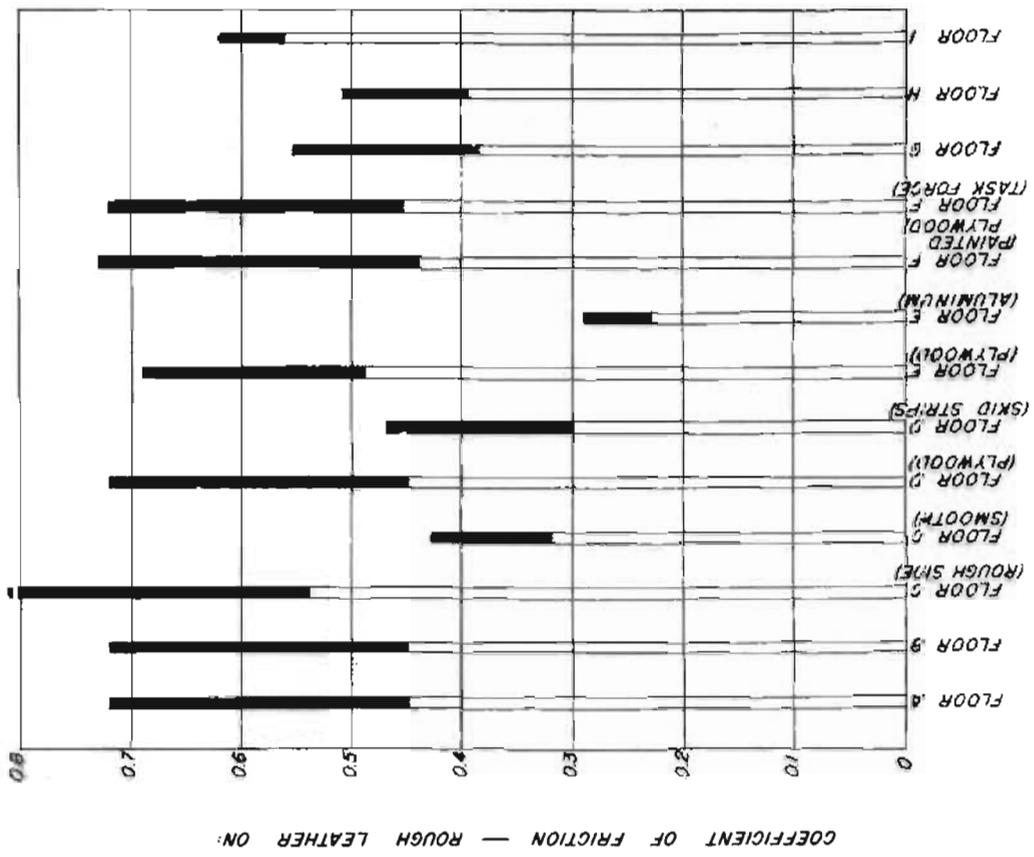


Figure 6.--Static and dynamic coefficients of friction between various types of flooring and Douglas-fir plywood or rough sole leather. The surfaces in contact were in the air-dry condition. Normal load on an area of 1 square foot was 200 pounds.

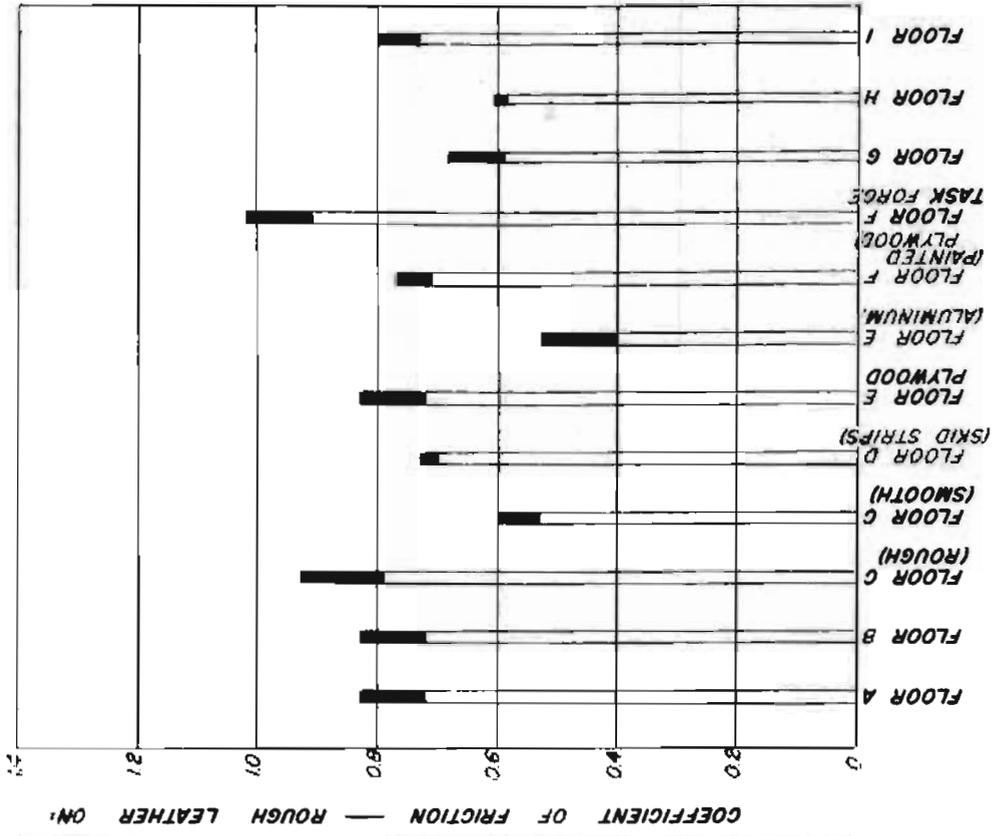
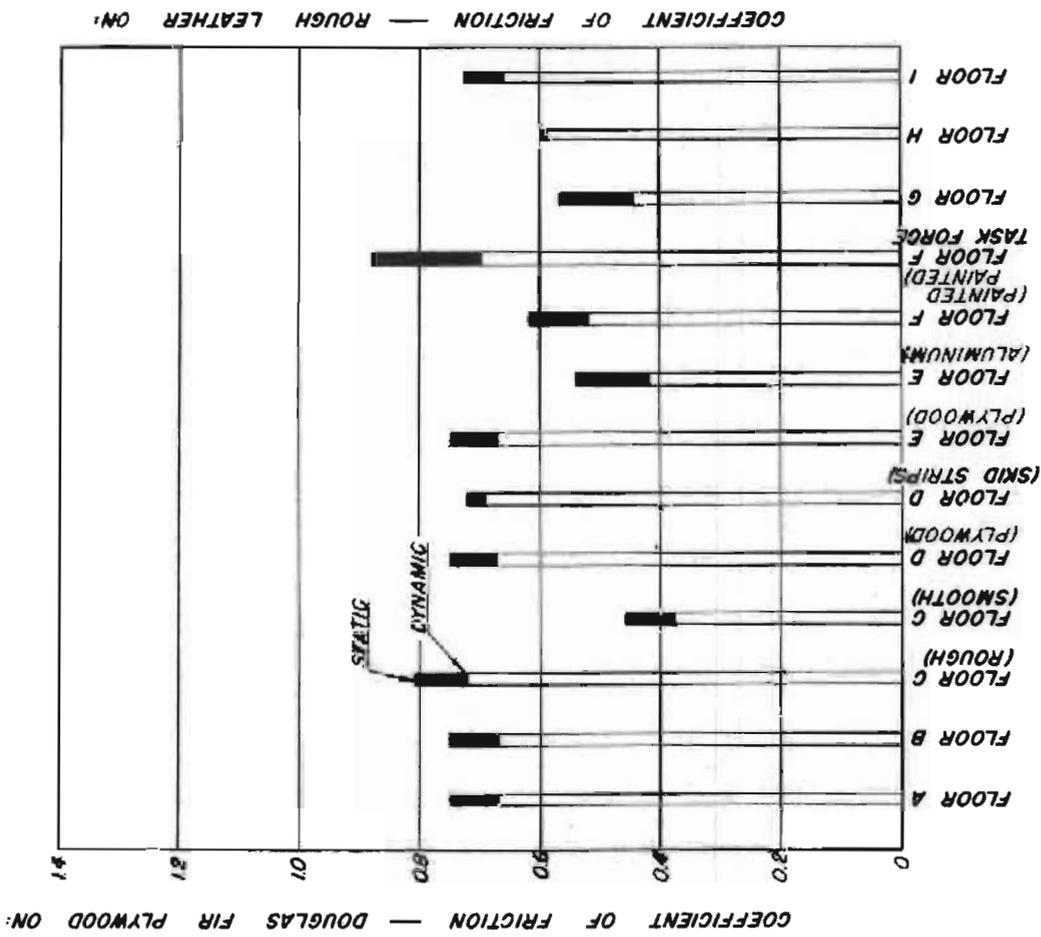


Figure 7.--Static and dynamic coefficients of friction between various types of flooring and Douglas-fir plywood or rough sole leather. The surfaces in contact had been immersed in water for 48 hours and a quantity of free water was placed on the flooring before test.

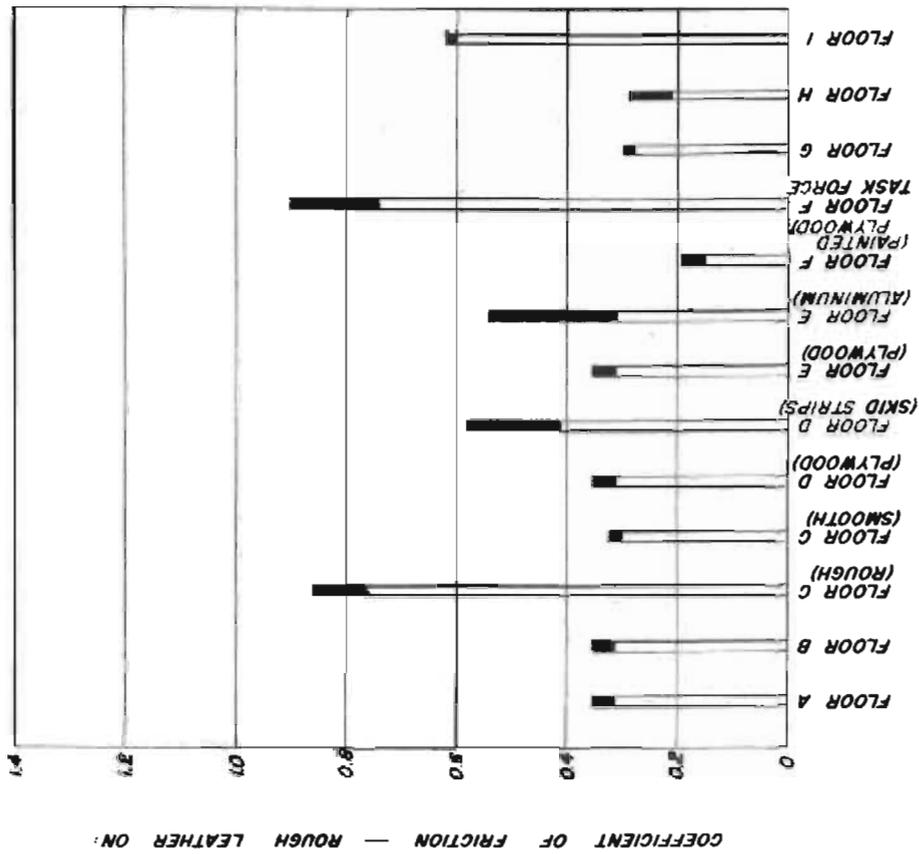
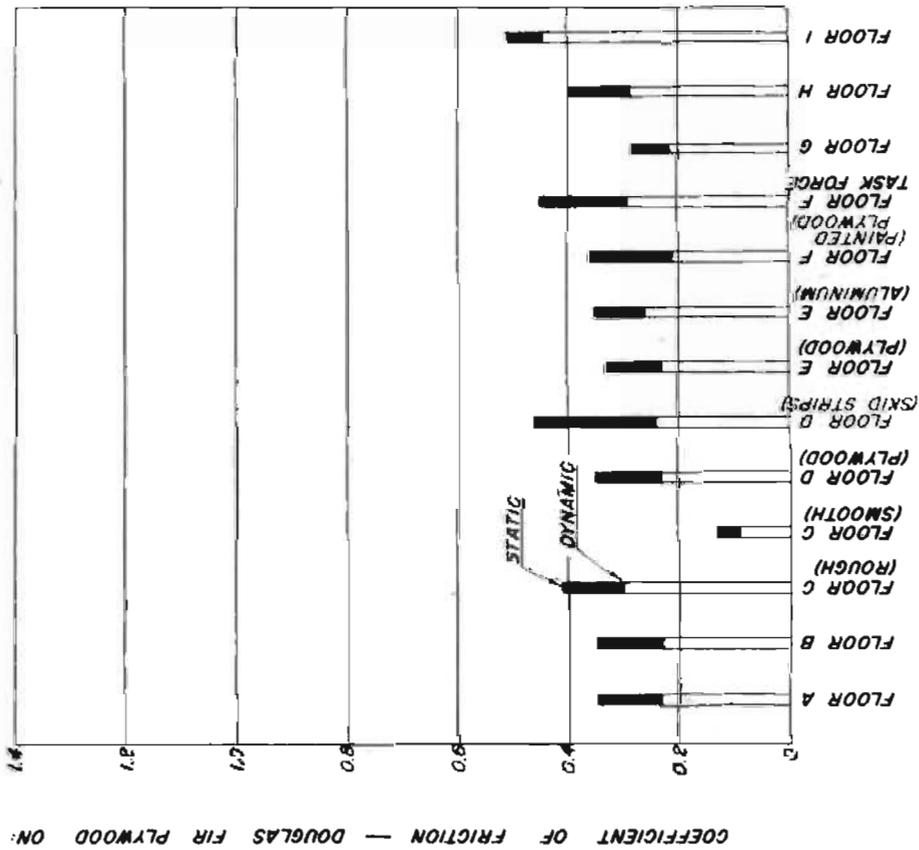


Figure 8.--Static and dynamic coefficients of friction between various types of flooring and Douglas-fir plywood or rough sole leather. The surfaces in contact were treated with a liberal application of SAE 30 oil prior to test.

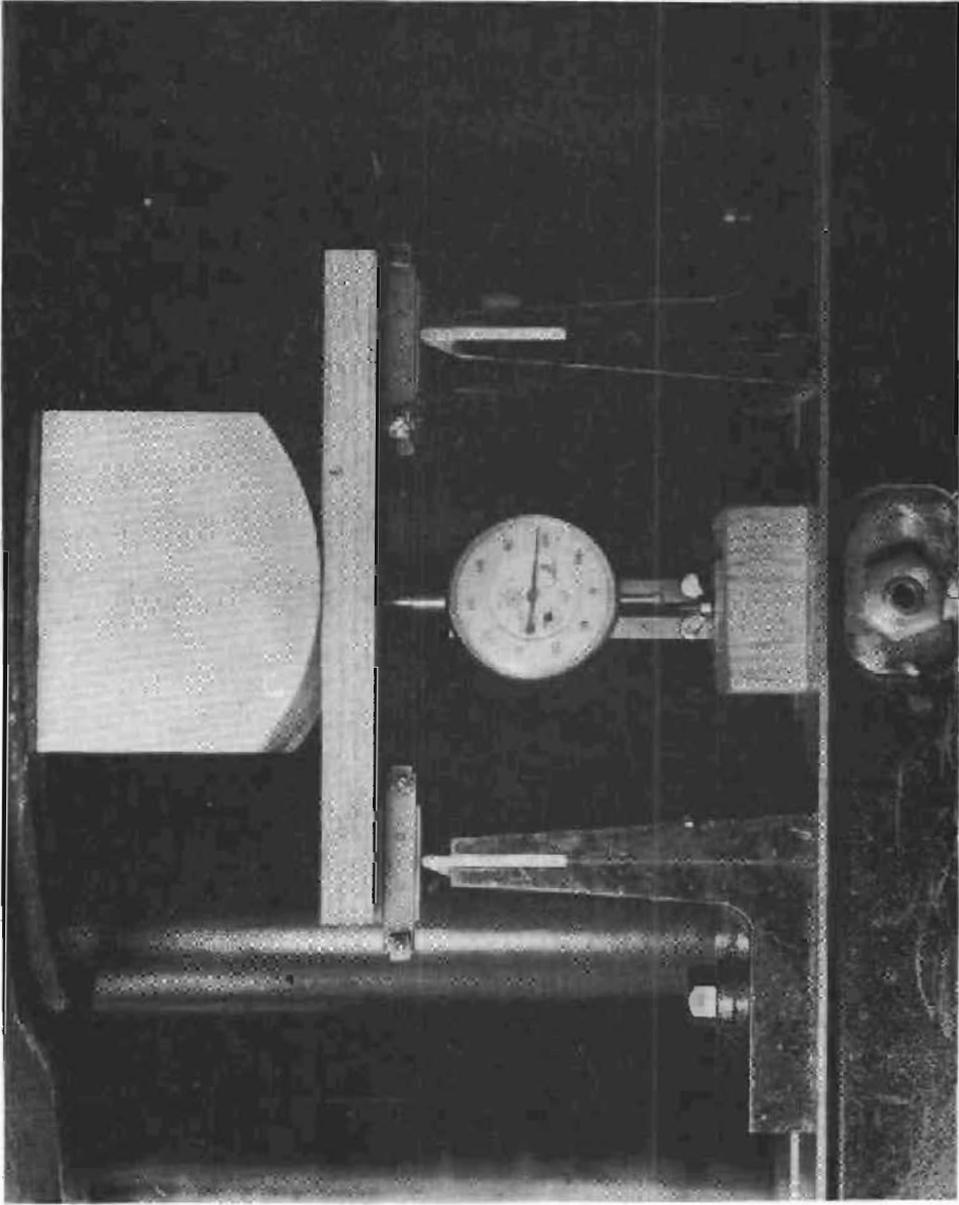


Figure 9.--Equipment used to test the static bending strength of cargo flooring. The specimen is supported on knife-edges and roller bearings placed to provide an 8-inch span. Load is applied by a 4-inch radius maple block bearing on the specimen, which is, 8 inches wide. Deflection at the center of the span is measured by a dial indicator graduated to 0.001 inch.

Z N 61398 F

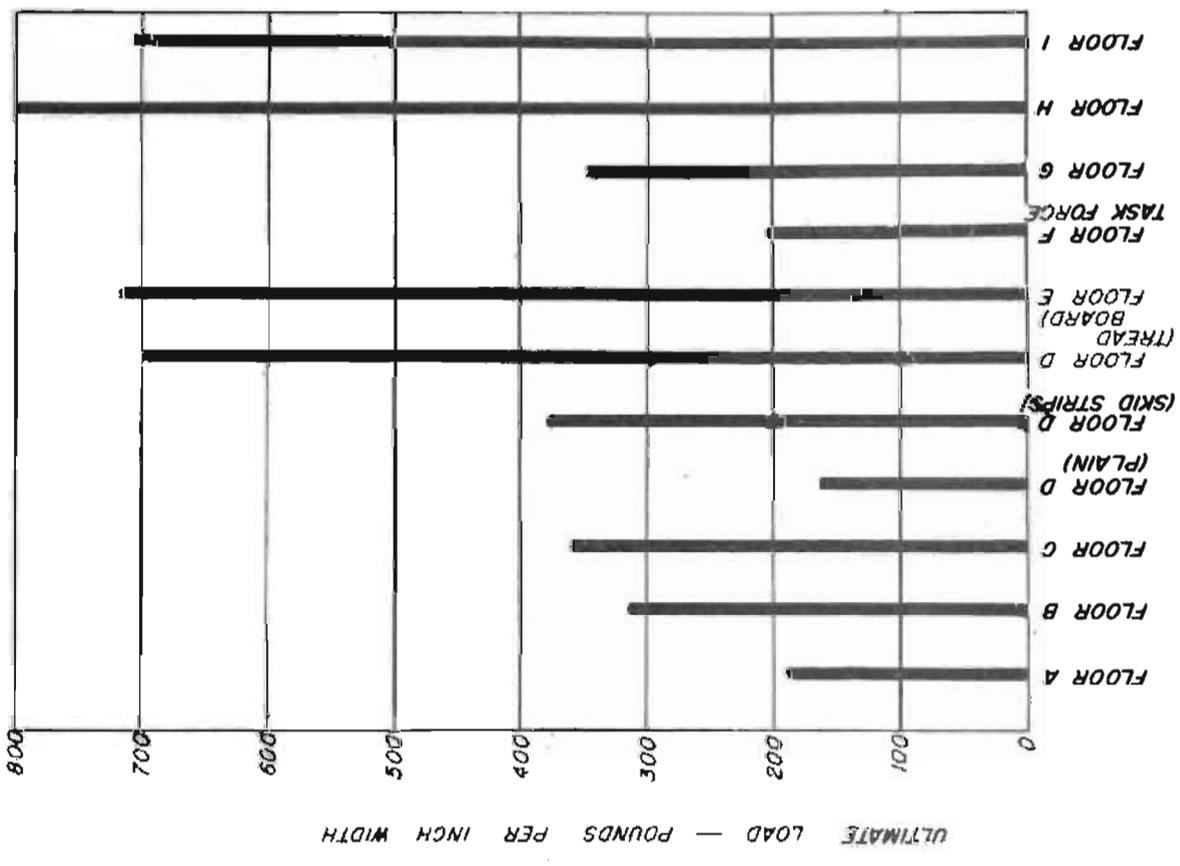
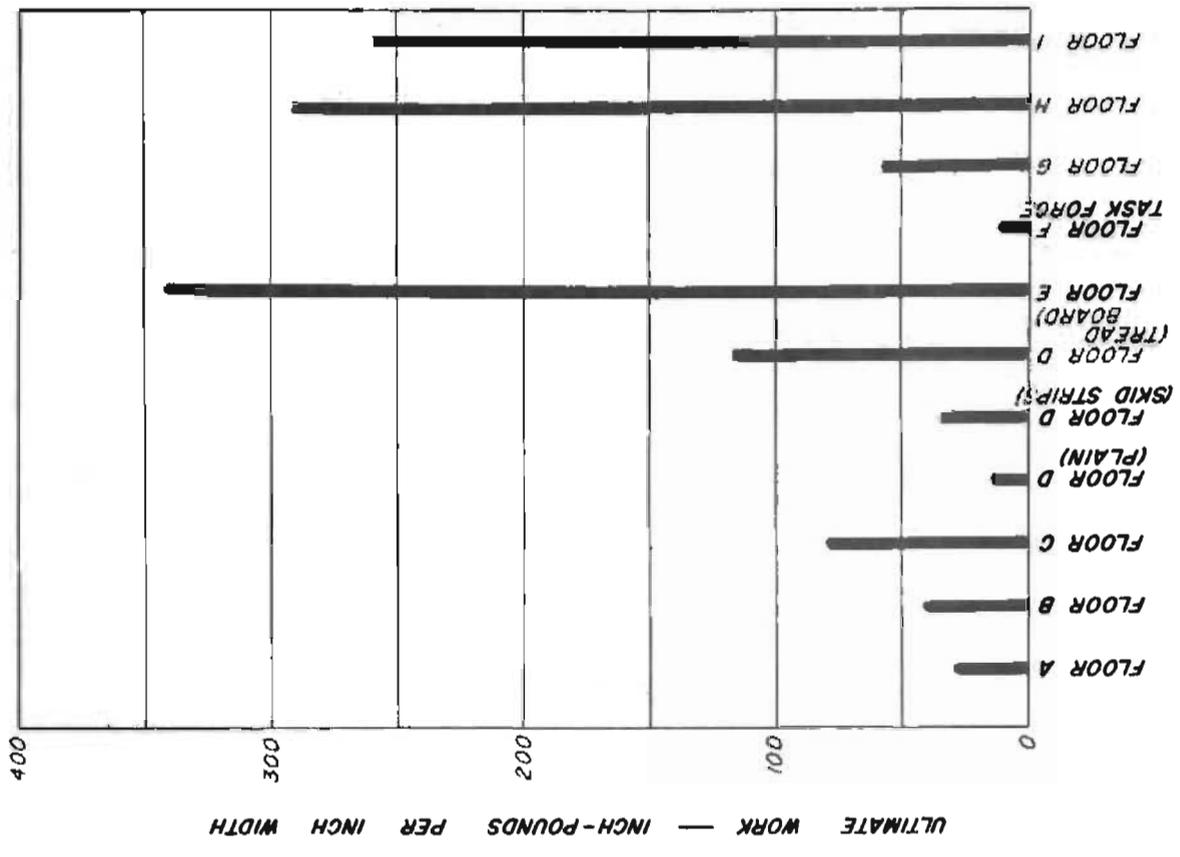


Figure 10.--Results of tests of the bending strength of cargo flooring showing the ultimate load and the ultimate work per inch width of floor supported on an 8-inch span. The specimens were 8 inches wide except in the case of floors D (skid strips), H, and I which were prepared in a 9-inch width.

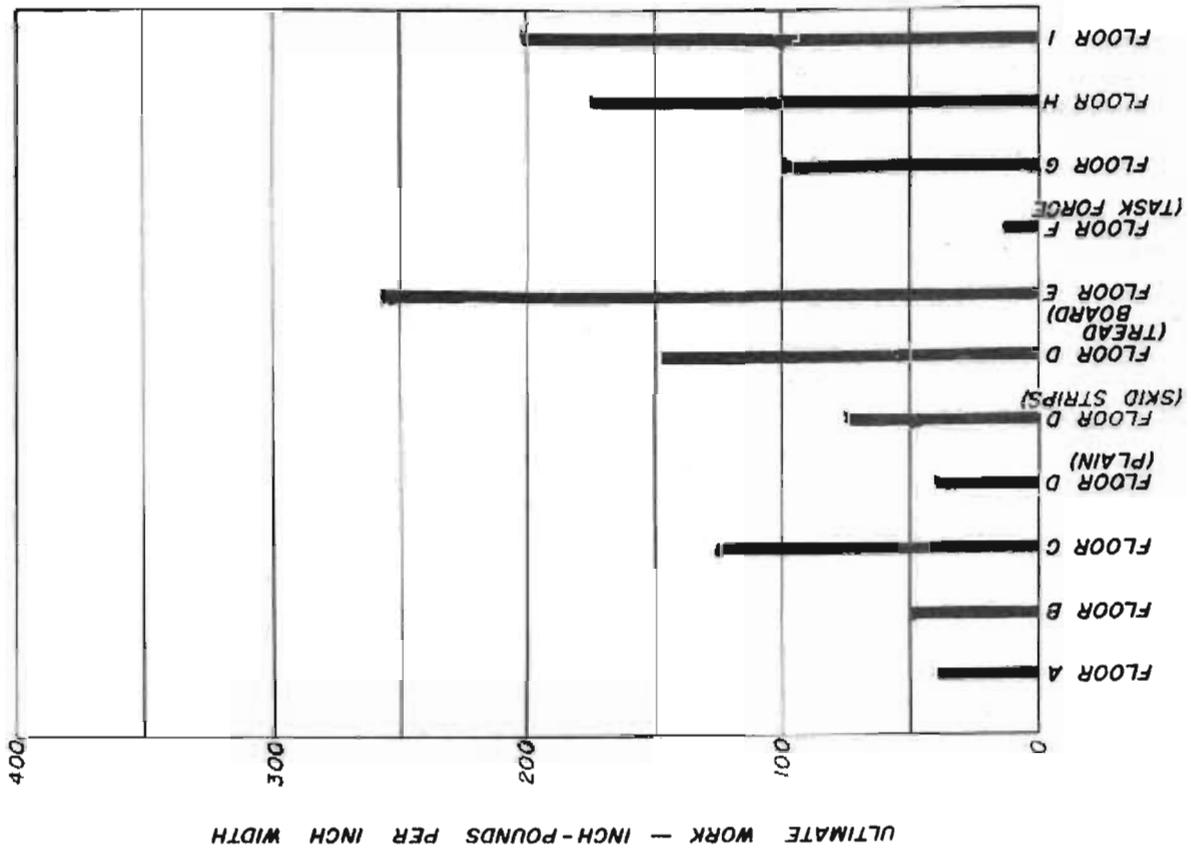
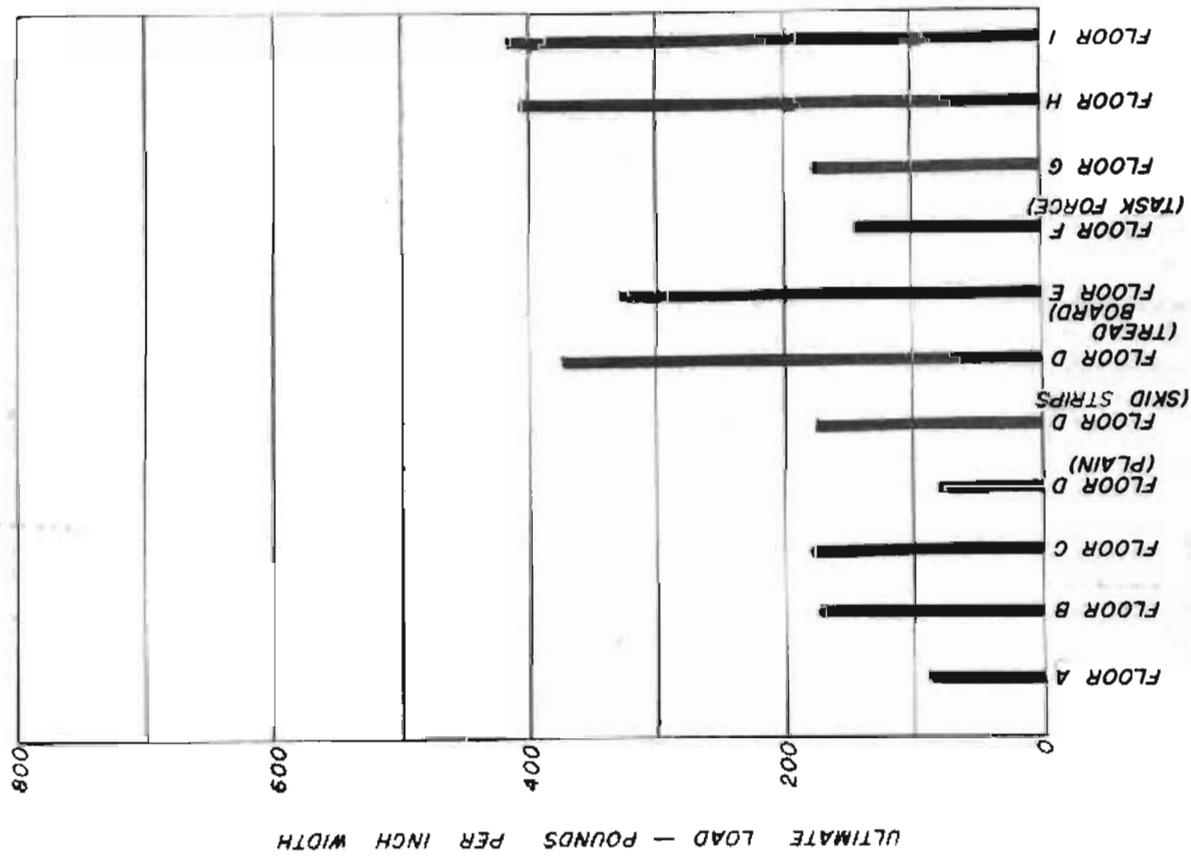


Figure 11.--Results of tests of the bending strength of cargo flooring showing the ultimate load and ultimate work per inch width of floor supported on a 16-inch span. The specimens were 8 inches wide except in the case of floors D (skid strips), H and I which were prepared in a 9-inch width.

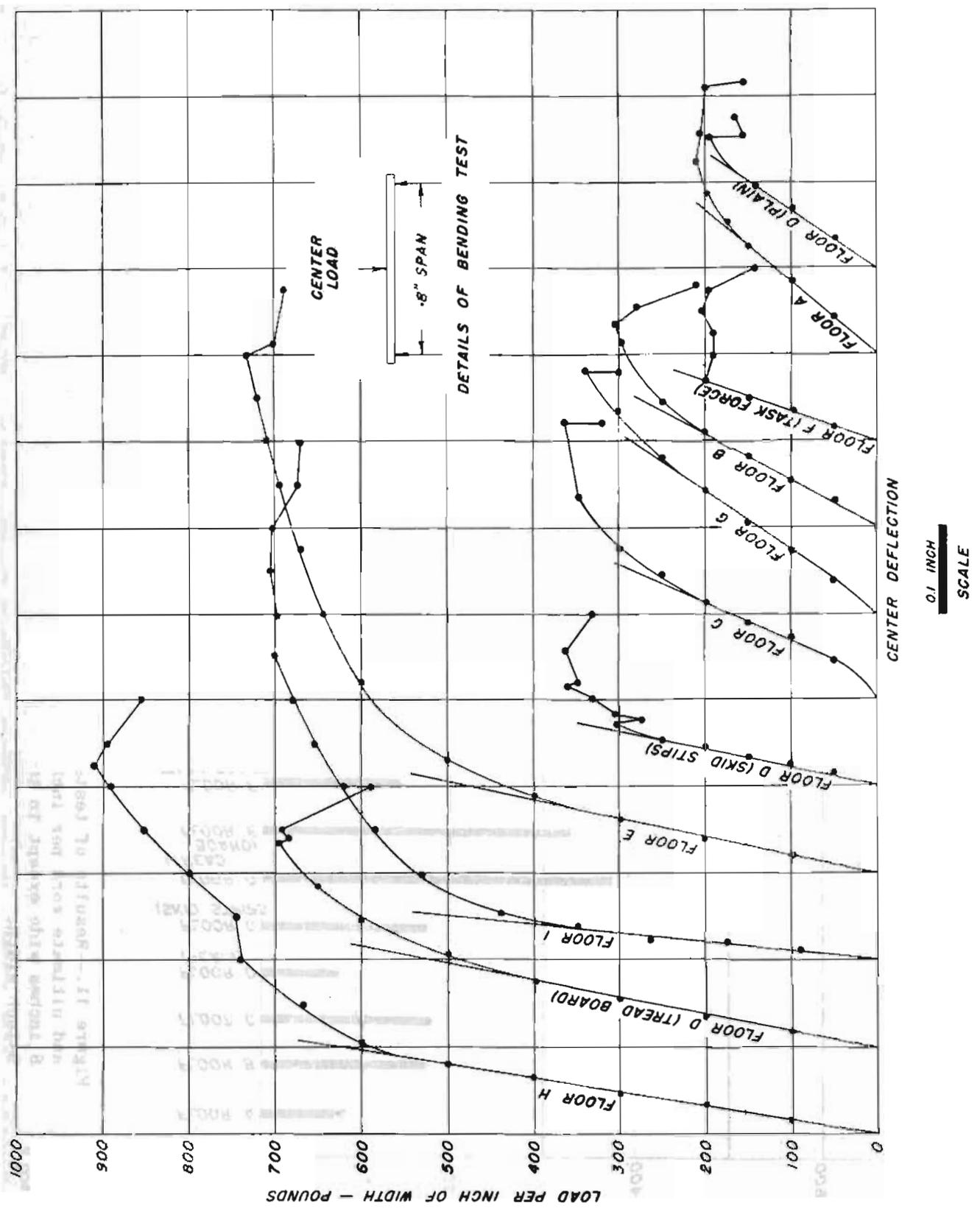


Figure 12.--Typical load-deflection curves from static-bending tests of specimens having an 8-inch span.

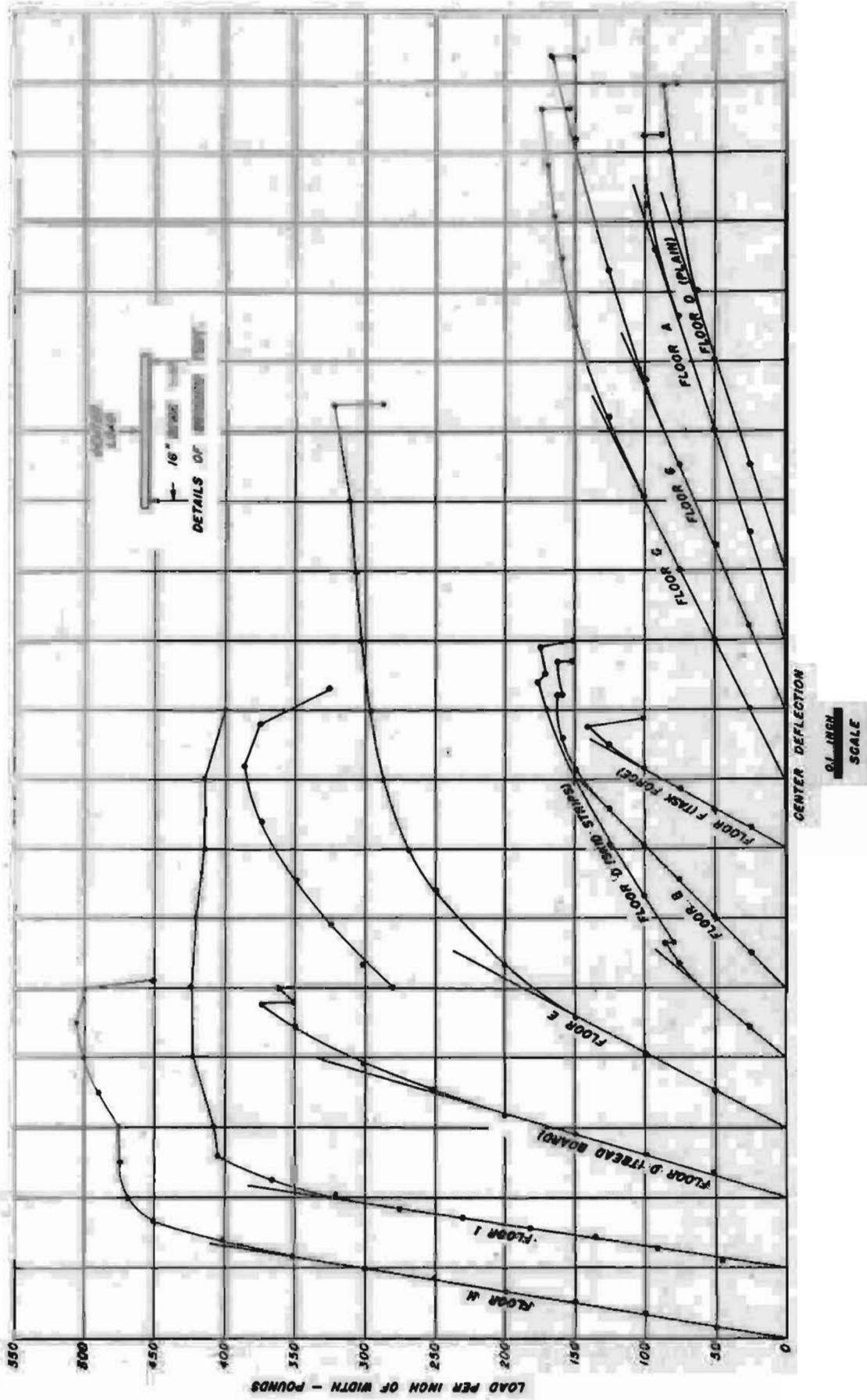


Figure 13.--Typical load-deflection curves from static-bending tests of specimens having a 16-inch span.

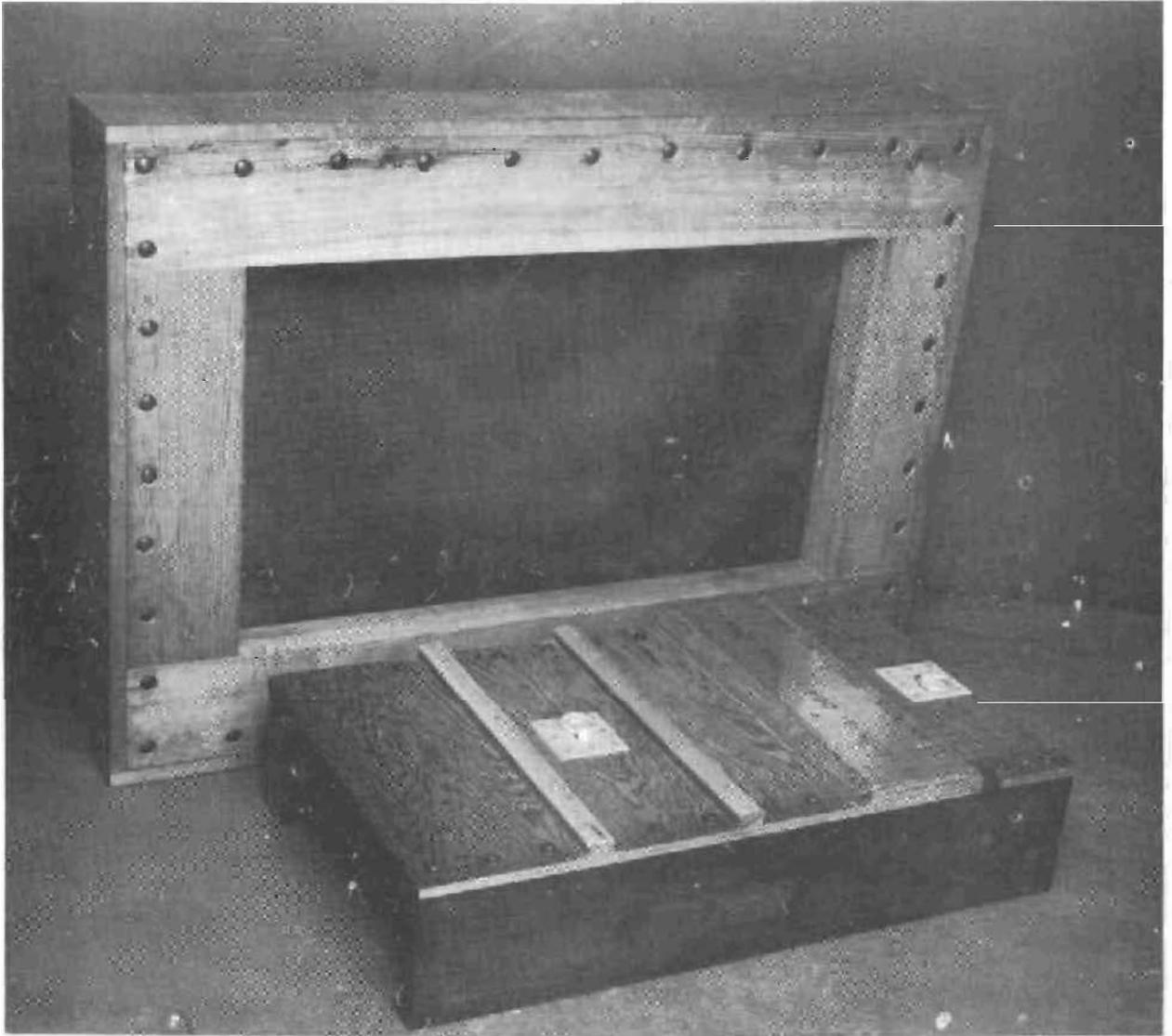
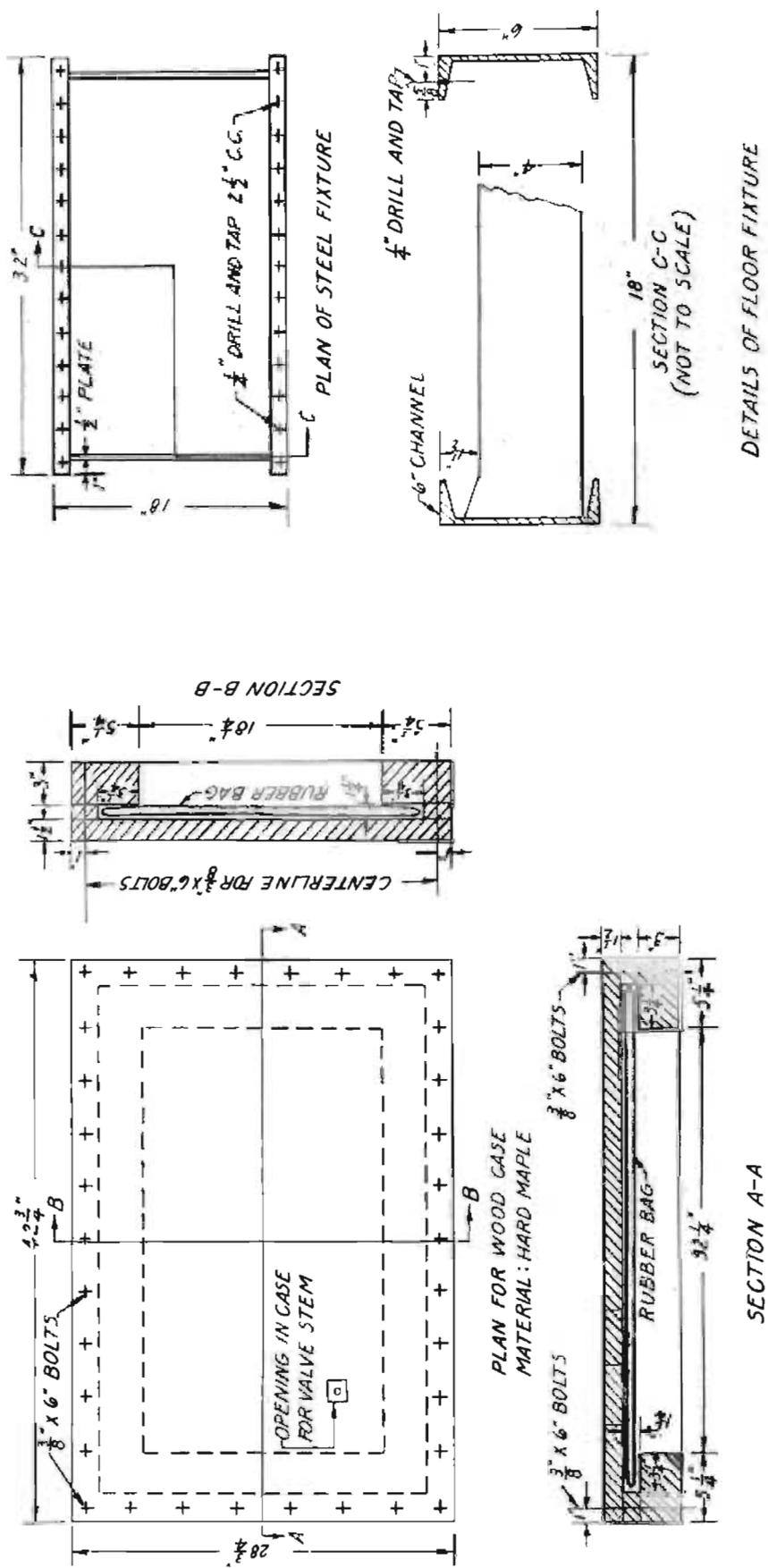


Figure 14.--Details of equipment used in tests of cargo flooring under uniform load. A floor panel attached to the steel fixture is shown in the foreground. The wood case containing a rubber bag for applying load by compressed air appears in position for assembly over the floor panel.

Z M 61403 F



DETAILS OF FLOOR FIXTURE

SECTION A-A

Figure 15.--Details of construction for apparatus used to apply uniform load on air cargo flooring.

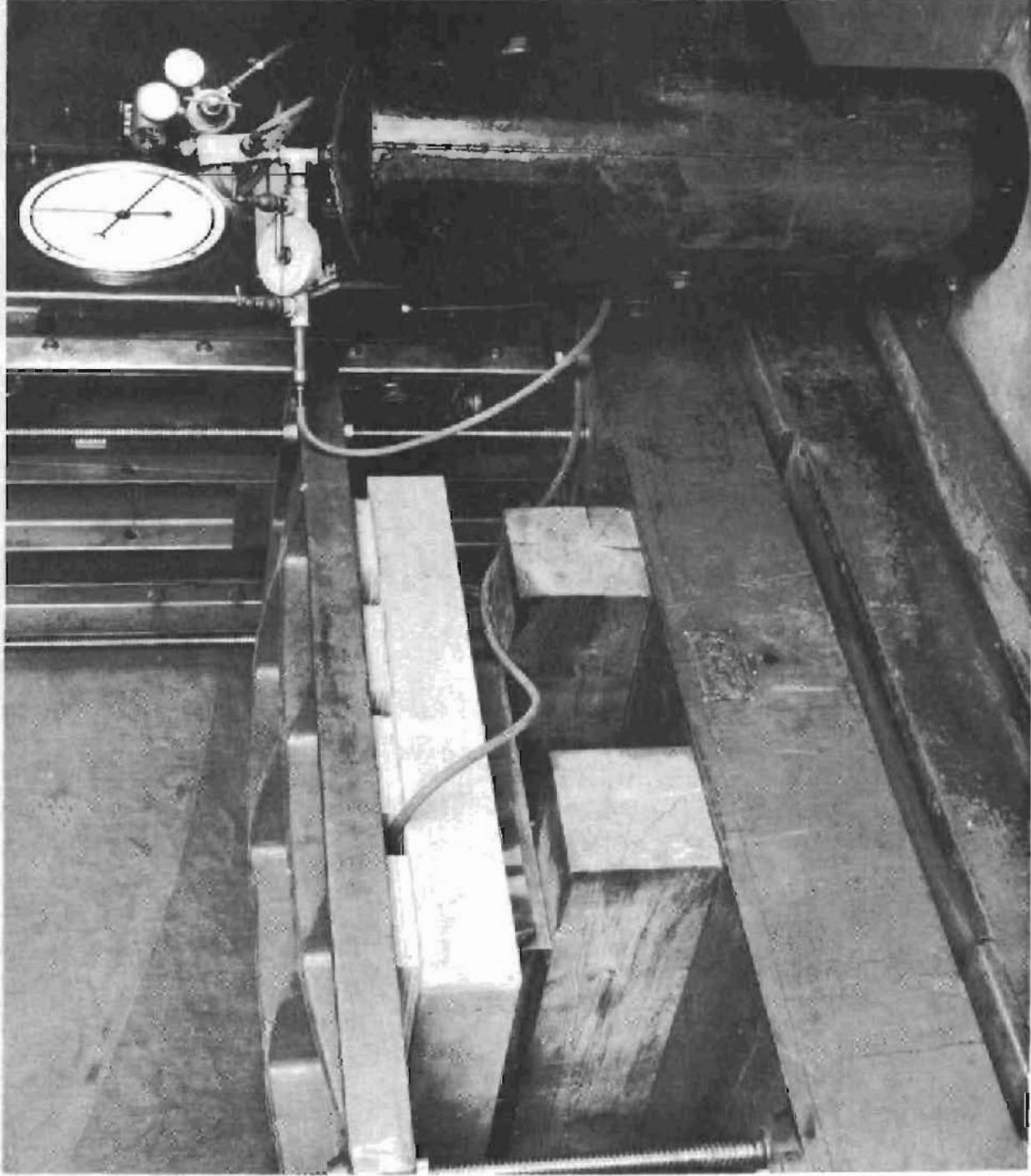


Figure 16.--Equipment used for testing flooring under uniform load. The specimen is mounted on a steel fixture and covered by a wood case containing an inelastic rubber bag. Air is passed into the bag from the tank and regulator shown at the right. The load applied to the panel is measured by the testing machine, which supports the fixture and wood case. Deflection at the center of the panel is measured by a dial indicator touching the bottom or tension face of the flooring.

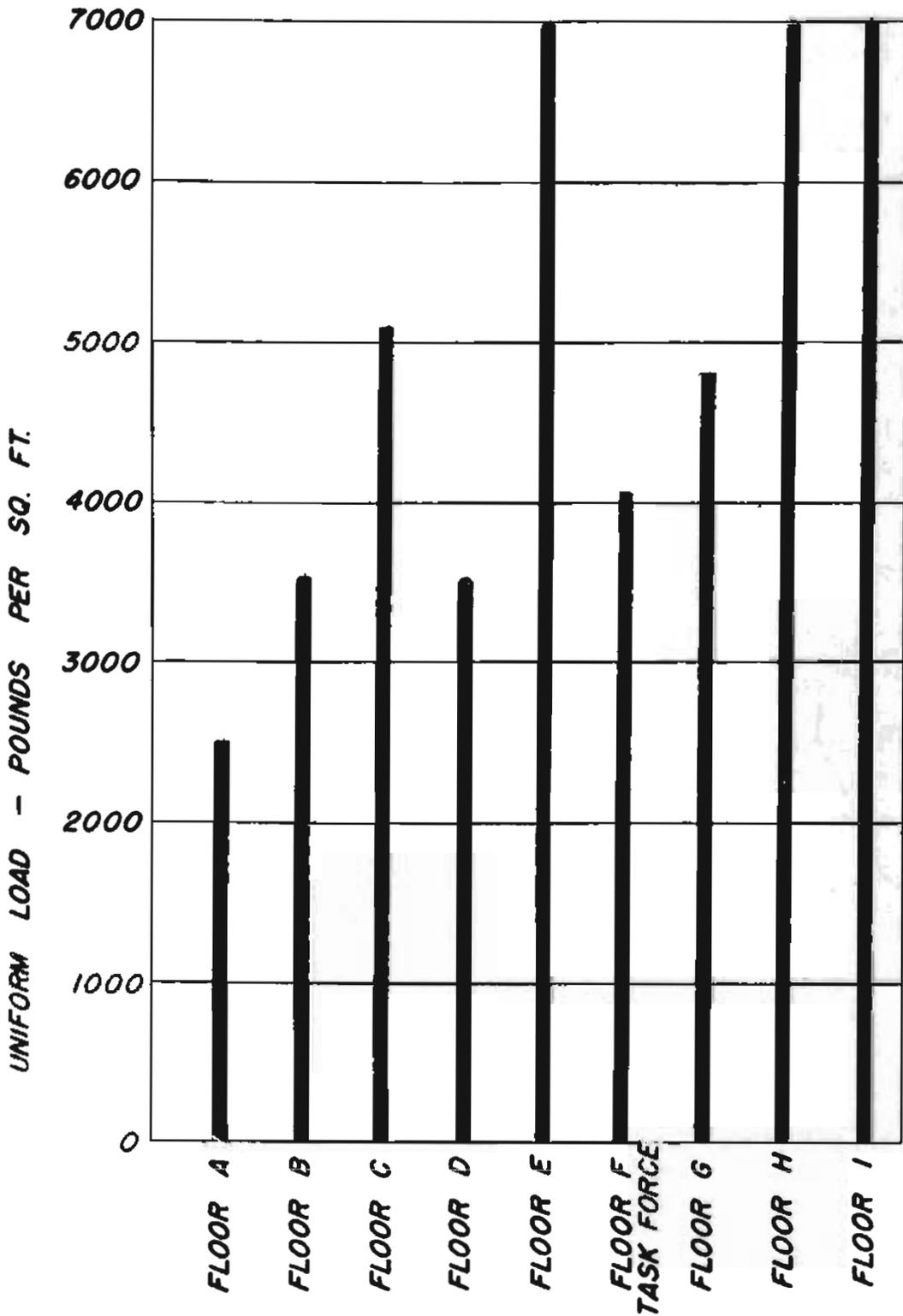


Figure 17.--Results of tests of the bending strength of 18-by-32-inch panels under uniform load. Floors E, H, and I did not fail under a load of 7,000 pounds per square foot. Floor F was not tested under uniform load as it could not be prepared for support on the standard test fixture.

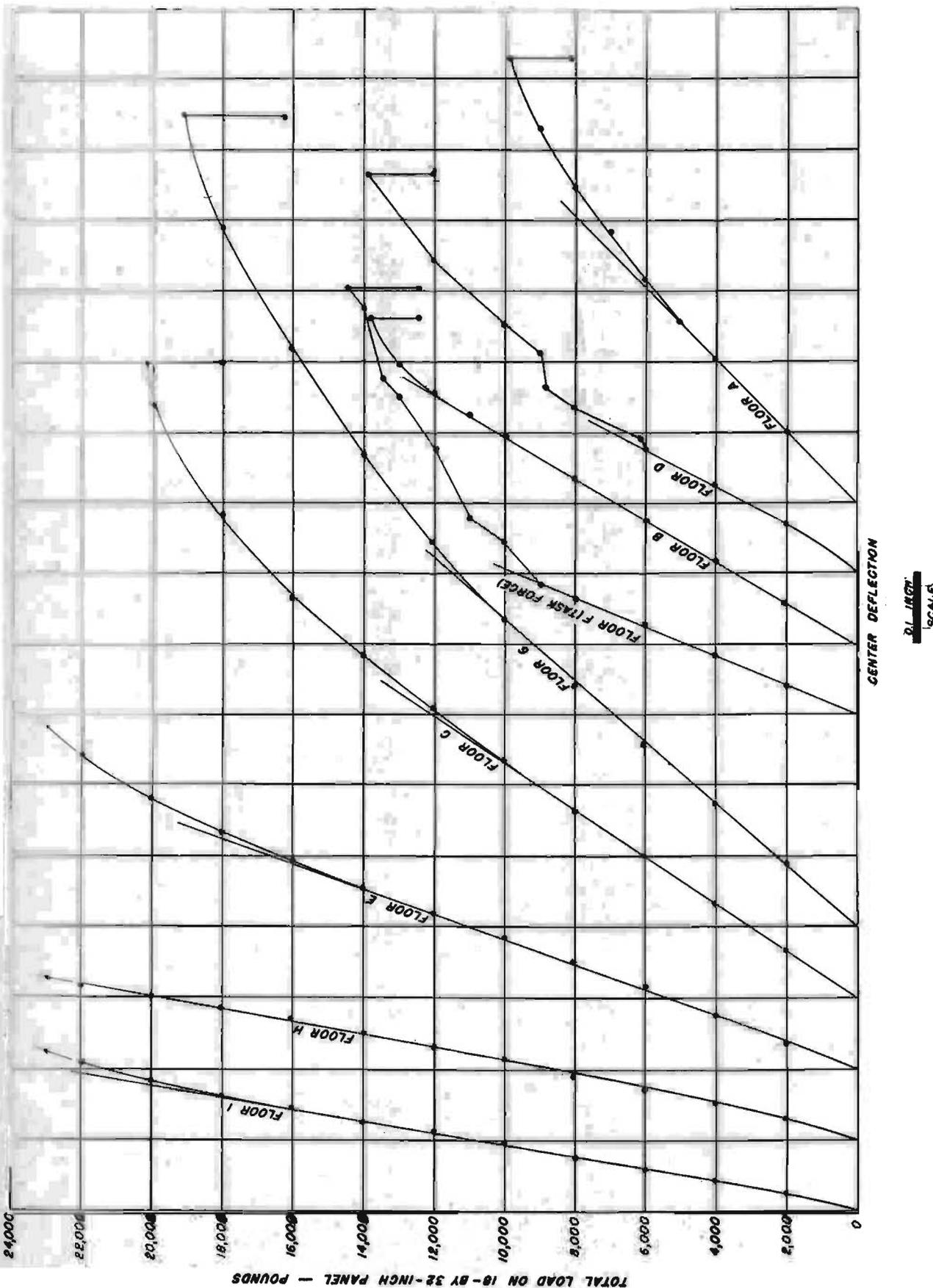


Figure 18.--Typical load-deflection curves from uniform load tests. Floors E, H, and I were not tested to failure.

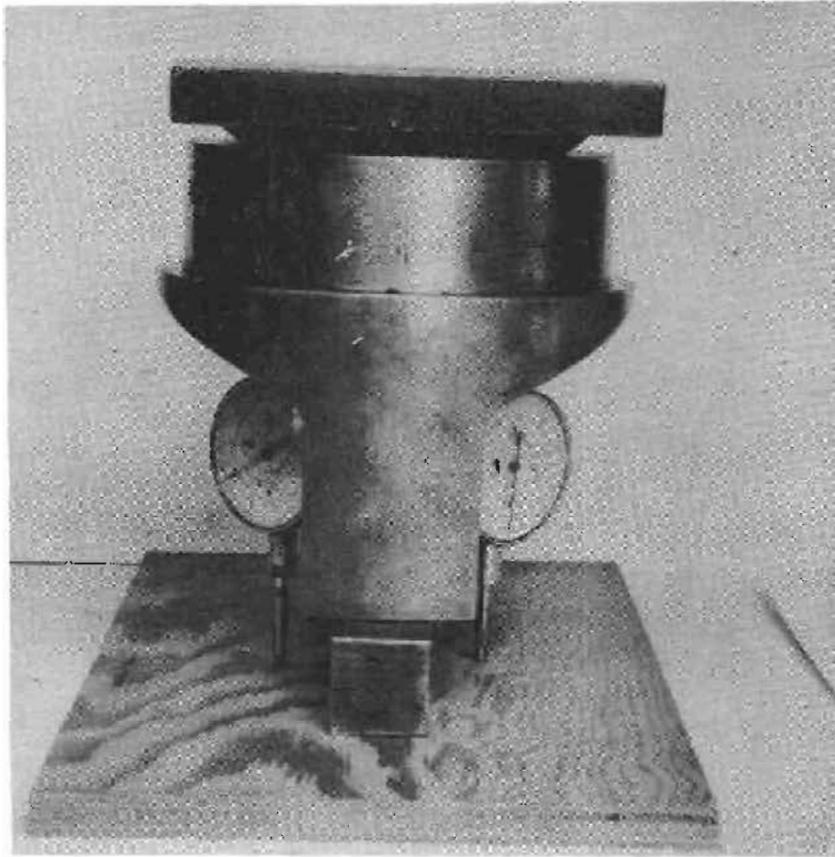


Figure 19.--Equipment used to test the crushing strength of cargo flooring under strip loading simulating the action of floor beams. The loaded strip is 1-1/4 inches wide and 9 inches long. Deformation is measured by the dial gages mounted on the loading head. The assembly shown is placed in a testing machine for application of load.

Z M 61408 F

MAXIMUM STRESS AT 0.05" SURFACE COMPRESSION - POUNDS PER SQ. IN.

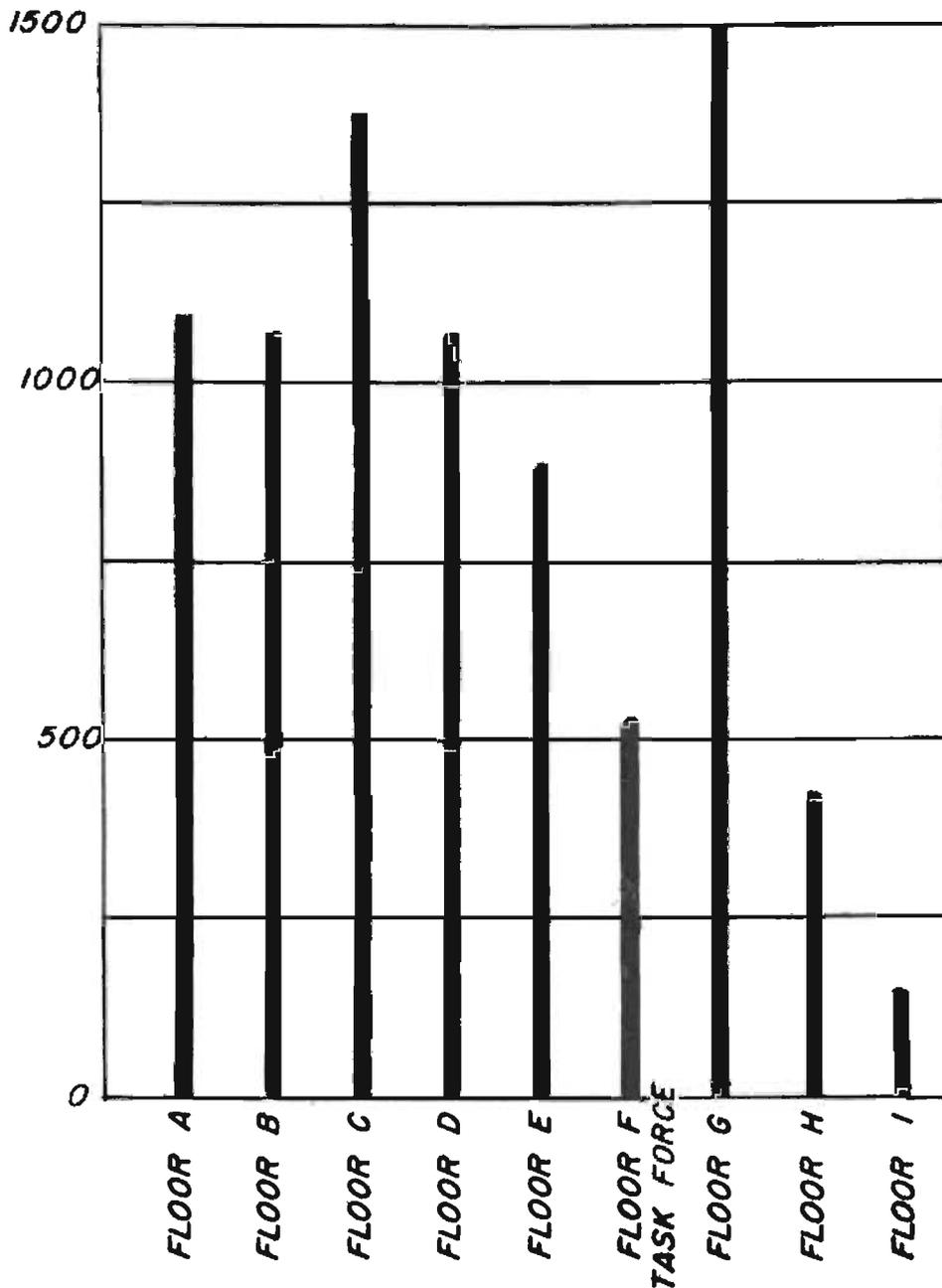


Figure 20.--Results of tests of flooring under strip loading simulating the effect of crushing over floor beams. Maximum stress corresponding to a deformation of 0.05 inch is shown for each floor except F which could not be adapted to this method of test.

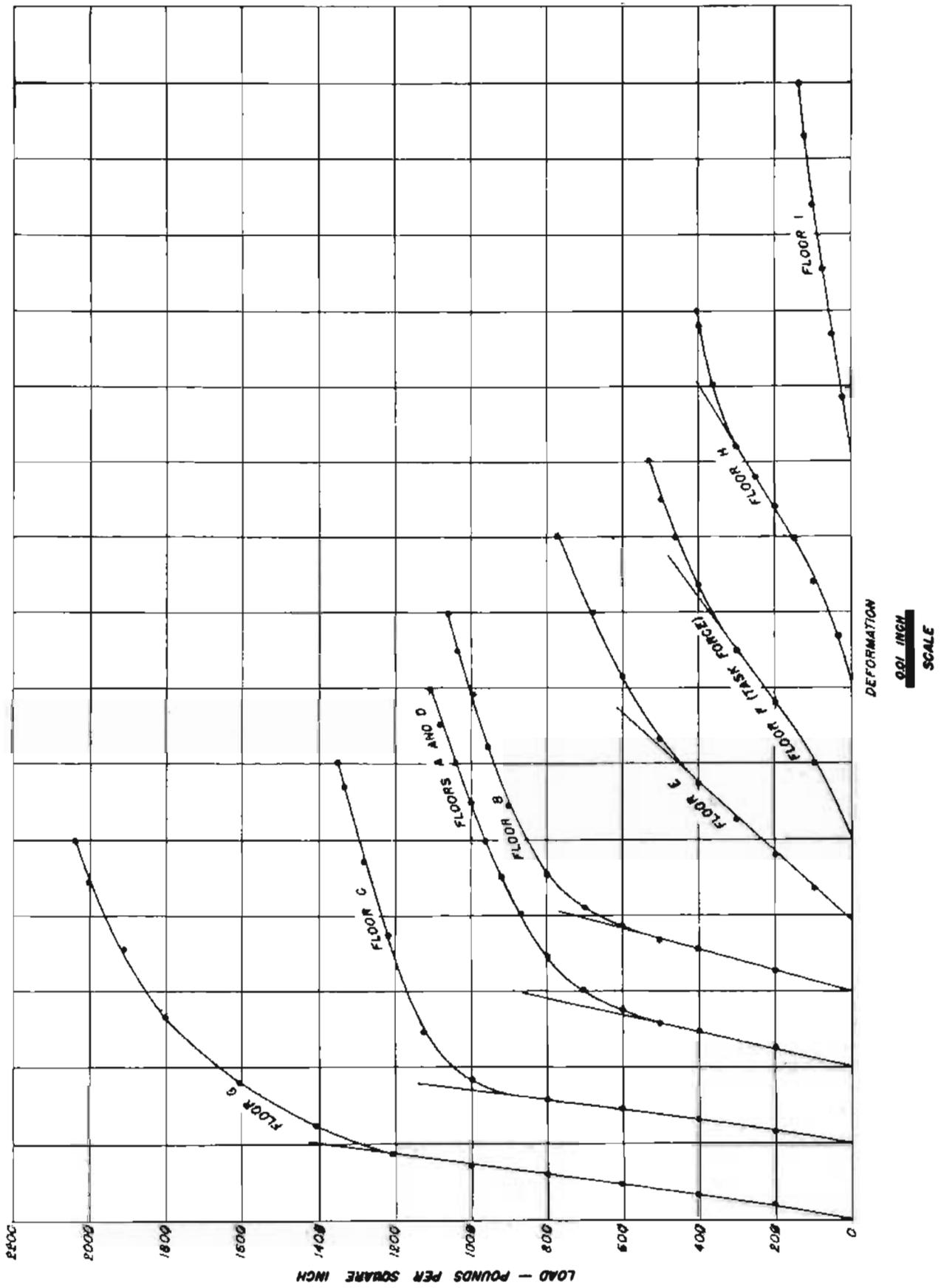


Figure 21.--Typical load-deformation curves from compression tests simulating the crushing effect of floor beams.

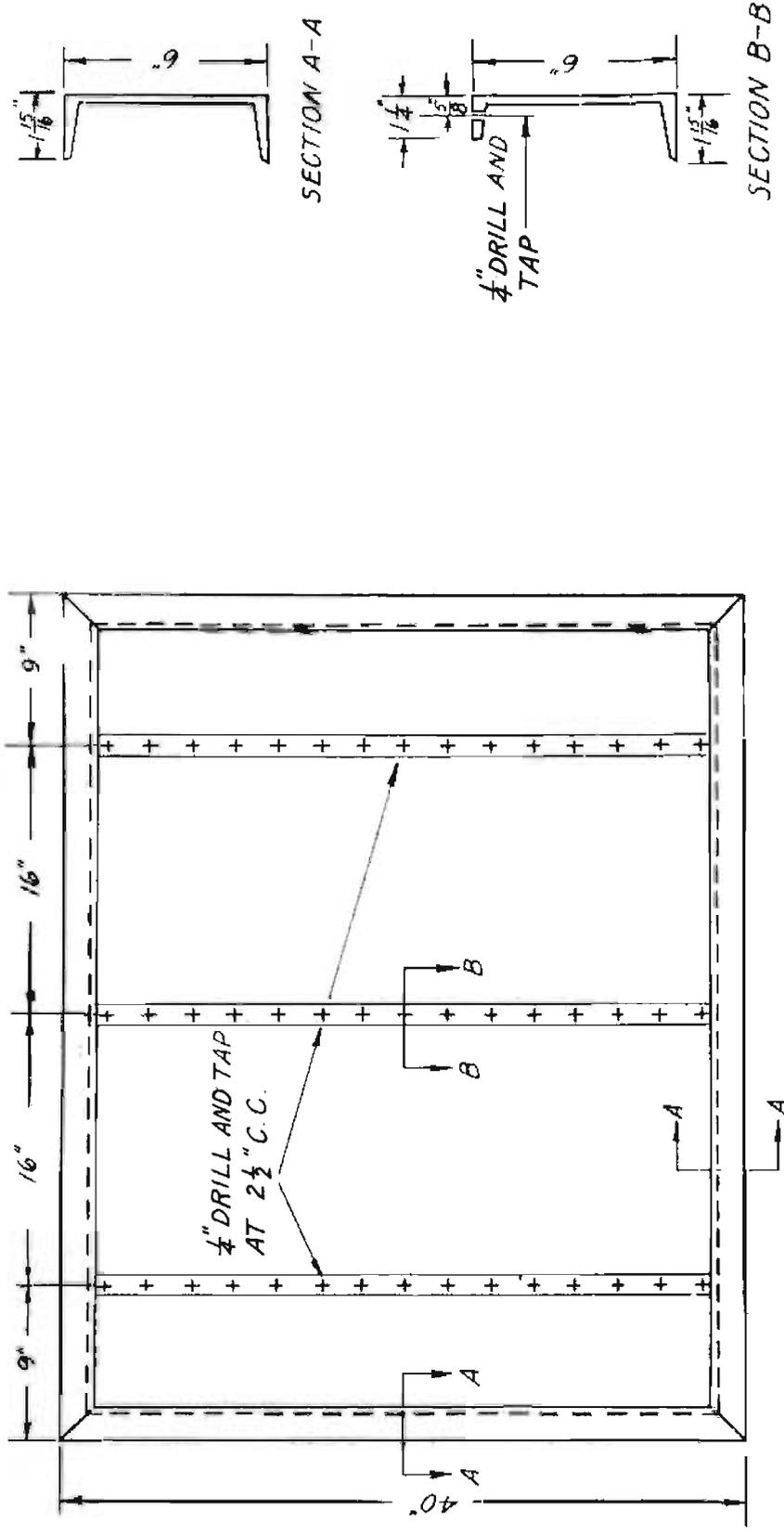
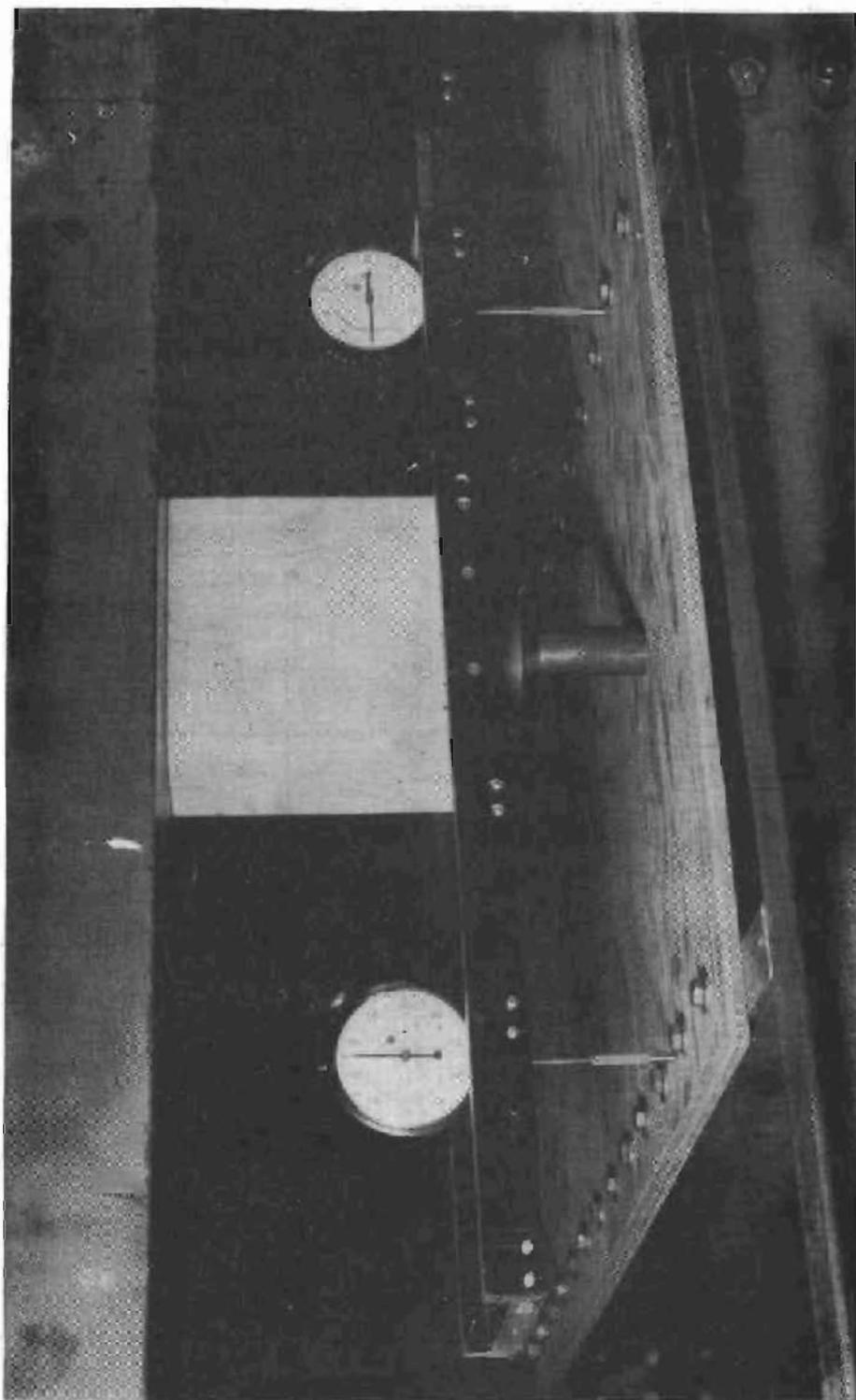


Figure 22.--Details of construction for steel fixture used to support air cargo flooring during concentrated, impact, and rolling-load tests. The spacing of the 0.25-inch tapped holes should conform to the requirements for corrugated types of flooring.



**Figure 23.**--Method of applying a concentrated load by a 1-inch cylindrical steel bar. Deflection under the bar is measured by a deflectometer composed of two dial gages supported in position over the floor beams. The gages are graduated to 0.001 inch.

Z N 61412 F

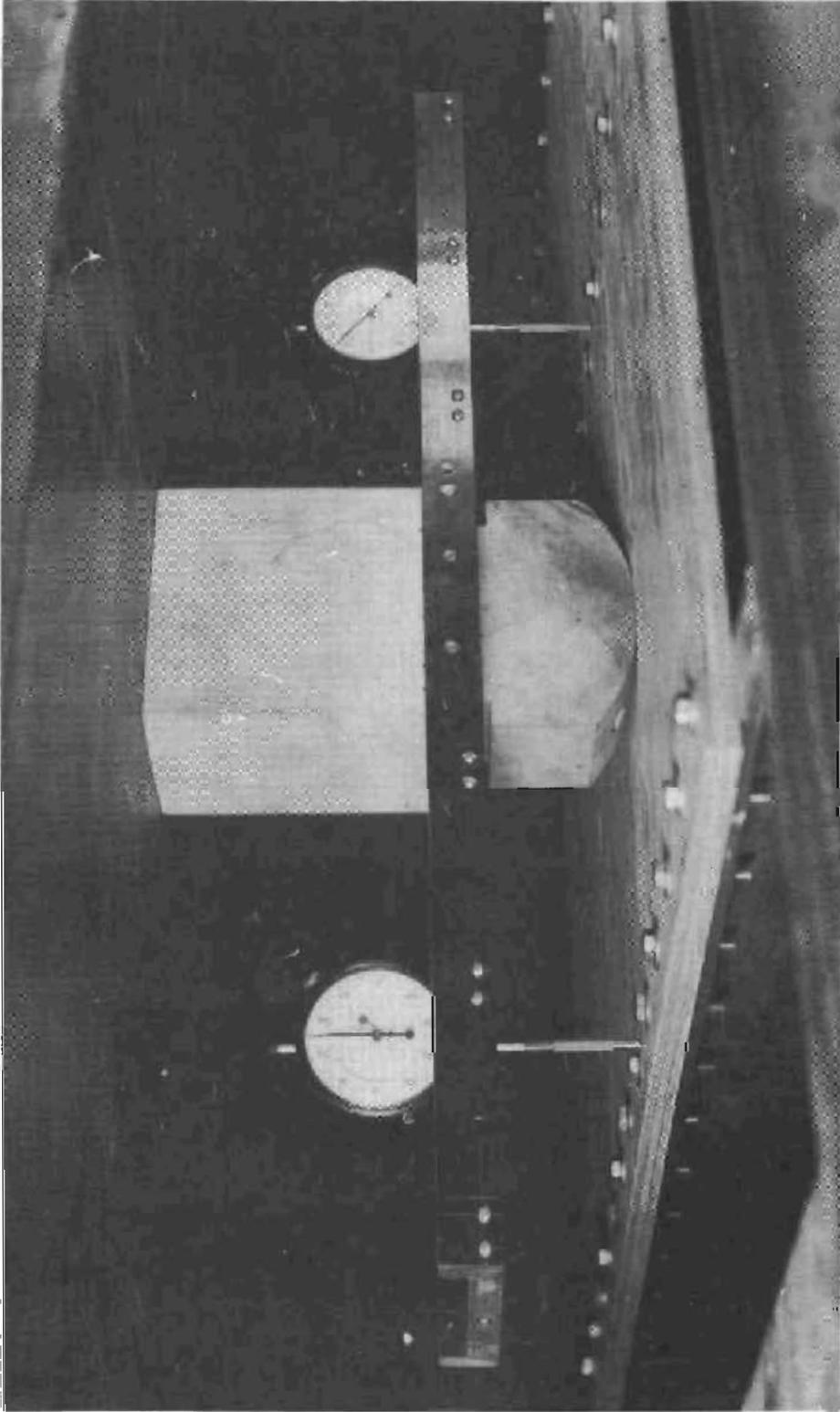


Figure 24.--Method of applying a load simulating an engine cradle wheel. A maple block 2-1/2 inches wide and having a 4-inch radius is used as a loading device. Deflection under the block is measured by a deflectometer composed of two dial gages supported in position over the floor beams. The block is oriented to simulate travel along the span.

Z N 51413 F

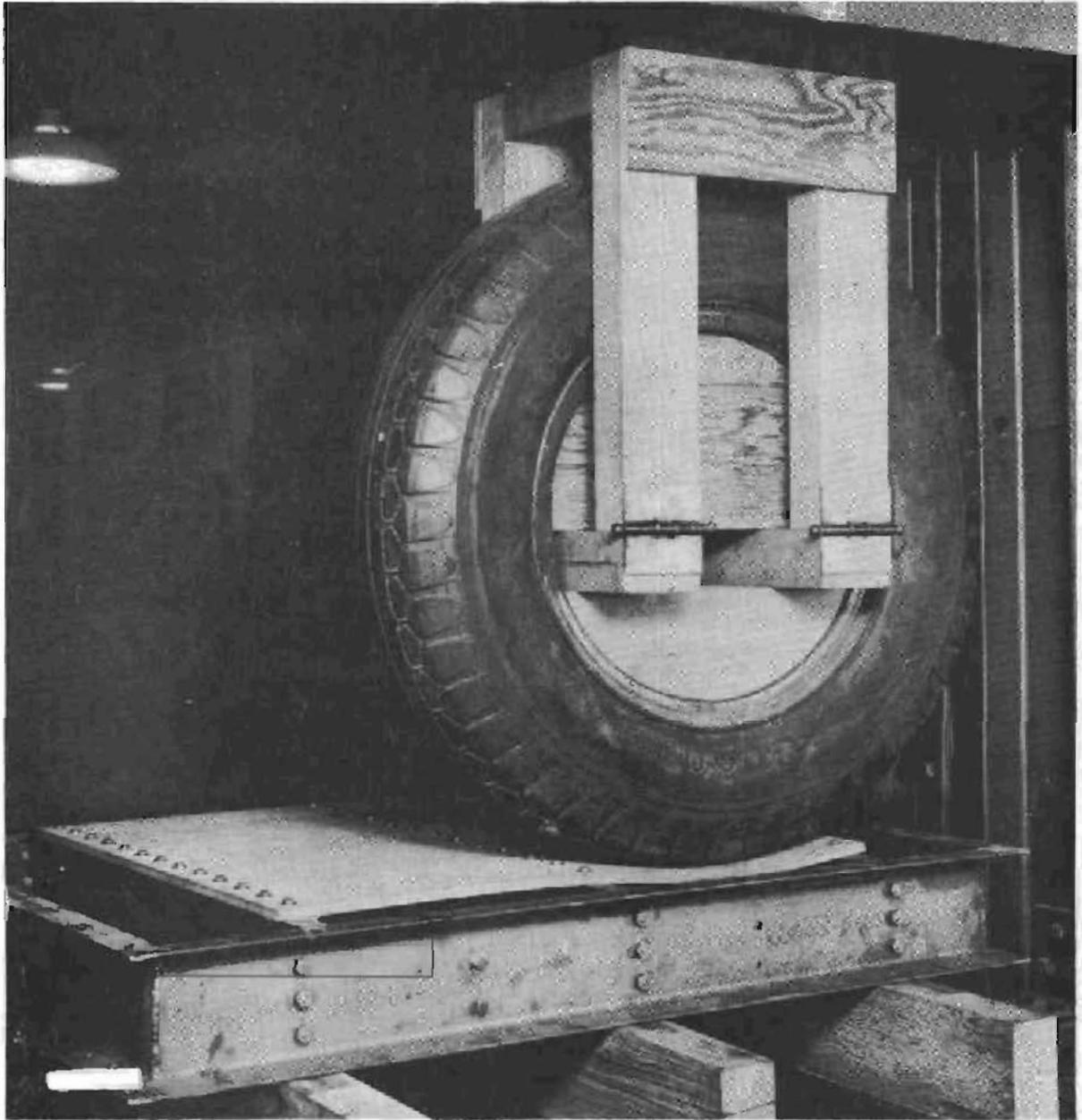


Figure 25.--Method of testing cargo flooring under load applied by an 8.25- by 20-inch ten-ply truck tire inflated to 90 pounds per square inch. Deflection of the panel is measured at midspan by a dial gage placed below the panel and touching the tension face. The gage is graduated to 0.001 inch.

Z M 61414 F

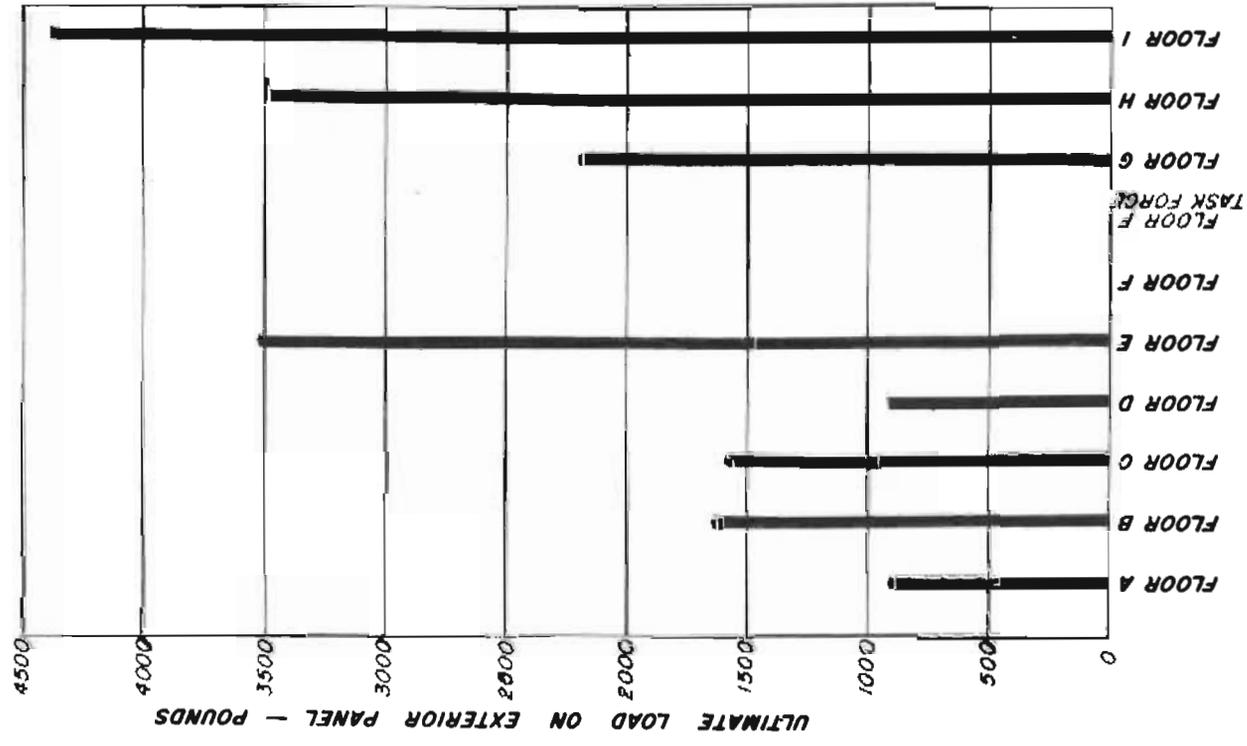
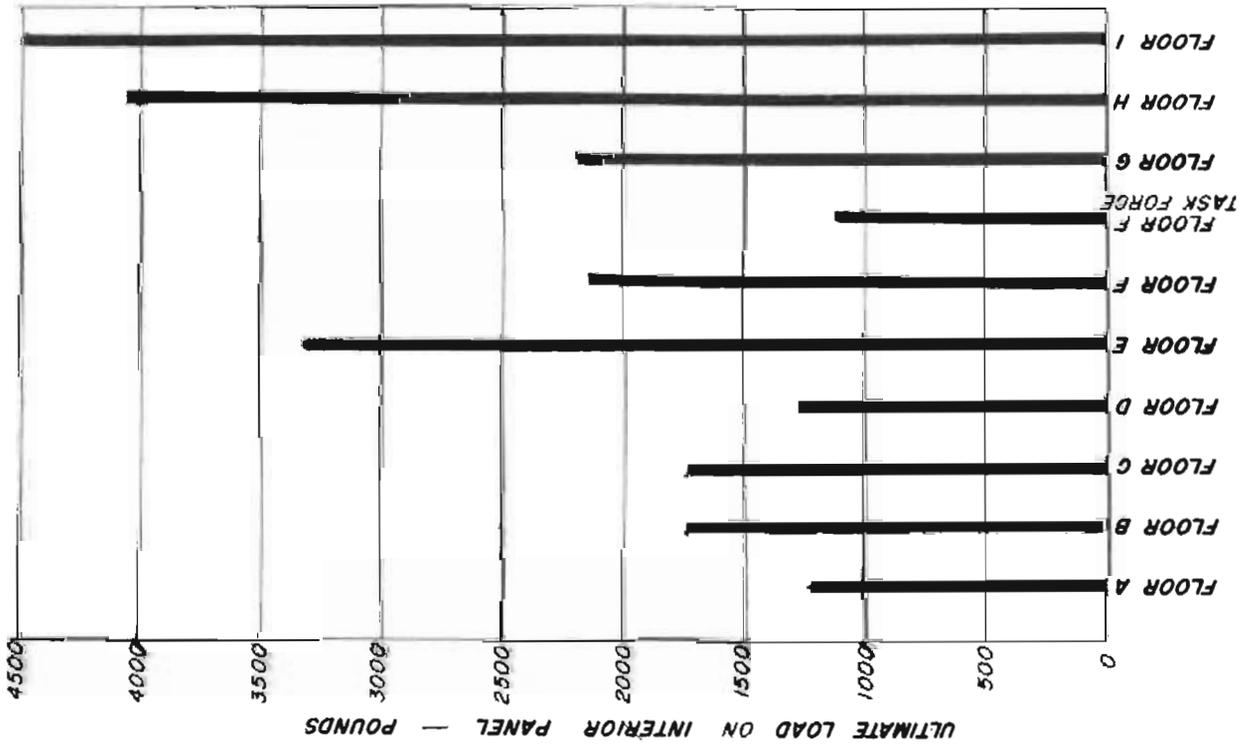


Figure 26.--Ultimate strengths of cargo floors tested by a 1-inch diameter steel bar applied at midspan of one of two equal and continuous 16- by 32-inch panels. The chart at the left shows the ultimate load at an interior position on the panel, while the chart on the right gives the results for a position within 4 inches of an unsupported edge. Floor F and floor F (task force) were tested on floor beams that form an integral part of the airplane.

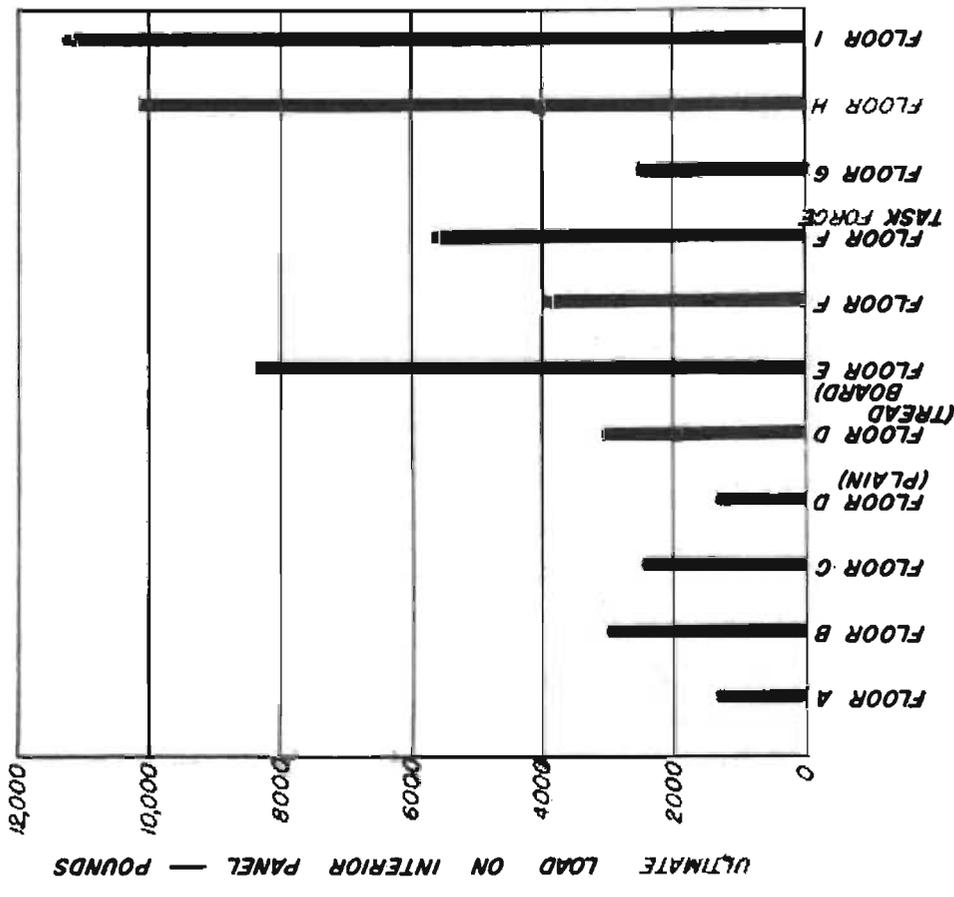
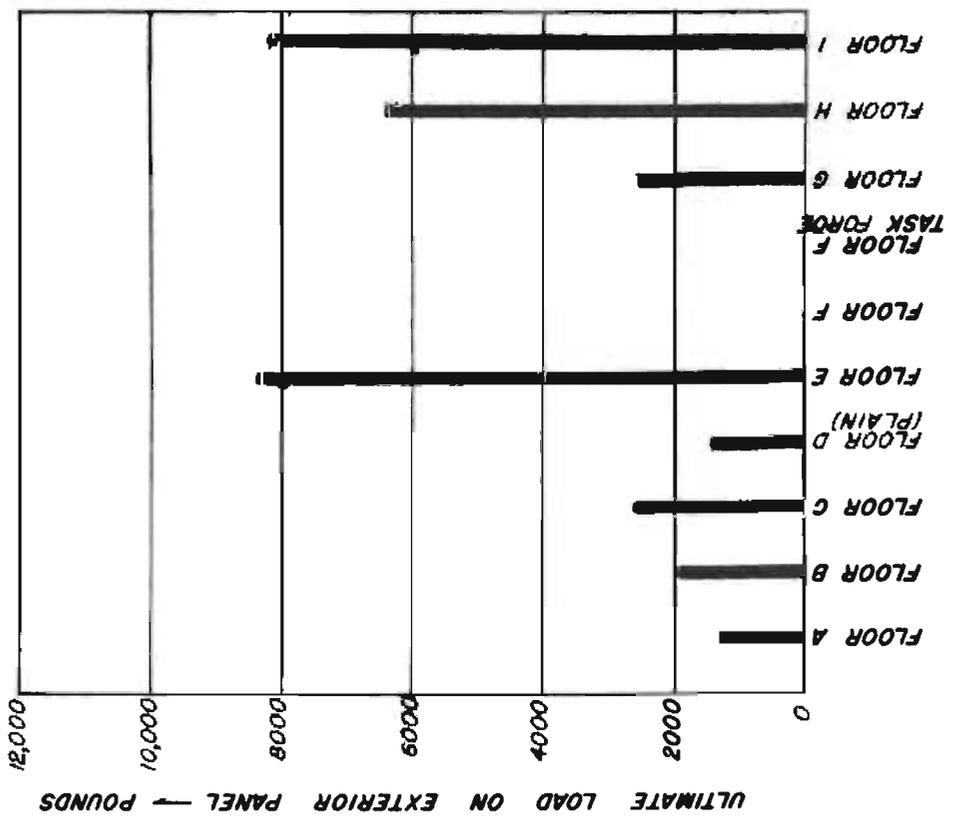


Figure 27.--Ultimate strength of one of two equal and continuous 16- by 32-inch panels of cargo flooring tested at midspan. Ultimate load was measured at an interior position on the panel and at an exterior position within 4 inches of an unsupported edge. Load was applied by a maple block 2-1/2 inches wide and curved to a 4-inch radius. Floor F and floor F (task force) were tested on floor beams that form an integral part of the airplane.

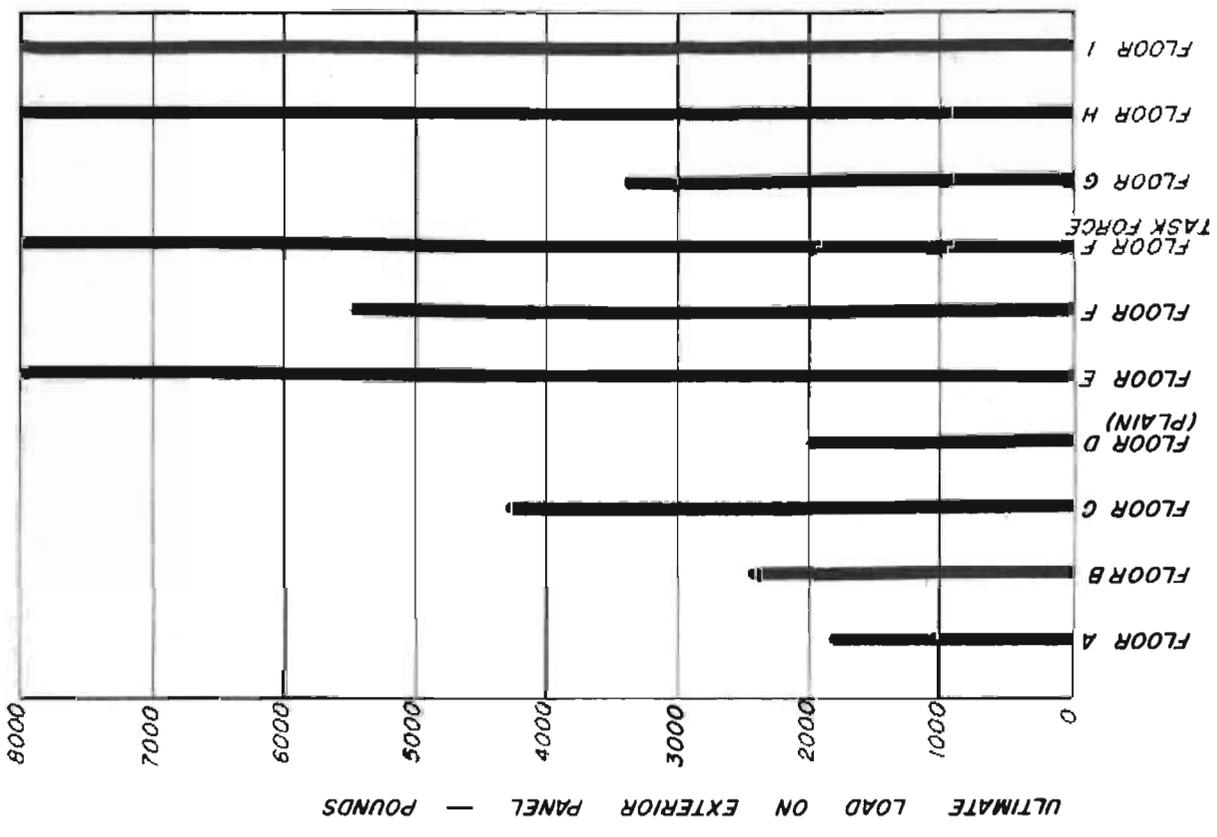
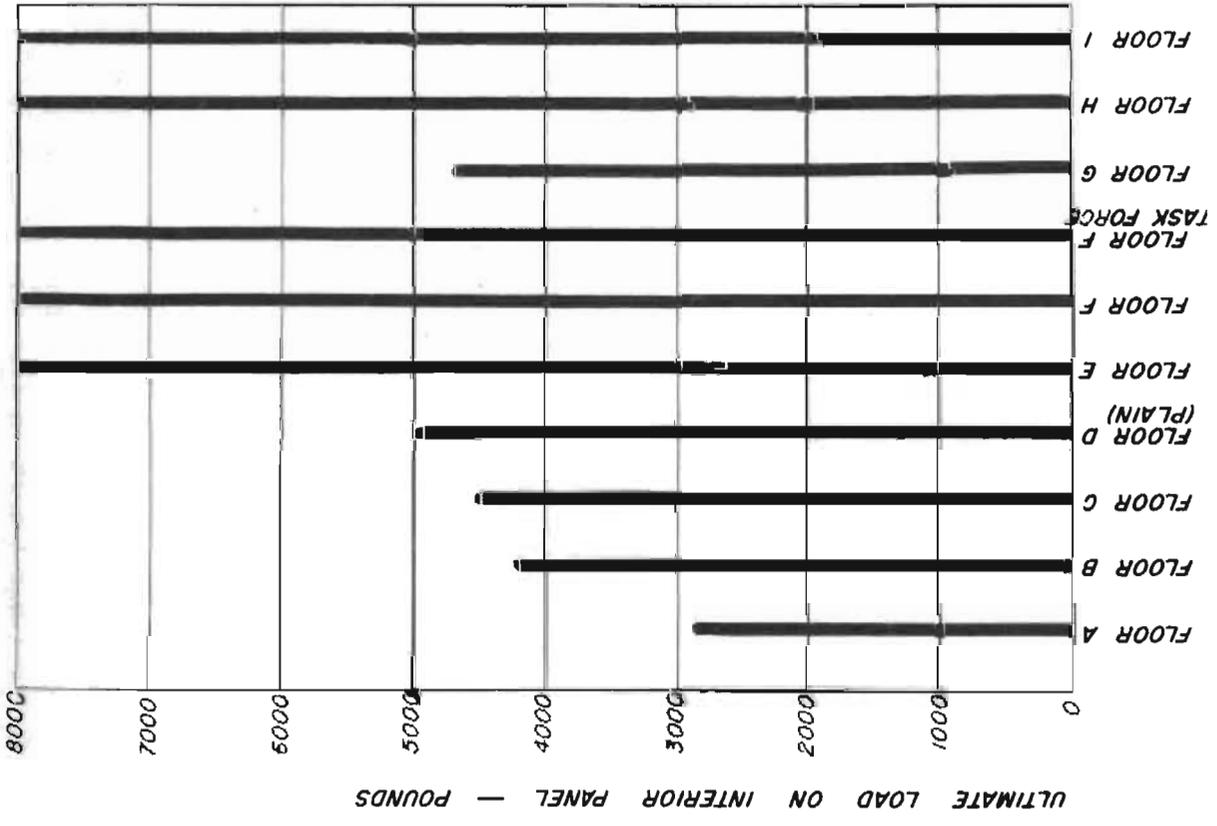


Figure 28.--Ultimate strength of cargo flooring tested by an 8.25- by 20-inch, ten-ply heavy-duty truck tire inflated to 90 pounds per square inch. The chart at the left shows results from tests on an interior portion of the panel, and the chart at the right is for tests on an exterior portion within 4 inches of an unsupported edge. Tests were made at midspan of one of two equal and continuous 16- by 32-inch panels except for floor F. Floors E, F, F (task force), H, and I were tested to a load of 8,000 pounds which did not cause ultimate failure.

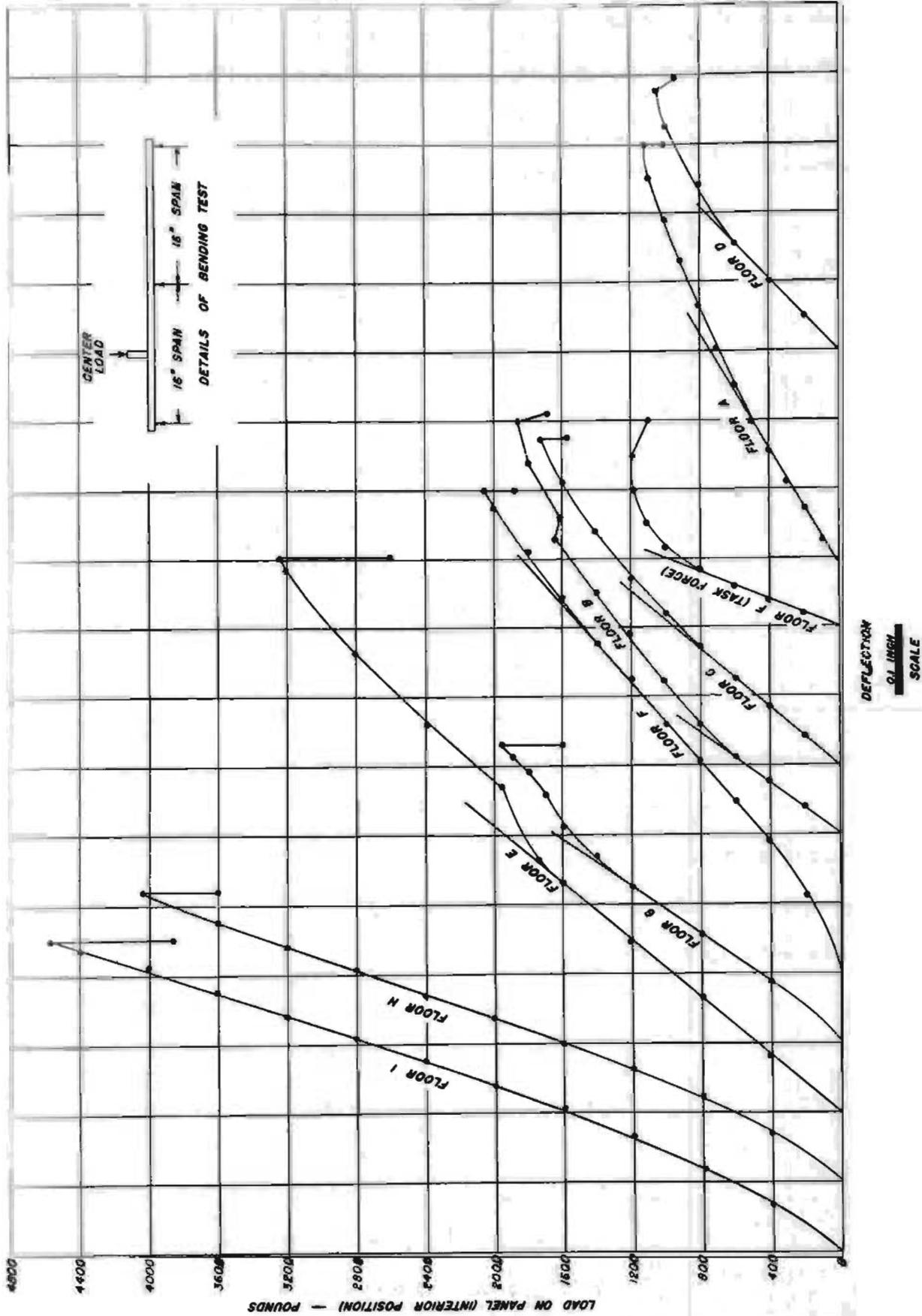


Figure 29.—Typical load-deflection curves from tests in which load was applied by a cylindrical steel bar 1 inch in diameter.

Z M 61418 F

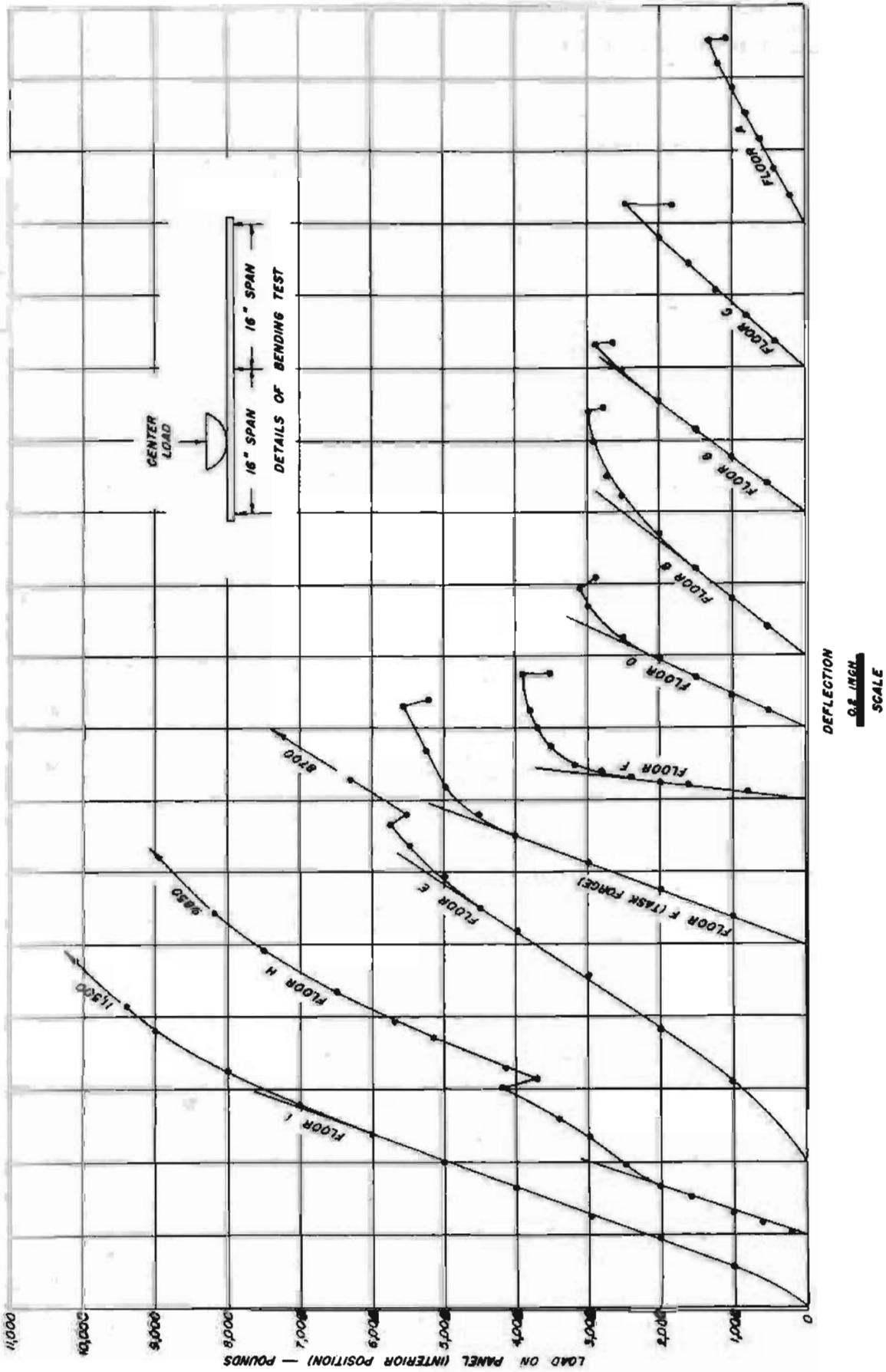


Figure 30.--Typical load-deflection curves from tests in which load was applied by a wood block 2.5 inches wide and shaped to a 4-inch radius.

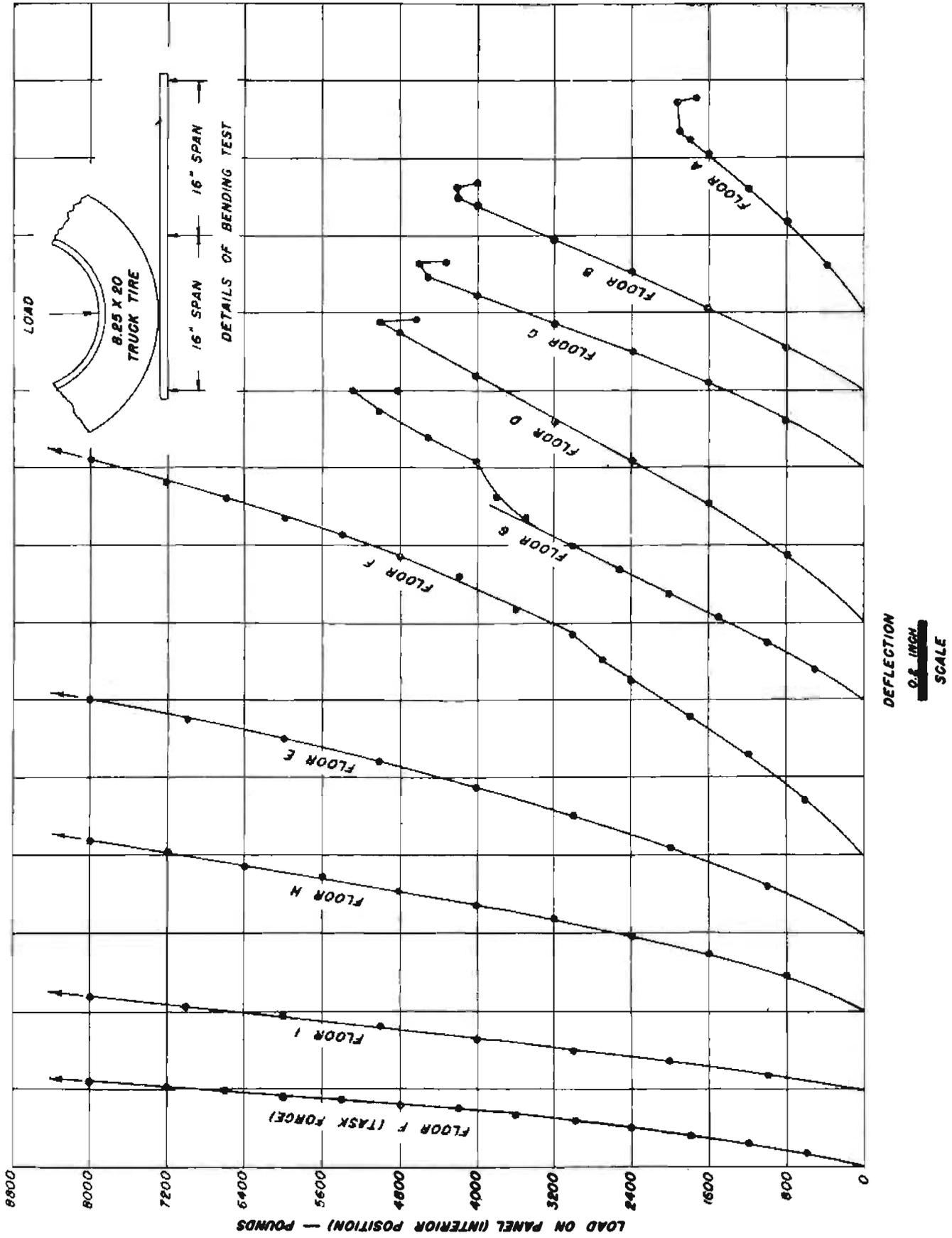


Figure 31.--Typical load-deflection curves from tests in which load was applied by an 8.25- by 20-inch truck tire inflated to a pressure of 90 pounds per square inch.

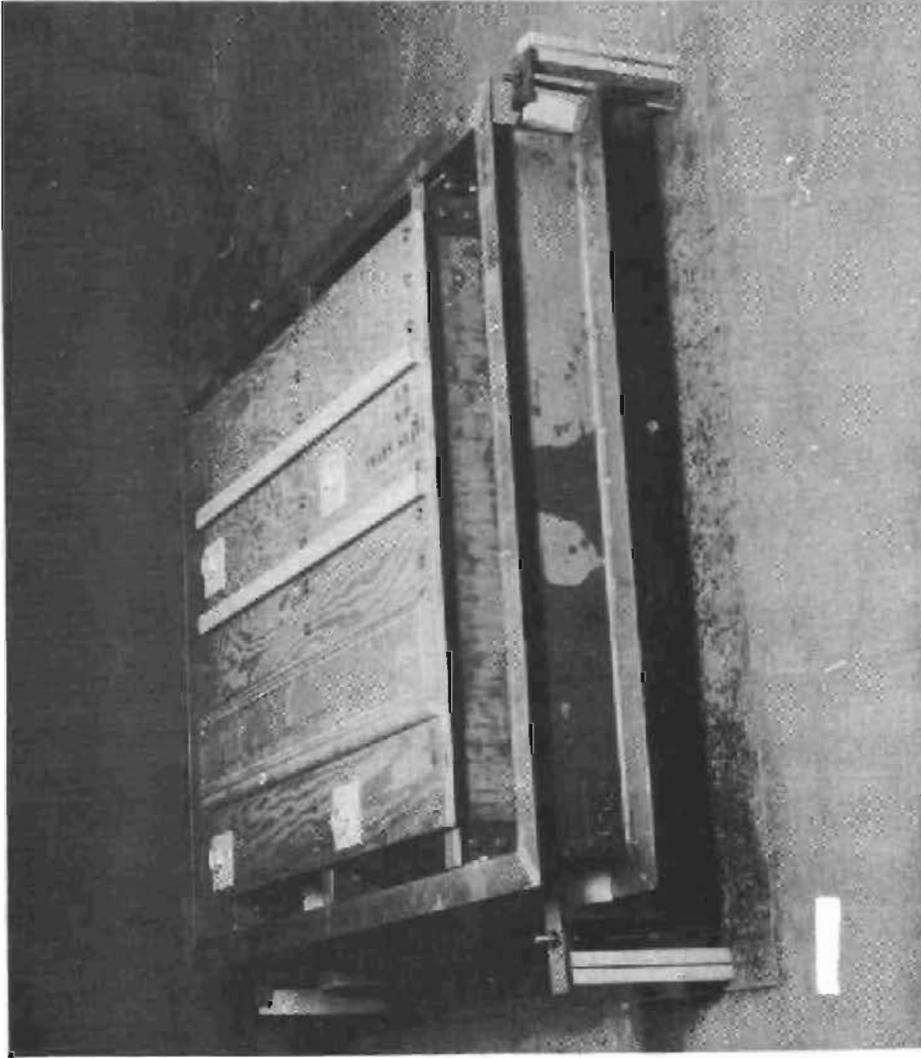
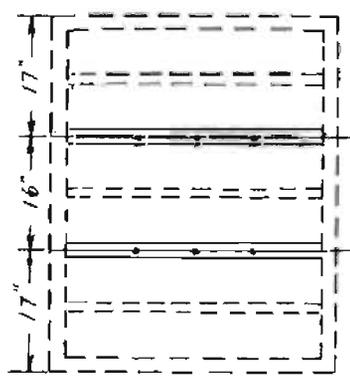
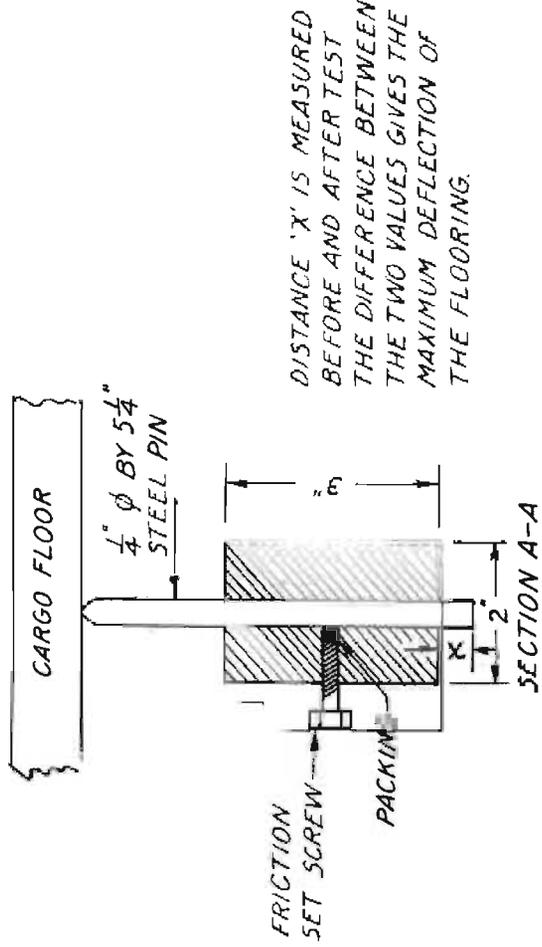


Figure 32.--Steel fixture used to support floor panels for impact tests.

Z M 61421 P



SKETCH OF FLOOR FIXTURE  
SHOWING LOCATION OF BEAM  
AND PIN DEFLECTOMETERS



DISTANCE 'X' IS MEASURED  
BEFORE AND AFTER TEST  
THE DIFFERENCE BETWEEN  
THE TWO VALUES GIVES THE  
MAXIMUM DEFLECTION OF  
THE FLOORING.

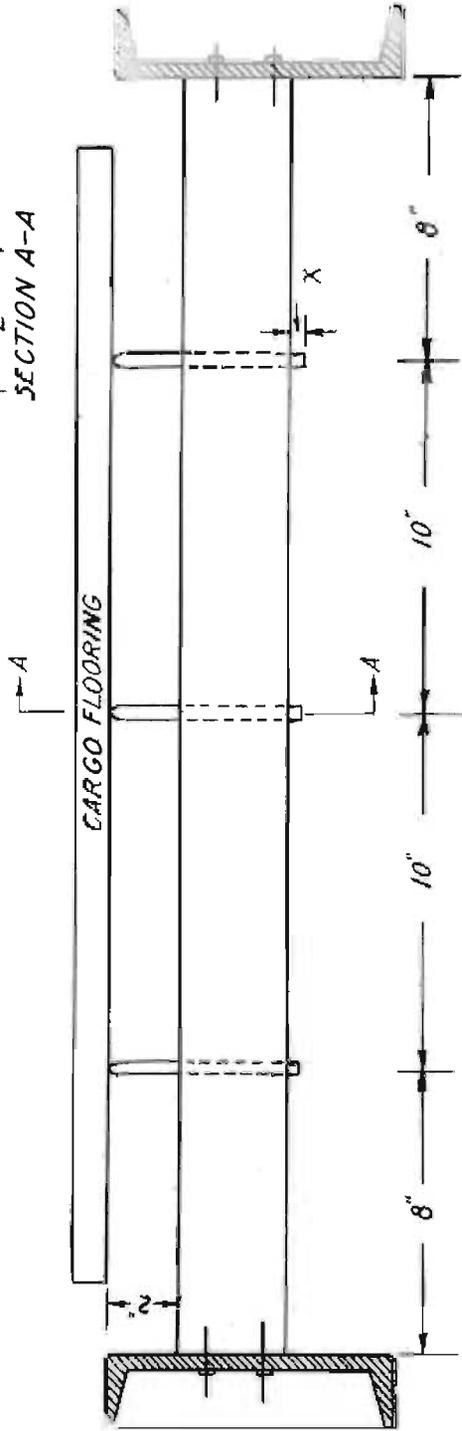


Figure 33.--Details of construction for beam and pin deflectometer used to measure  
the deflection of air cargo flooring tested by impact and rolling loads.

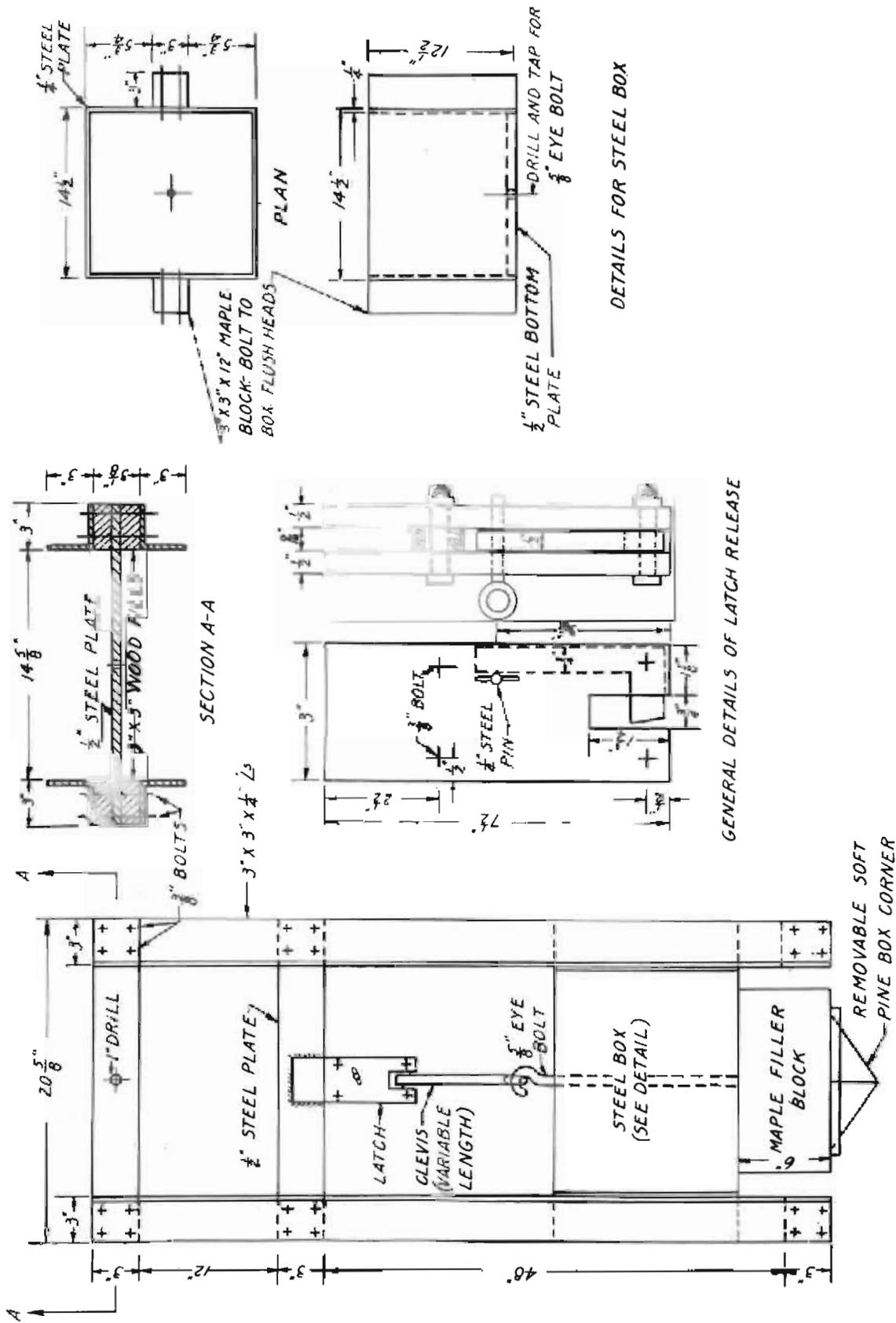
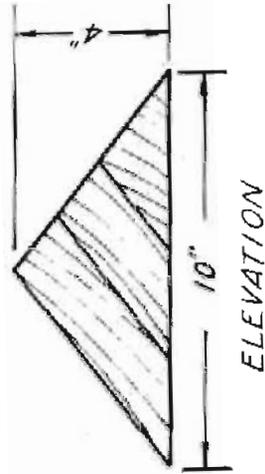
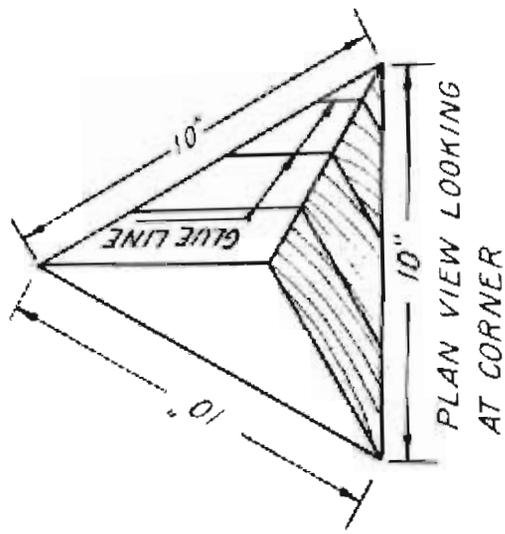
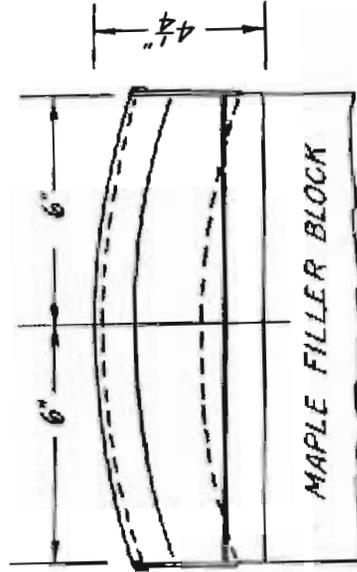
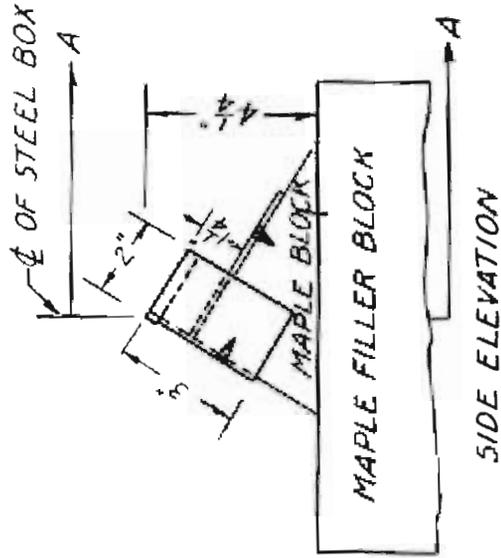


Figure 34.--Details of construction for apparatus used to apply impact loads to air cargo flooring.



DETAILS OF CORNER SAWN  
FROM SOFT PINE BLOCK  
FABRICATED FROM 2" LUMBER



ELEVATION A-A  
DETAIL OF EDGE FROM 55 GALLON  
GASOLINE DRUM. CUT DRUM SO LINE  
THROUGH Ø OF STEEL BOX PASSES  
THROUGH CENTER OF GRAVITY OF DRUM.

Figure 35.--Details of construction for simulated soft pine box corner and edge of 55-gallon gasoline drum.

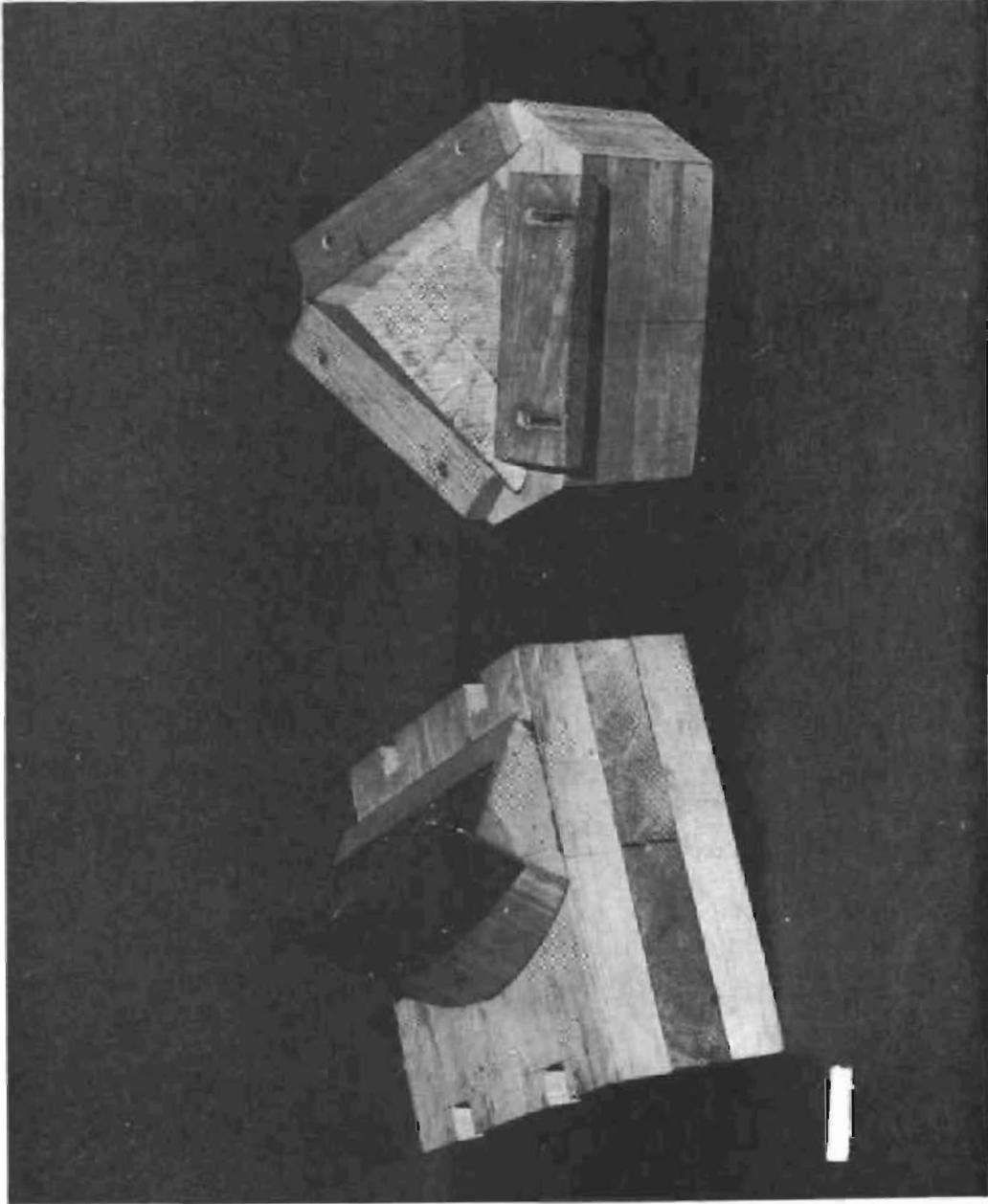


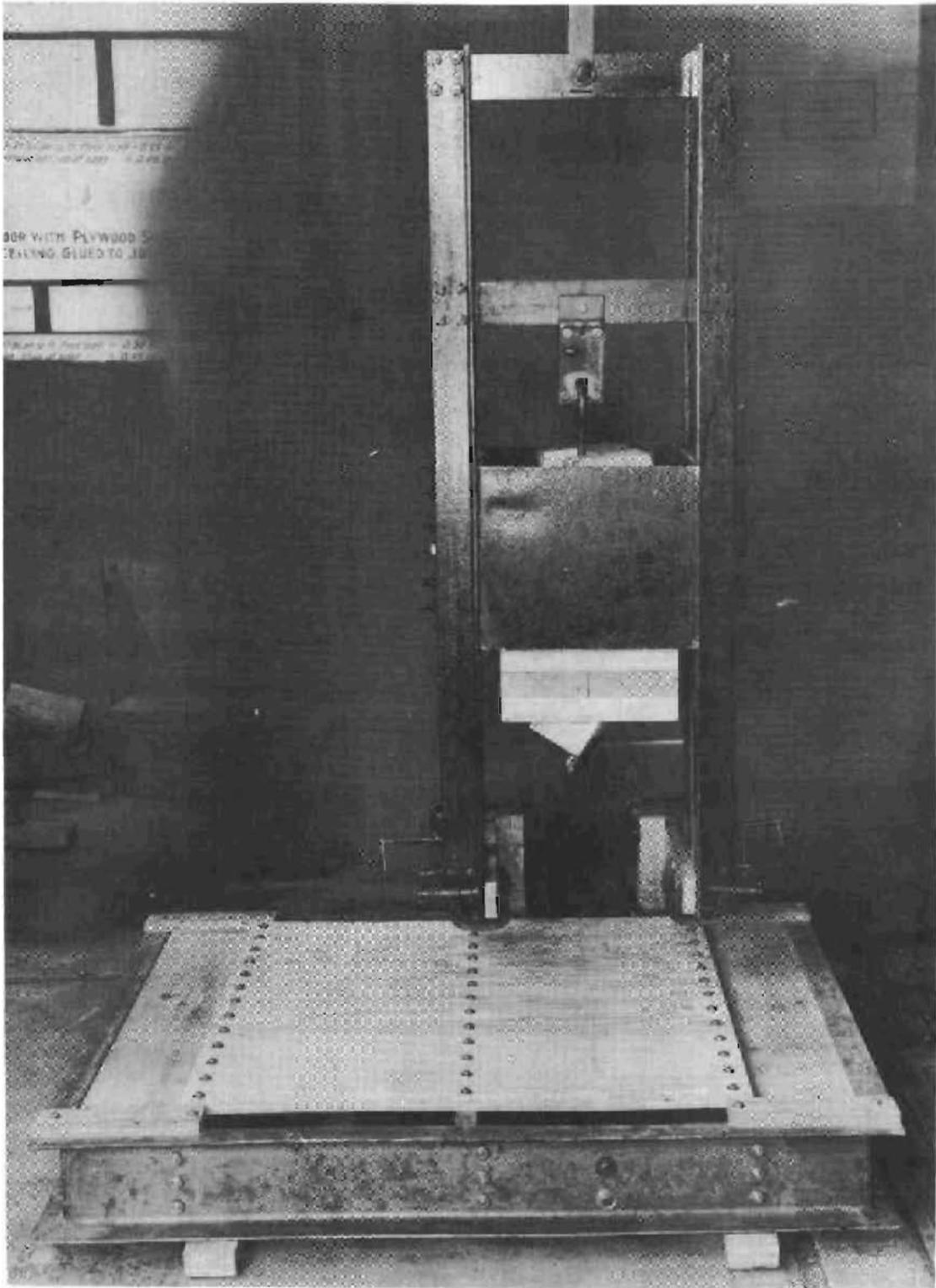
Figure 36.--Details of construction for striking devices simulating the edge of a gasoline drum or the corner of a soft pine box. The box corners are readily removed and replaced by demounting one cleat.

Z M 61425 F



Figure 37.--Equipment for test of floor under impact of 200-pound box. The impact apparatus is shown before lowering into position for desired height of drop.

Z M 61426 F



**Figure 38.**--Impact apparatus in position for test using the edge of a gasoline drum.

Z M 61427 F

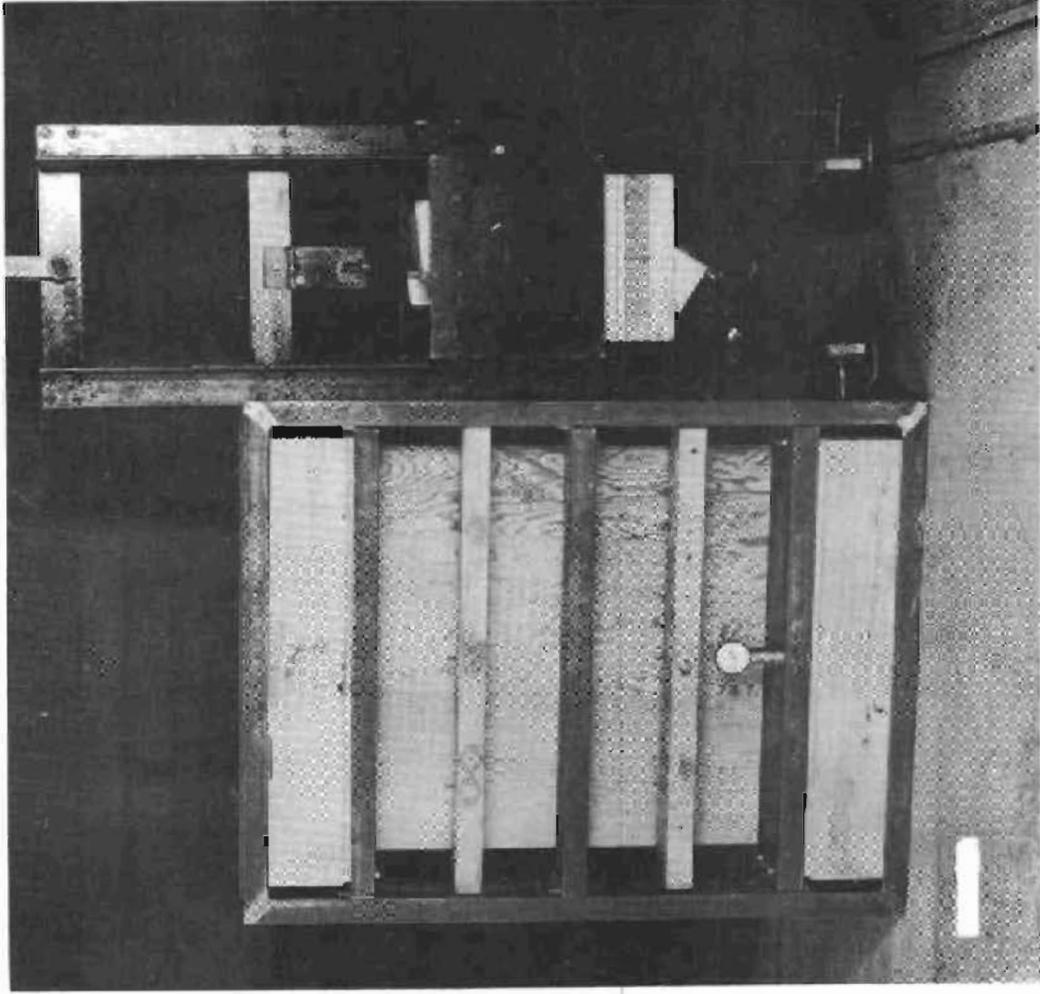


Figure 39.--General view of impact apparatus. The lower side of the steel floor fixture is shown with the beam and pin deflector appearing at midspan of each panel. A dial gage attached to a hollow cylinder as used to measure movements of the pins has been placed on the lower floor beam.

Z M 61428 F

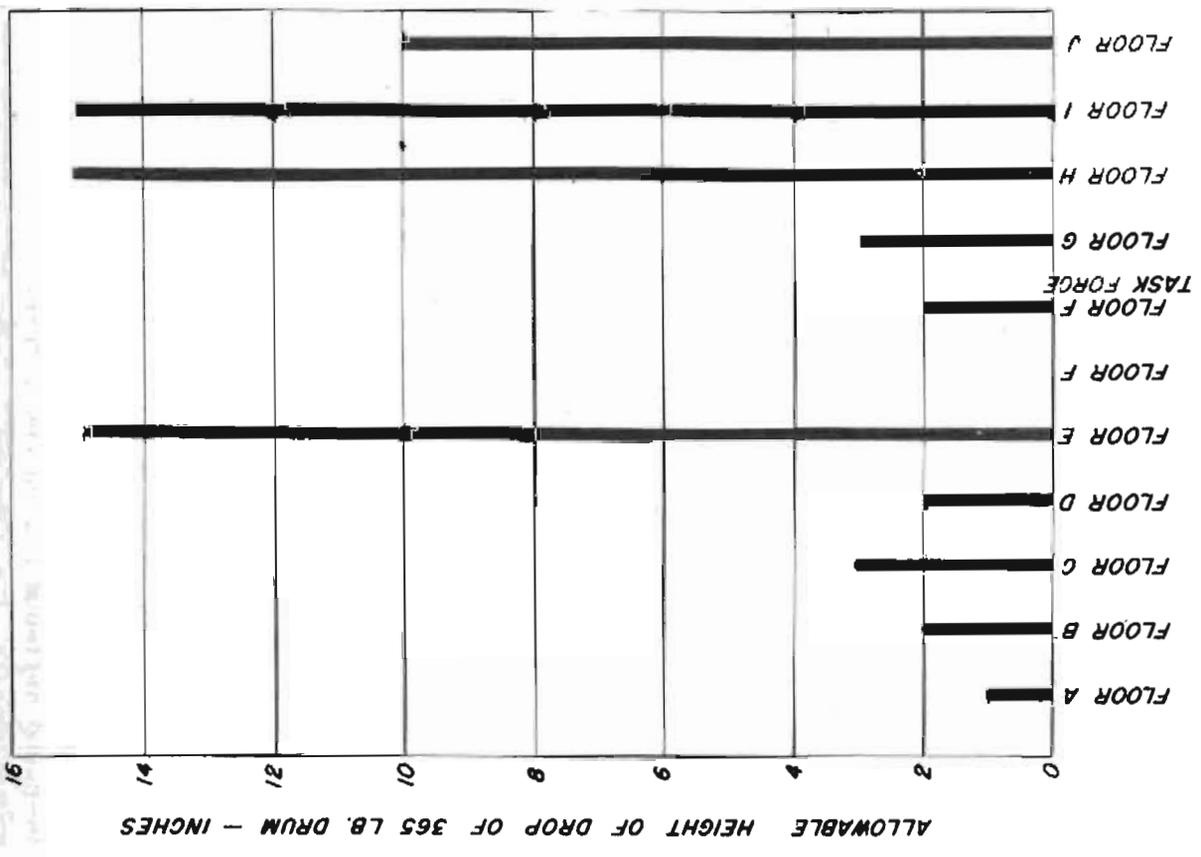
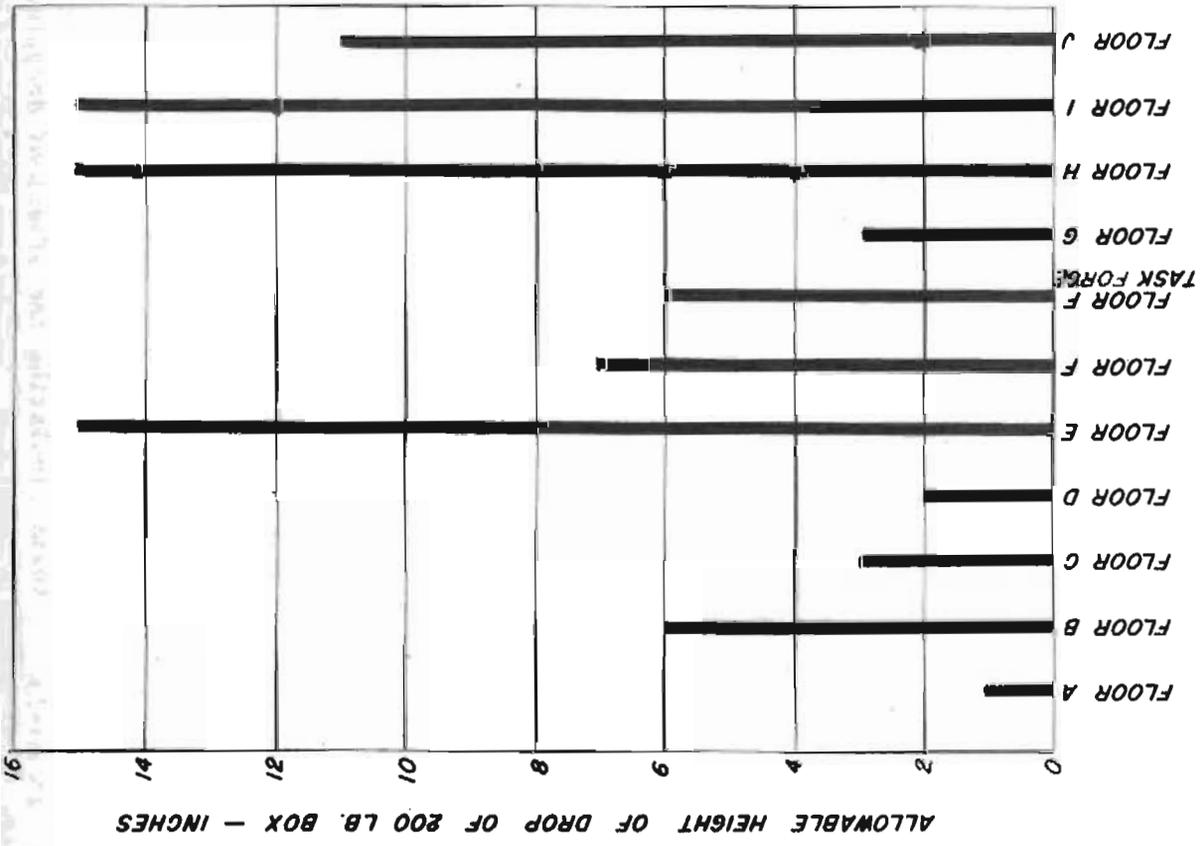


Figure 40.--The chart at left shows the allowable heights of drop for a 200-pound wood box and the chart at right the allowable heights of drop for a 365-pound steel drum which the several floors will sustain without damage of a nature requiring repair. Under both types of test floors E, H, and I sustained the load imposed by a drop from 15 inches without serious damage. Floor F was not tested by the 365-pound drum owing to insufficient material. Floor F (task force) was tested by striking over the interior stiffeners or between them. The results shown are for the former condition. The allowable height for tests between stiffeners is less than 1 inch.

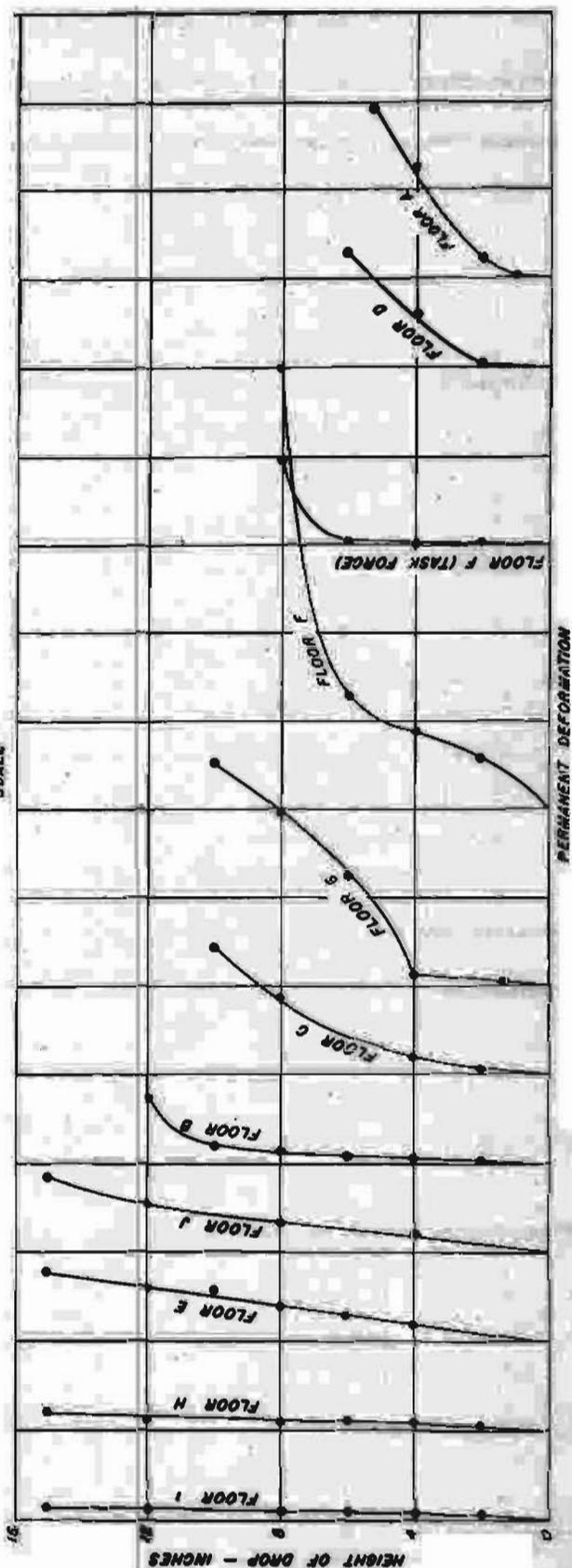
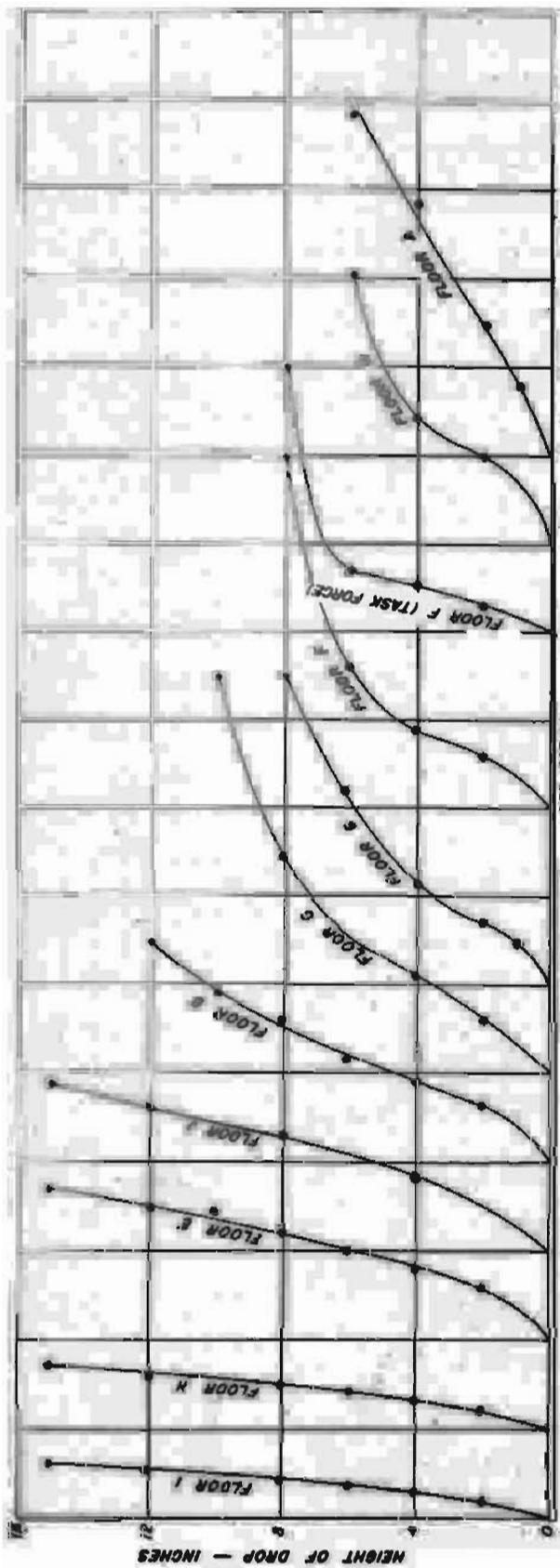


Figure 41.--Relationship of height of drop to deflection or permanent deformation from impact tests simulating the effect of dropping a 200-pound softwood box on one corner.

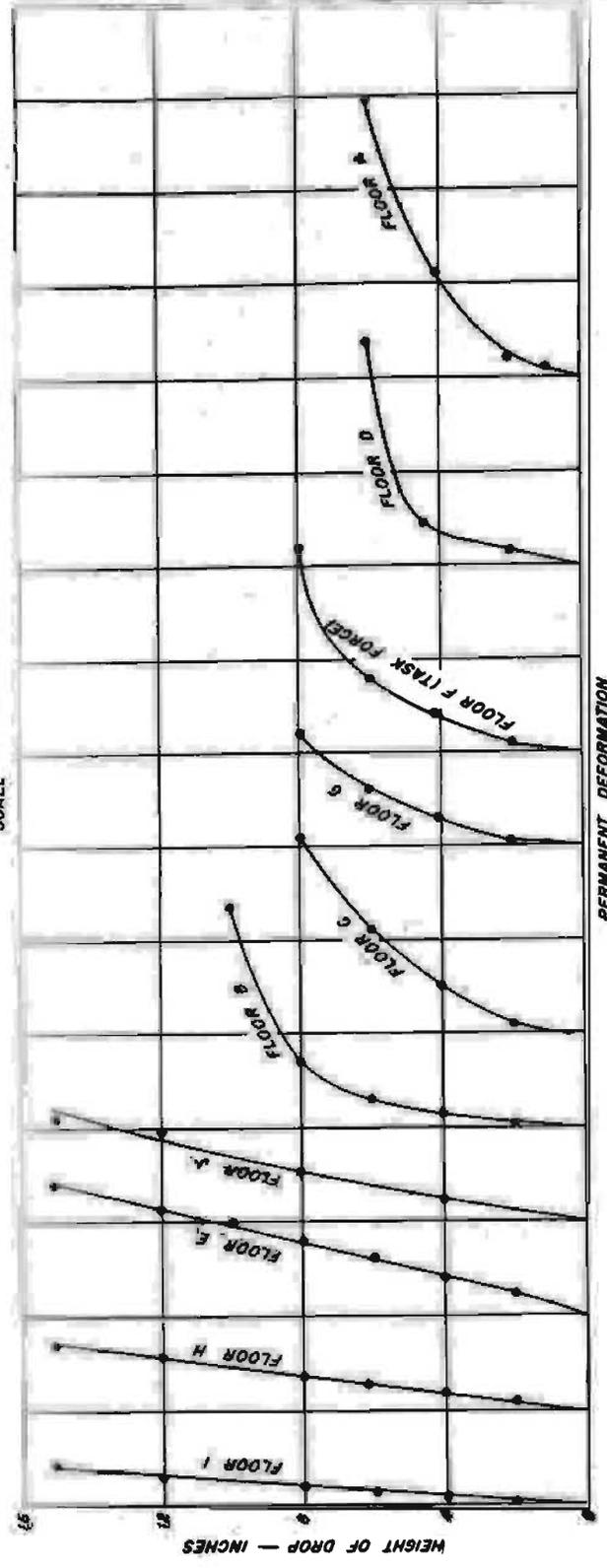
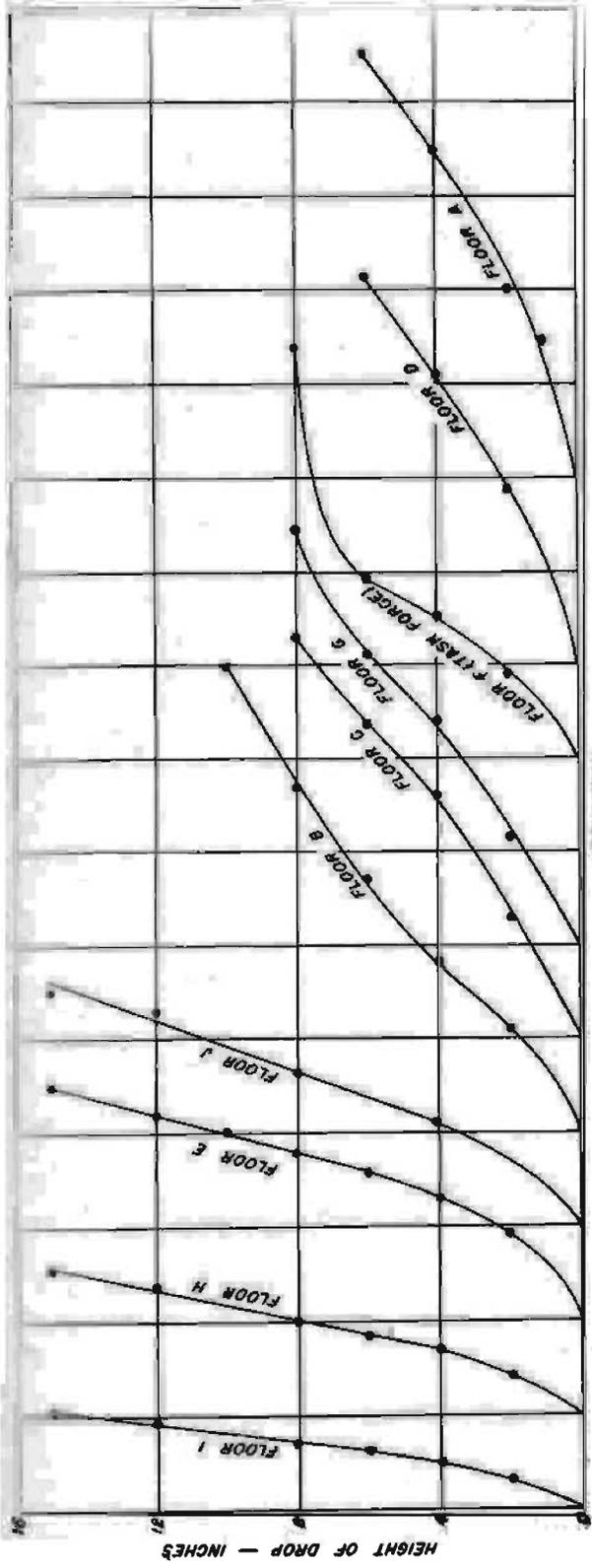
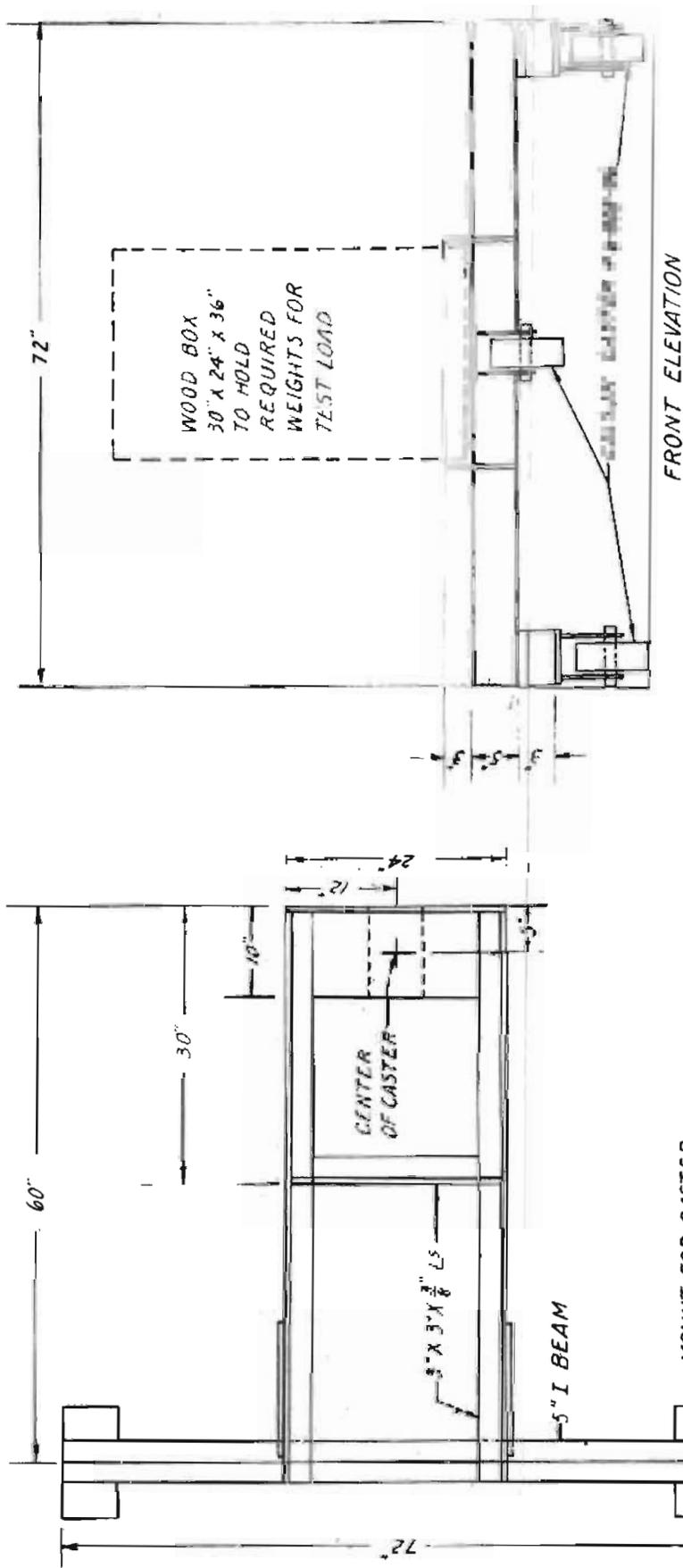


Figure 42.--Relationship of height of drop to deflection or permanent deformation from impact tests simulating the effect of dropping a 365-pound gasoline drum on edge.



PLAN VIEW SHOWING DETAILS OF FRAME FOR ROLLING LOAD CRADLE

FRONT ELEVATION

Figure 43.--Details of construction for steel cradle used to apply rolling-load tests to air cargo flooring.

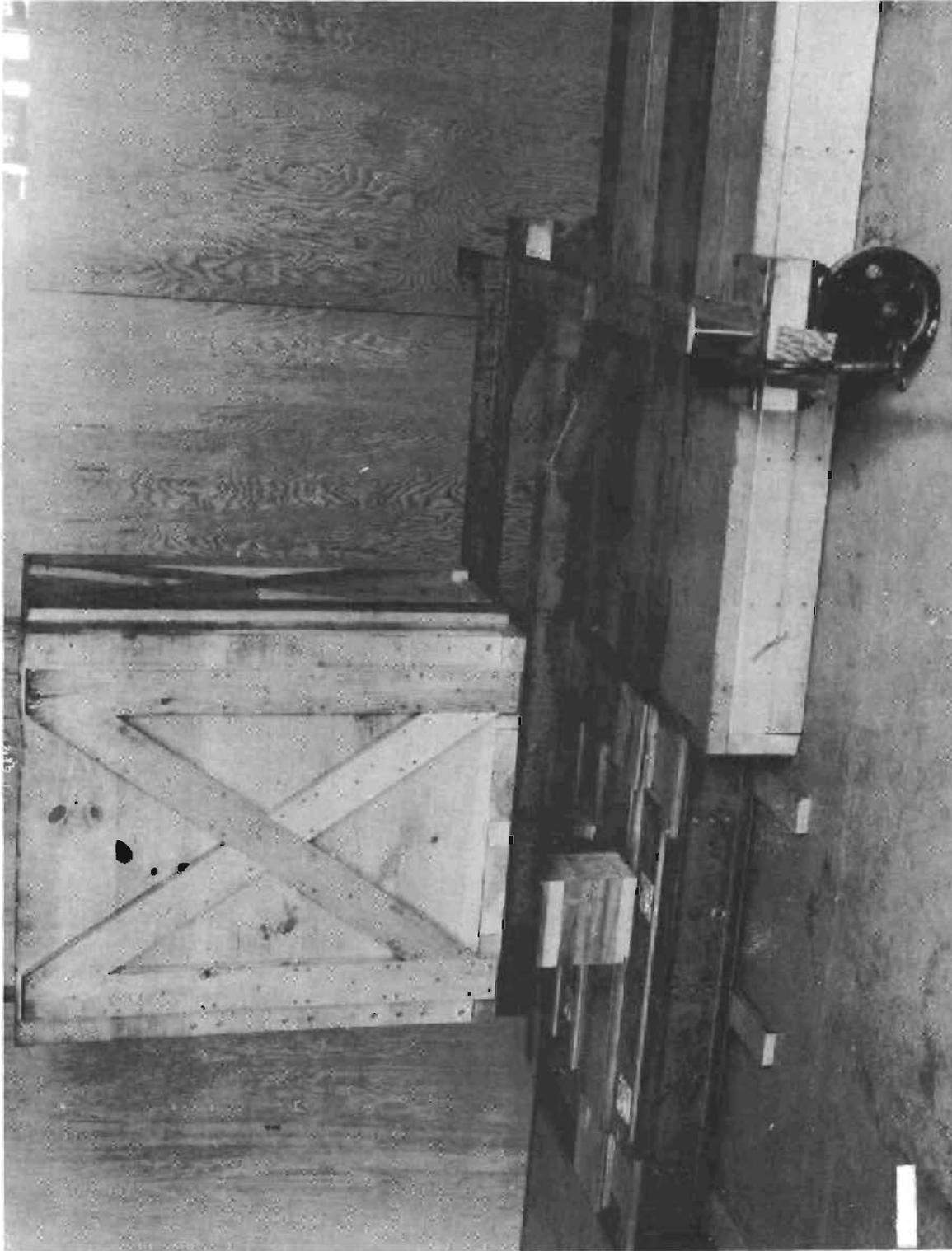


Figure 44.--Equipment used to test flooring under rolling load simulating the effect of an engine cradle wheel. The center wheel is in place on the panel, and the outside wheels travel adjacent to the panel but not on it. The wood blocks on each side of the center wheel prevent the loaded cradle from falling completely through the cargo flooring when failure takes place. The imposed load is obtained by placing the necessary weight in the wood box mounted on the cradle.



Figure 45.--Method of mounting a floor on the steel fixture. The beam and pin deflectometers are installed at midspan of each panel.

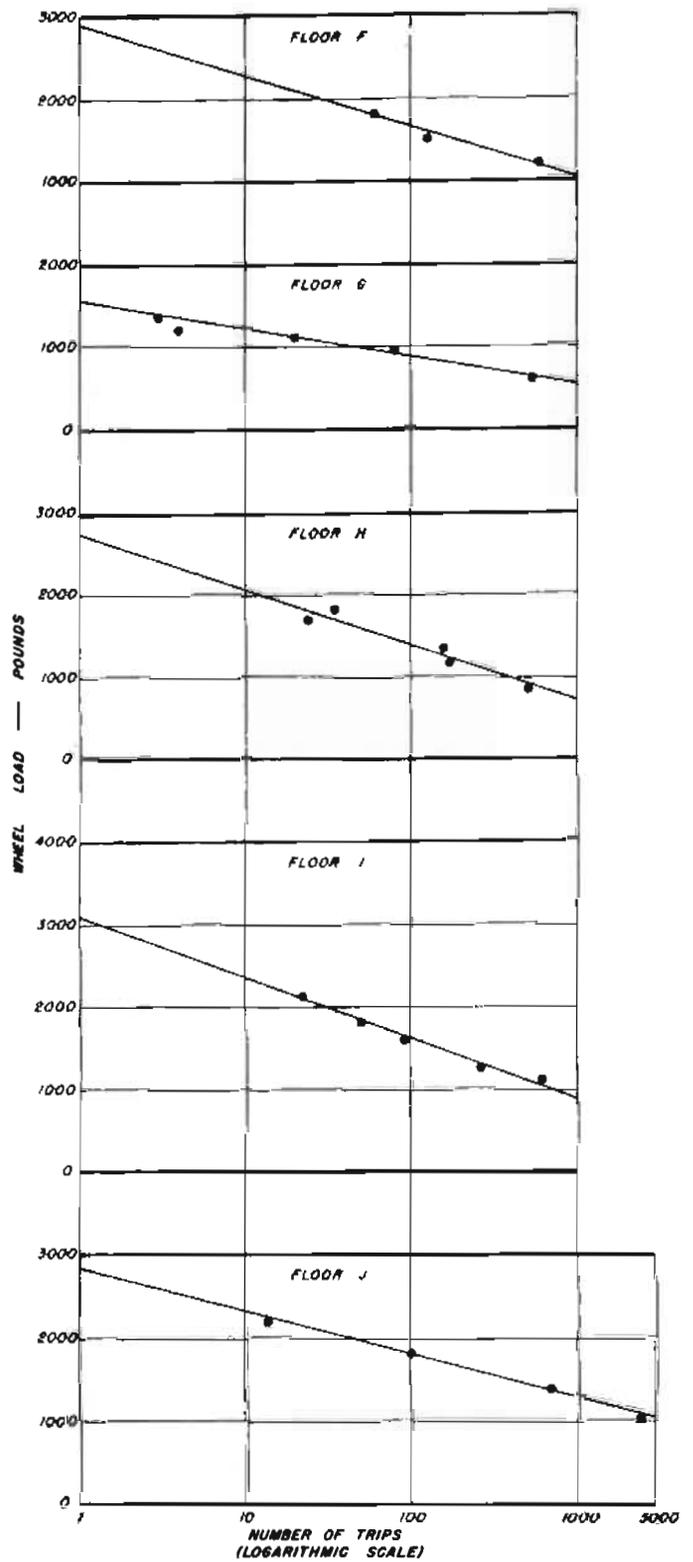
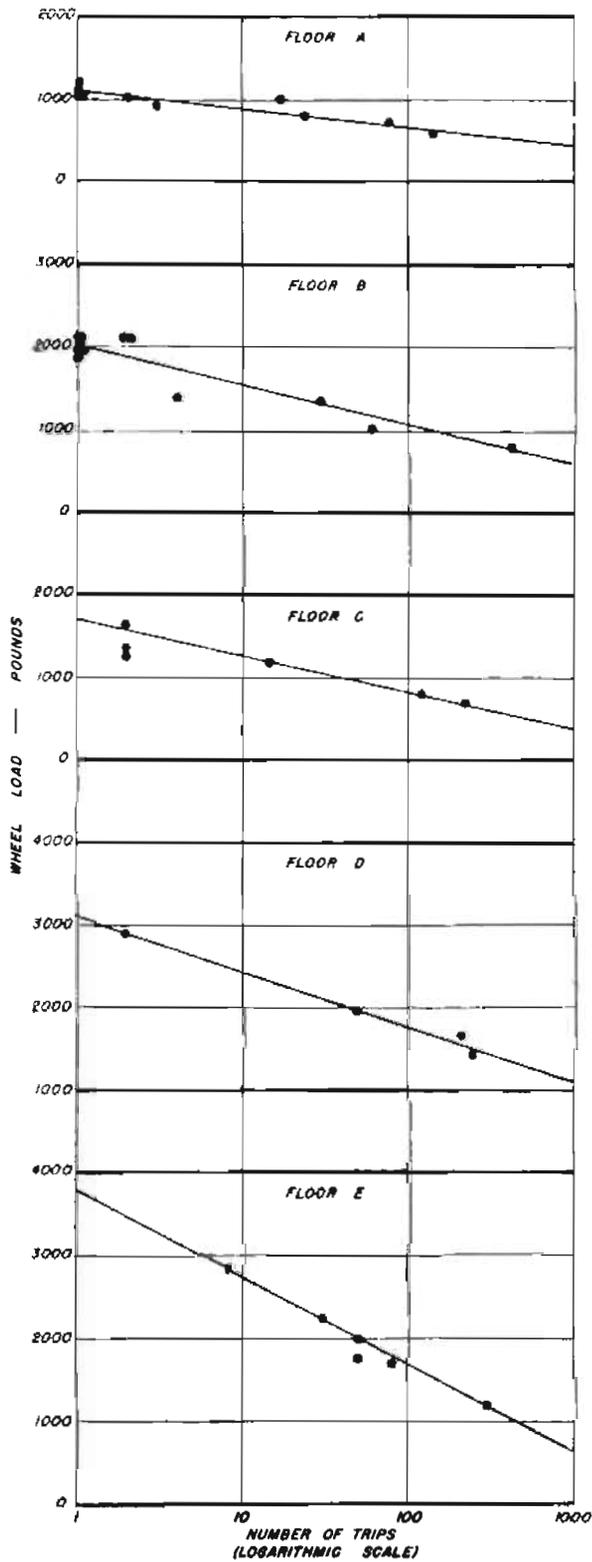


Figure 46.--Fatigue curves constructed with data from engine-cradle rolling-load tests.

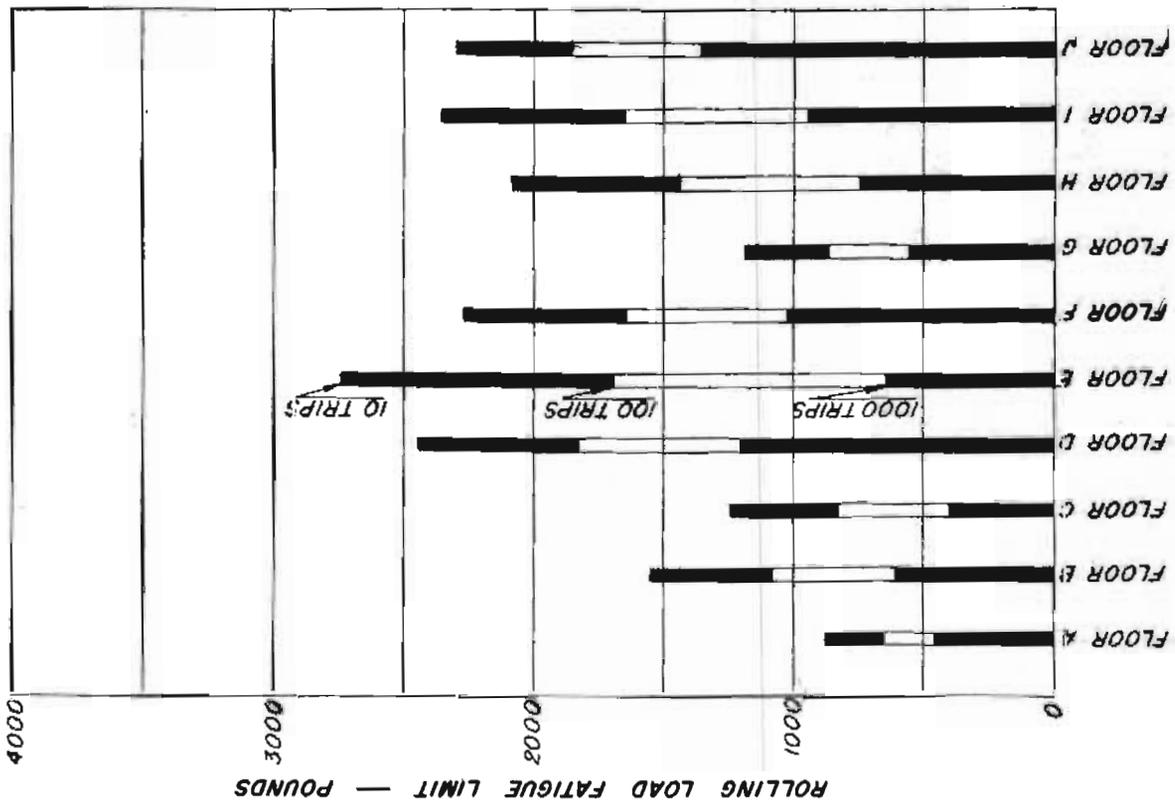
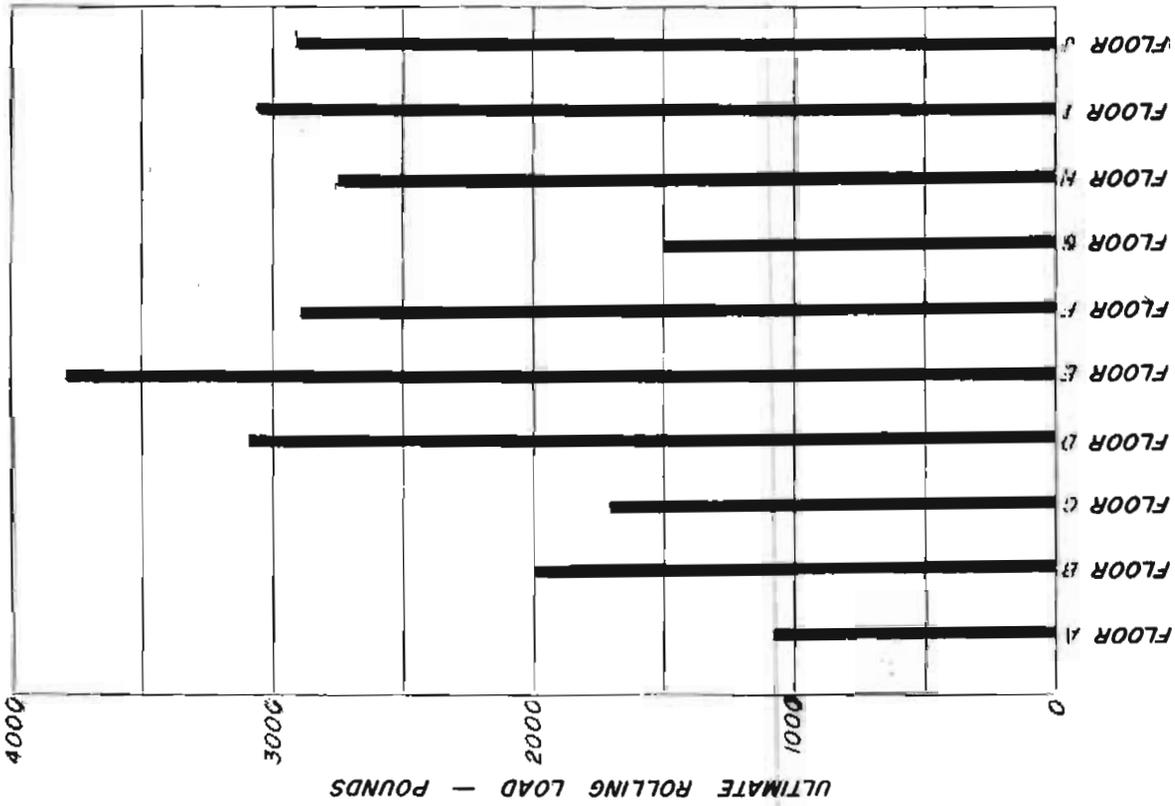


Figure 47. Results of rolling-load test simulating the effect of a steel engine-cradle wheel, 8 inches in diameter, and 2-1/2 inches wide. The chart at the left presents the ultimate single-trip rolling loads expected to cause failure of the several floors. The chart at the right shows the rolling-load fatigue limit for 10, 100, and 1,000 trips of a cradle wheel. Floor E has the highest single-trip ultimate strength but is surpassed by floor J when tested by fatigue loading.



Figure 48.--Equipment used to test the structural and wear resistance of flooring to a rolling load imposed by a 1,000-pound bomb equipped with rings. The bomb is moved across the floor by two men.

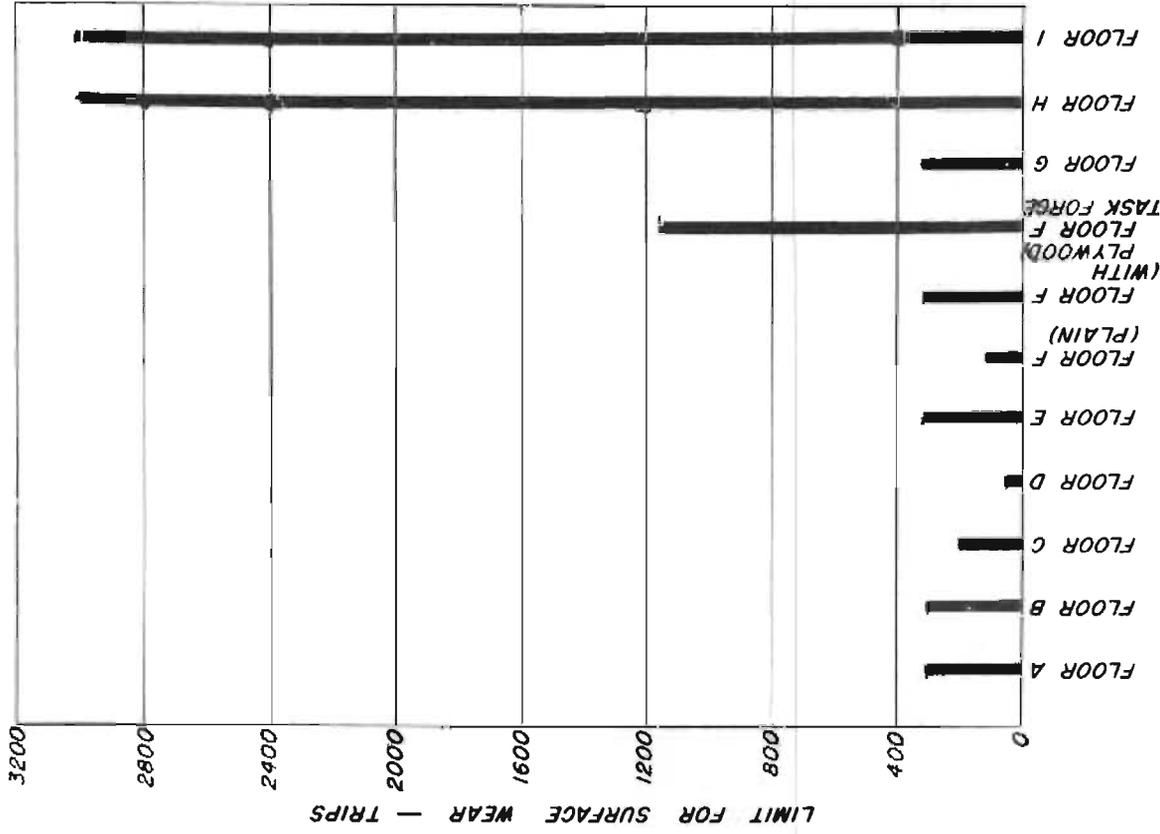
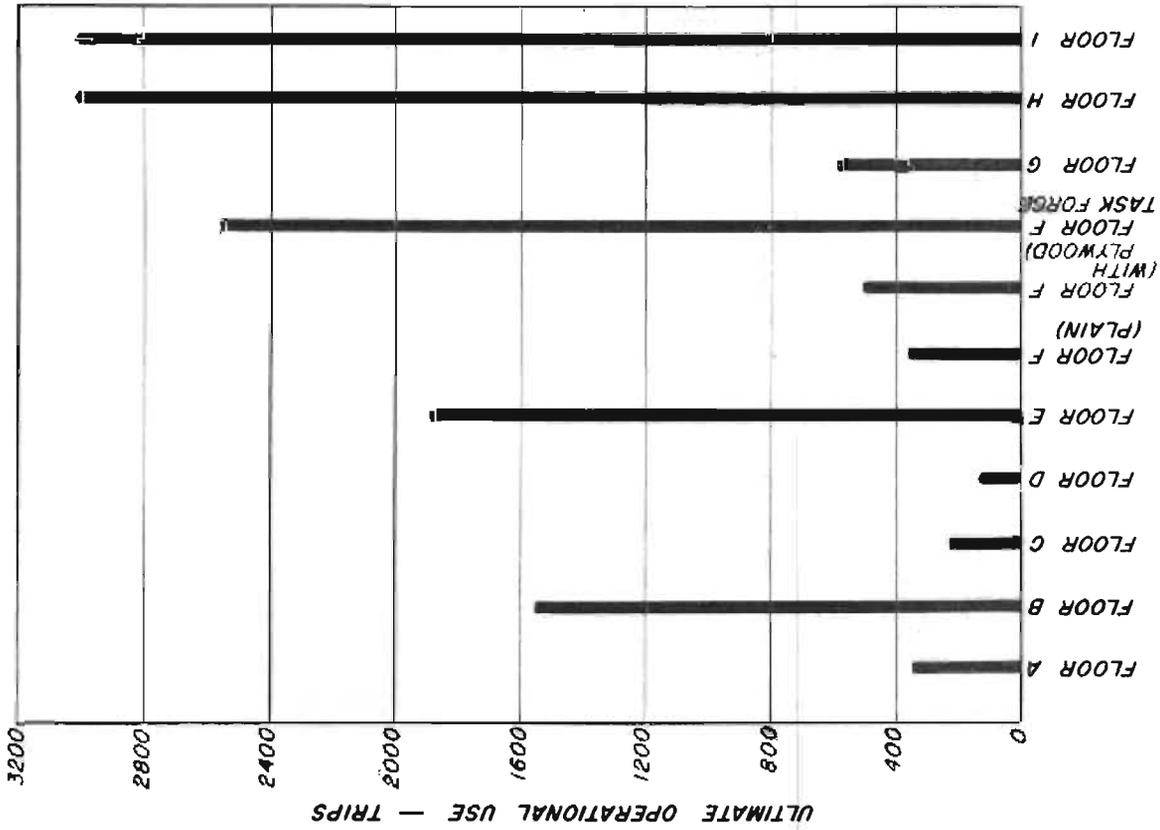


Figure 49.--Results of tests of the effect of rolling a 1,000-pound bomb, equipped with rings, over the several types of cargo flooring. The chart at the left presents the number of trips required to cause structural failure. At the right, the number of trips resulting in surface wear of a nature that would seriously impair the handling of wire- or strap-bound boxes and crates, or result in progressive structural damage if exceeded, are shown. Floors H and I were not seriously damaged and could have sustained in excess of 3,000 trips. Floor J was not subjected to this test because of the satisfactory performance under the engine-cradle wheel at much higher loads.

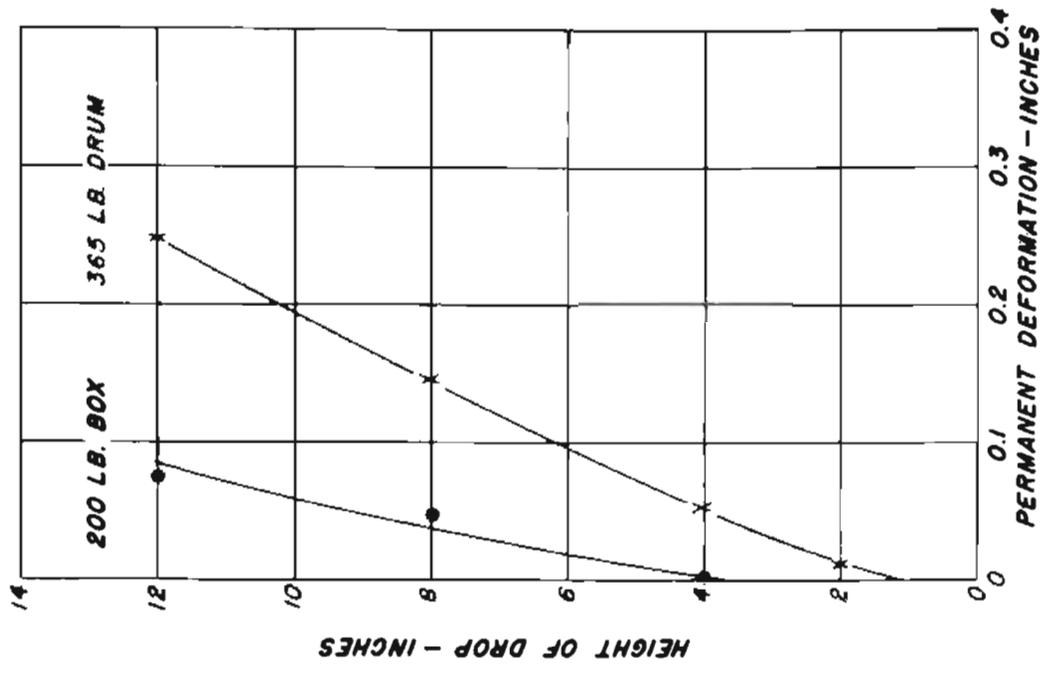
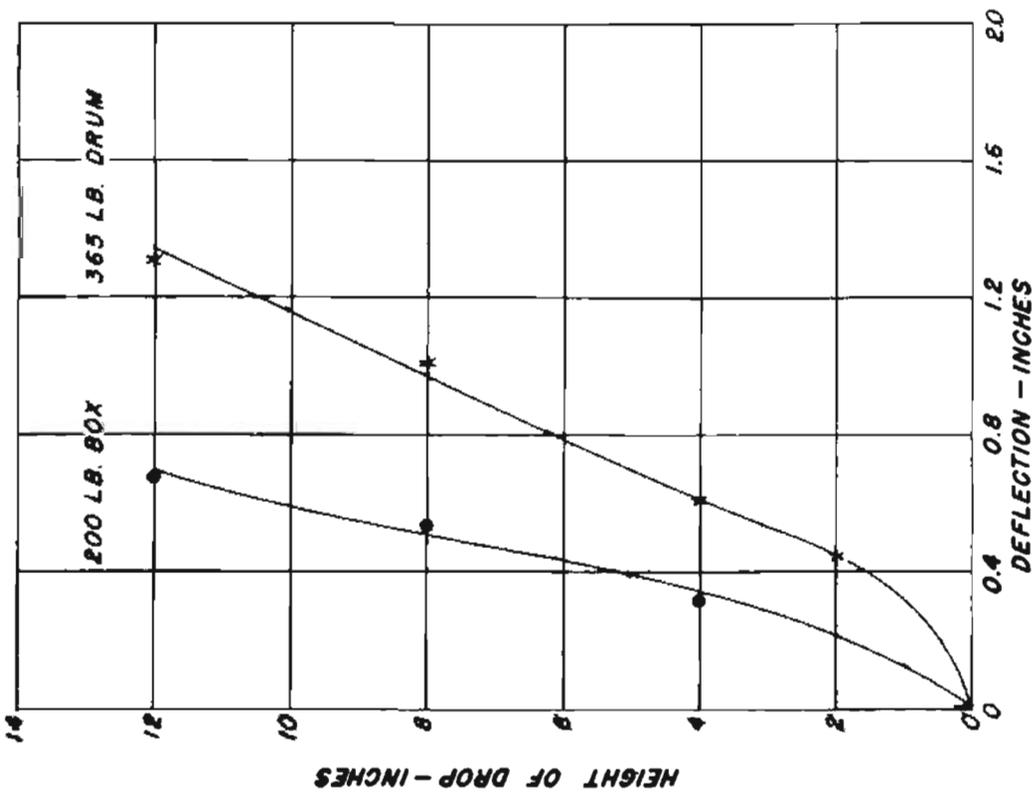


Figure 50.--Relation of height of drop of a simulated 200-pound box and 365-pound steel gasoline drum to deflection and permanent deformation in floor K.

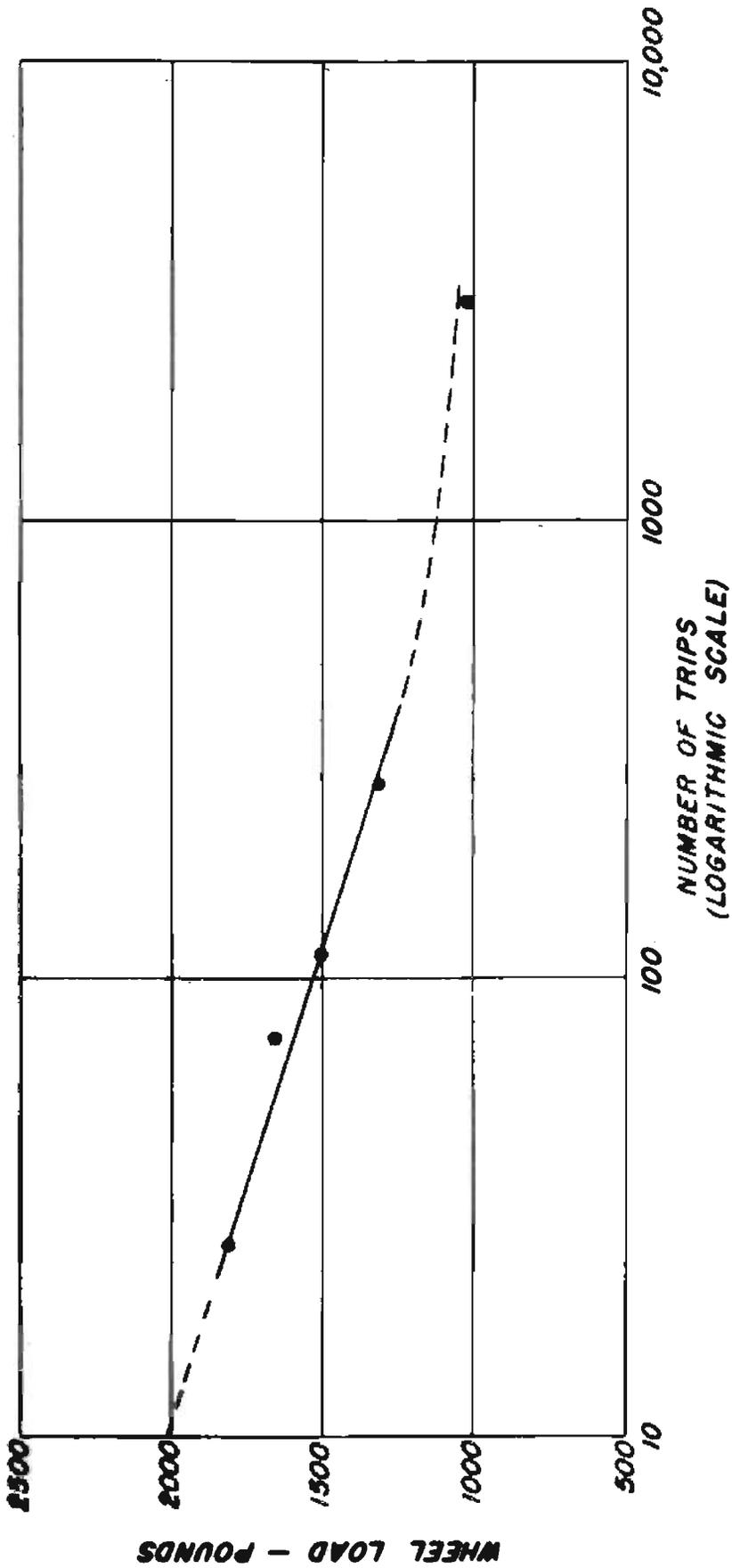


Figure 51.--Relation of number of trips to wheel load sustained by fl cor K tested by a rolling load simulating an aircraft engine cradle.