NATIONAL BUREAU OF STANDARDS REPORT

10 317

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Report on Study of

EVALUATION CRITERIA FOR FLOORS UNDER CONCENTRATED LOAD

A Report
prepared for the
Office of Research and Technology
Department of Housing and Urban Development

NBS

U.S. DEPARTMENT OF COMMERCE

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by
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IMPORTANT NOTICE

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Study of Evaluation Criteria
for Floors Under Concentrated Load

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Summary

Five conventional plywood floor systems, constructed in accordance with minimum requirements of FHA "Minimum Property Standards" were tested under concentrated loads in order to determine compliance with Operation Breakthrough Guide Criterion D.1.4.1(b).

In 24 out of 26 tests the performance of the floor systems exceeded that required by the criterion. No change in Criterion D.1.4.1(b) is recommended, but it is proposed that the term "residual indentation" be changed to "residual deflection" and that a loading rate of 1/2 lb per second be specified in the test. It is also recommended that an additional investigation be conducted in order to develop a test method for the determination of sustained-load capacity and to study occupancy-generated concentrated loads.

I. Introduction

1.1 Content of Report

This report is abstracted from the report entitled: "Study of the Behavior of Plywood Floors under Concentrated Load" [1][1/]. It conveys those conclusions which are relevant to the study of criterion D.1.4.1(b) of "Guide Criteria for the Design and Evaluation of Operation Breakthrough Housing Systems." [2]

1.2 Purpose of Study

The study was conducted as part of an effort to develop and improve evaluation criteria for housing. The criteria will be used to guide the development and evaluation of prototype housing for the Department of Housing and Urban Development's OPERATION BREAKTHROUGH.

The subject of this study are requirements for the resistance of floors to concentrated load. The objective of the study is to determine the level of performance of conventional floor systems and compare their performance with

1/ Figures in brackets indicate literature references that required in evaluation criterion D.1.4.1(b) of "Guide Criteria for the Design and Evaluation of Operation Breakthrough Housing Systems.

1.3 Background Information

1.3.1 The Need to Evaluate the Structural Performance of Floors Under Concentrated Load

Present U.S. building codes and design standards for residential construction provide for floor capacity under distributed load. The only U.S. recommendation related to concentrated loads acting on floors is contained in a performance standard by HHFA [3] which is advisory and not enforceable. The standard recommends deflection limitations under a 250-lb concentrated load, and an "extended-load capacity" of 450 lb with a residual deflection not to exceed 25 percent of the maximum deflection. The concentrated loads are to be applied over a 1-inch diameter area.

The lack of enforceable provisions for concentrated-load capacity is not attributable to a lack of necessity for such provisions. It is merely brought about by the fact that codes are based on conventional building systems, which by and large tend to perform in a manner acceptable to the user under conditions of normal use. On the other hand it is envisioned that some innovative systems may comply with code provisions for distributed loads, but exhibit insufficient strength under other types of occupancy load. It is therefore necessary to evaluate these innovative systems under various types of loading generated by occupancy, including critical concentrated loads.

1.3.2 Occupancy-Generated Concentrated Loads Acting on Floors

Concentrated loads on floors may be caused by heavy furniture or by human activity. Two critical conditions are identified:

1. A concentrated load of critical magnitude that may cause damage to the entire floor, or more likely to a section of the floor, by exerting excessive bending moments and/or excessive shear.
2. A load that is concentrated over a very small area, thereby causing failure by excessive compressive stress and/or excessive punching shear.

Typical heavy concentrated loads have been studied by Boyd [4] and are summarized below:

1. A person carrying a heavy load....................350-450 lb
2. A crowded sofa (per front caster)..................300-350 lb
3. An upright piano (1 caster)...........................200 lb

4. A grand piano (1 caster)..............................280 lb

5. Transportation of an upright piano (per wheel)....250-350 lb

6. Transportation of a grand piano (per wheel).......350-450 lb

Boyd concluded that since the use of grand pianos is relatively rare, the following design-loads should be used:

(a) 400 lb for several seconds

(b) 350 lb for 1/2 hour

(c) 200 lb indefinitely.

In extreme cases some casters may spread these loads over an area as small as 0.5 in^2.

Critical loading caused by load concentration over a small bearing area is caused by stiletto heels. Even though these heels are no longer fashionable, their future use cannot be ruled out.

A study of typical stiletto-heel pressures [5] indicates a range of compressive stresses from 550 psi to 1390 psi, and one extreme value of 2,260 psi. Values of punching shear computed from these data range from 80 lb/in to 117 lb/in. The case that produced the 2260-psi compressive stress produced a punching shear of 156 lb/in.

1.3.3 Discussion of the Evaluation Criterion for Concentrated Load on Floors

The following criterion has been adopted as a guide for OPERATION BREAKTHROUGH [2]:

Criterion D.1.4.1(b)

"The structural floor should resist a 400-lb load, applied on a circular area of 5/8-in diameter and sustained for one hour, without causing a residual indentation of the structural surface in excess of 1/16 in, measured 1 hour after removal of the load, and a 280 lb long-term sustained load, applied on a circular area of 5/8-in diameter.

If the wearing surface is of non-durable material, or if there is a possibility that this surface may be removed during the useful life of the structure, the floor should satisfy criterion D.1.4.1(b) with the wearing surface removed."

This criterion is intended to test the structural floor and not the wearing surface. However, permanent-type wearing surfaces are left in place, so that the beneficial effect of such surfaces on the load capacity of structural floors can be relied upon.

The criterion requires reasonable deflection recovery under a 400-lb concentrated load sustained for one hour and a 280-lb long-term sustained-load capacity. The term "sustained-load" capacity is not defined in the criterion. In this investigation it is assumed that the intent of the criterion is that a 280-lb load applied over a 5/8-in diameter area continuously during the useful life of the structure should not cause a residual deflection greater than 1/16 in.

The 400-lb requirement would be in many cases associated with the capacity to support a higher short-term load; however, the relationship between the short-term capacity, the one-hour capacity, and the long-term capacity would depend on the material of the structural floor. As an example, this relationship is considered for the case of wood.

The following approximate capacities can be calculated using the information in Reference [6] and assuming that capacities are interpreted in terms of maximum residual deflection and that the residual deflection is related to flexural strength:

30-second capacity..........485 lb

1-hour capacity............400 lb

1-year capacity............290 lb

On the other hand, for another material, instantaneous and long-term capacities may differ very little from the one-hour capacity.

The compressive stress caused by the 400-lb load required in the criterion is 1300 psi and the punching shear is 203 lb/in.

If we compare the concentrated load, the compressive stress and the punching shear with the data in section 1.3.2, it is evident that the criterion represents reasonable minimum requirements with little or no margin with respect to extreme occupancy loads. However, it should be noted that some of the extreme loads, caused by the moving of heavy furniture, could be modified or avoided by simple precautions.

The loading requirements in the criterion differ from existing techniques, such as the ASTM E72 test [7] and the ASTM D 2394 test [8]. Both of these test methods use a 1-in diameter disc to transmit the load, while the criterion requires a 5/8-in diameter loading area.

The E72 test is intended to measure the structural capacity of the system, and the D2394 tests measure the strength of the finished flooring. These tests, with proper choice of load levels, could adequately evaluate most floor systems. A problem, however, arises with floor systems that consist of a thin structural skin supported by stiffening elements. In this case the system may perform satisfactorily under the D2394 test, while under different support conditions the structural skin may fail by punching shear. On the other hand, in order to generate adequate stress under a 1-in diameter disc, the concentrated load would have to be increased to over 1000 lb, and in order to generate adequate punching shear the load would have to be increased to at least 500 lb. These heavier concentrated loads would be higher than the extreme concentrated loads that actually act on the floor in service.

2. Scope of Testing Program

Seven different kinds of plywood subflooring were tested, representing typical minimum construction standards presently used. Most of the subflooring specimens tested were supported by wooden joists of 2 x 4-in nominal size, spaced 16 in on center. In a small number of specimens joist spacings of 24 in, 20 in, 10 in and 6 in were used in order to investigate failure modes. The small 4-in joist depth was selected, since in all cases the joists were fully supported, and joist - deflection and hence, joist size, was not a variable considered in this investigation. Test loads were concentrated loads which were increased until failure occurred. For part of the specimens loads were applied in several cycles of unloading and reloading. Deflections were measured near the point of load application. The test loads were applied over circular areas of 1 in, 5/8 in, and in a limited number of tests, 1/2 in diameter. Table 2.1 shows the test variables and the scope of the testing program. Out of the number of

TABLE 2.1

Number of Tests Performed

Joist Spacing, in		16			24		20		10		6		
Diameter of Loaded area, in		1	5/8	1/2	1	5/8	1	5/8	1	5/8	1	5/8	TOTAL
Subflooring System	A	12	18			6	6	6	6	6	6	6	72
	B		18			12		6		11		6	53
	C	5	6	2									13
	D	14	7										21
	E	14	7										21
	F		6										6
	G		7										7
Total No. of Tests													193

SUBFLOORING SYSTEMS:

A: 15/32-in-thick underlayment grade Southern Pine interior-type, 5-ply plywood.

B: 1/2-in-thick standard grade Southern Pine interior-type with exterior glue, 5-ply plywood.

C: 1/2-in-thick standard grade Douglas Fir interior-type, 3-ply plywood.

D: 1/2-in-thick standard grade Douglas Fir interior-type, 3-ply [a/] plywood. under 7/32-in-thick hardboard underlayment.

E: 1/2-in-thick plywood as in D under 1/4-in-thick plywood underlayment.

F: 1/2-in-thick plywood as in C under 7/32-in-thick hardboard underlayment.

G: 1/2-in-thick plywood as in C under 1/4-in-thick plywood underlayment.

a/ The core of this plywood was laminated giving the interior ply double thickness.

tests shown in table 2.1, 26 tests were conducted at locations simulating the most critical conditions likely to occur in actual buildings.

3. Test Specimens

3.1. Materials

All materials were purchased from local suppliers and were typical of those presently used in building construction.

3.2 Description of Specimens

All the standard specimens were constructed in accordance with the provisions in "Minimum Property Standards" [9], Sections 817.3 and 817.4.

Standard specimens were constructed in small widths compared to the size of plywood sheets actually used in construction. This provided simulated conditions representing the least strength and stiffness that the floors may be expected to develop in service.

3.2.1 Standard Specimens without Underlayment

Figure 1 shows a typical specimen. The 2 x 4 joists were 16 in long and were spaced 16 in on center. Plywood sheets, nominally 1/2 in thick. 14 in wide, and 48 in long, were nailed to both narrow sides of the joists. The plywood sheets were oriented with the grain of the outer plies perpendicular to the axis of the joists. The joists were 2 in longer than the width of the plywood sheet to give the specimens stability under concentrated load, applied at the long edge of the plyywood. The plywood sheets were nailed to the joists with 8d common nails. Three nails, spaced 6 in on center, were used for the two outside joists. The inside joists were nailed with two nails, spaced 10 in on center.

3.2.2 Standard Specimens with Underlayment

Figure 2 shows a typical standard specimen with underlayment. The two 48 in long 2 x 4 joists were spaced 16-in on center. Four 12-in long and 16-in wide sections of nominally 1/2-in thick plywood were nailed to each of the narrow sides of the joists. Each 12 x 16-in plywood section was nailed on each side by three 8d common nails, spaced 5 in on center. This spacing was less than the 6-in spacing required in "Minimum Property Standards." The reduced nail spacing was chosen in order to compensate for the fact that this specimen was only 16 inches wide, while in an actual building an 8 ft sheet would be used, providing continuity at least at one of the two joist supports. The 1/2-in plywood sheets were oriented with the grain of the outer ply perpendicular to the axes of the joists. A continuous sheet of underlayment, 16 in wide and 48 in long, was nailed to the outer face of the 1/2 in plywood sheets. This underlayment consisted of either 7/32-in thick hardboard or 1/4-in thick plywood. The underlayment was nailed to the 1/2-in plywood sheets by 4d annular-thread nails spaced 6-in on center.

4. Testing Procedure

The specimens were built and stored in the laboratory at approximately 73°F and 50 percent relative humidity. The tests were performed in the same laboratory.

The load was transmitted from the head of a 60,000-lb capacity testing machine. The test setup is shown in figure 3. The specimen rested on the platten of the testing machine. Load was applied to the specimens through the end of a 6.5-in long steel rod. The end of this rod was sharp edged and machined to the required diameter. This steel rod was connected to a load cell which was inserted between the upper end of the rod and the head of the testing machine.

Deflection[2/] was measured by a displacement transducer (LVDT). The transducer was connected to a base, made of a 2 x 4 in wooden member, 18 in long, that rested on three adjustable bolts. These bolts were so spaced, that the base could be supported on the centerline of two joists on 16 in centers. Deflections were measured to the face of a bracket, which was connected to the upper end of the load cell. Thus deflections were measured by measuring the downward movement of the loading device, relative to points, spaced 16 in apart and located at the surface of the specimen. The distance between the centerline of the displacement transducer and the centerline of the loading rod was 4 in.

Deflections thus measured also included shortening of the loading rod and the load cell. To determine the magnitude of this effect, the shortening of the rod and the load cell was measured for loads up to 1000 lb. It was determined that the effect of this shortening on test results was of second order magnitude and corrections for this effect were therefore unnecessary.

2/ The term "indentation" used in the criterion was interpreted as a deflection of localized nature which was measured relative to two points on the surface of the floor, spaced 16 in apart and which in some cases included a well defined indentation of the floor surface, as well as a localized deflection between two adjacent supporting joists. In the case of the standard specimens, the measured deflections at the critical locations were referenced to two points at the floor surface located above the centerlines of two adjacent supporting joists.

Data were recorded electronically, by transmitting the output from the displacement transducer and the load cell to an X-Y recorder. The X-Y recorder plotted loads on the Y axis to a scale of 100 lb per 1 in, and deflections on the X axis to a scale of 0.1 in per 1 in. This produced a graphical record of the data which had adequate resolution.

The load was applied at a rate of 1/2 lb/sec. Most specimens were loaded continuously to failure, but several specimens were subjected to cycles of unloading and reloading. After each load increment of 100 lb these specimens were completely unloaded and reloaded to a load 100 lb greater than the previous load or to failure, whichever came first. This procedure left a record of instantaneous deflection recovery for each specimen. On two specimens, a 400-lb load was maintained for one hour, and the specimens were then unloaded and deflection recovery was measured after one hour. In some tests failure occured at loads higher than 1000 lb. In these cases the load cell which had a 1000-lb capacity, was removed prior to the completion of the test and loads were measured by the testing machine. For these tests, only failure loads, as identified by a sudden drop in applied load of 30 lb or more were recorded since the deflections at failure were not measured.

5. Compliance with Criterion D.1.4.1(b)

5.1 Concentrated-load capacity

Figure 4 is a plot showing the range of load capacities and average load capacities when load was applied at the weakest location likely to be encountered in a built floor. The shaded rectangles show the range of the failure loads and the unshaded rectangles show the range of loads that caused initial distress. The solid and hollow circles[3/] show the average loads at failure and initial distress, respectively. Test results are plotted for loaded areas of 5/8 in, as well as 1 in diameter. The heavy, horizontal line shows the load level required by criterion D.1.4.1(b).

The following conclusions can be derived from figure 4:

1) All specimens tested failed at load levels equal to, or higher than that required by the criterion.
2) Except for floor system E, all specimens tested showed first signs of distress at load levels equal to or higher than that required by the

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[3/] In some cases the test results do not cover a significant range, or only one single test was performed. In these cases only the solid and hollow circles are shown.

criterion. For system E, two out of the three specimens tested showed first signs of distress at load levels higher than that required by the criterion. The third specimen showed first signs of distress at a load level of 360 lb.

3) In all cases, specimens tested by the 1-in diameter disc had significantly greater load capacity than specimens tested with the 5/8-in diameter disc.

The overall conclusion is, that except for one specimen in system E, all specimens satisfied criterion D.1.4.1(b) and most specimens exceeded the capacity required in the criterion by a substantial margin. It should be noted that this conclusion is based on a test setup which uses specimens of 14 in and 12 in width, respectively. This is a simulation representing the least strength that a floor may be expected to develop. In an actual building, where floors are continuous over much larger areas, load capacities may be somewhat higher.

5.2 Deflection Recovery

Figure 5 shows the load-deflection curve for a test in which floor system C was loaded in accordance with the requirement of criterion D.1.4.1(b). Deflections are plotted along the abscissa, and loads along the ordinate.

Note that the instantaneous deflection under the 400-lb load was approximately 0.178 in. When the load was sustained for an hour, this deflection increased by 0.012 in and when the load was removed, there was an instantaneous deflection recovery to a residual deflection of 0.02 in. One hour after unloading, the remaining residual deflection was 0.01 in. This should be compared with the 1/16 in (0.0625 in) residual deflection permitted by the criterion. Thus this specimen exceeded the performance required by criterion D.1.4.1(b) by a substantial margin.

Figures 6 through 10 show deflection-recovery characteristics for floor systems A,B,C,F, and G, respectively. In all cases the residual deflection, measured immediately after removal of the 400-lb load, was less than 1/16 in. Thus all these floor systems have deflection-recovery characteristics which would satisfy criterion D.1.4.1(b). Floor systems D and E were not tested under cycles of unloading and reloading. The load-deflection curves for these specimens tend to the linear below the 400-lb load. This is taken as an indication that these systems have deflection-recovery characteristics similar to those of systems A,B,C,F and G.

5.3 Sustained-Load Capacity

No tests were conducted to determine the sustained-load capacity of the specimens. Some indication of the magnitude of that capacity can be derived using the data presented in reference [6]. In accordance with these data, a 1-hour capacity of 400 lb would correspond to a 1-year capacity of 290 lb and to a 30-year capacity of 265 lb.

If we define the 30-year capacity as the required sustained-load capacity, a one-hour capacity of 422 lb should be required in order to satisfy the 280-lb requirement in criterion D.1.4.1(b). Of the 26 specimens tested at critical load locations, 24 exceeded this capacity.

Thus it can be concluded that the floor systems tested generally satisfy the requirement for sustained-load capacity.

6. Conclusions and Recommendations

6.1 Conclusions

1) Out of 26 tests performed on the specimens at the weakest location likely to be encountered in a built floor, 24 exceeded the one-hour load capacity.

requirement in criterion D.1.4.1(b) by a substantial margin, 1 test exactly satisfied the criterion and 1 test specimen developed first signs of distress at a load level lower than that of the criterion.

2) For those tests that exceeded the one-hour load capacity requirement, residual deflections were generally smaller than the 1/16-in maximum permitted in criterion D.1.4.1(b).

3) On the basis of the data presented in reference [6], it can be concluded that 24 out of the 26 points tested probably satisfy the sustained-load requirement of the criterion.

4) Load capacity under a 1-in diameter loaded area exceeded the capacity under a 5/8-in diameter loaded area by a substantial margin. Under a 1/2-in diameter loaded area vertical compressive stresses exceeded the material strength under a 400-lb concentrated load.

6.2 Recommendations

1) No change in the criterion is recommended at the present time, however it is proposed that the term "residual indentation" be changed to

"residual deflection" and that the ASTM E72 test procedure be ammended to require a loading rate of 1/2 lb per second. It is also proposed to define sustained-load capacity in terms of a 1/16-in residual deflection.

2) It is recommended that an investigation of all materials likely to be used in floor systems in the forseeable future be conducted, in order to develop a test method by which the sustained-load capacity can be determined in a reasonably short period of time. This test method, once defined, should be made part of criterion D.1.4.1(b).

3) Since in accordance with present information the one-hour capacity required in criterion D.1.4.1(b) represents a minimum requirement with no margin with respect to occupancy-generated concentrated loads, it is recommended that a study be conducted to determine occupancy-generated concentrated loads in order to verify the adequacy of the required load level.

References

[1] Yokel, F.Y., Study of the Behavior of Conventional Plywood Floors Under Concentrated Load, NBS Report No. 10315, February 1971.

[2] National Bureau of Standards, Building Research Division, Guide Criteria for the Design and Evaluation of Operation Breakthrough Housing Systems, revised October 1970.

[3] Housing and Home Finance Agency, Performance Standards, Structural and Insulation Requirements for Houses, Washington, D.C., June 1947.

[4] Boyd, J.D., Minimum Strength and Stiffness Necessary for Wooden Floors in Houses, Paper No. 34, CSIRO, Division of Forest Product Technology, Melbourne, Australia, 1964.

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[6] Wood, Lyman W., Relation of Strength of Wood to Duration of Load, Forest Products Laboratory, Madison, Wis., December 1951.

[7] ASTM Designation E72-68, Conducting Strength Tests of Panels for Building Construction, American Society for Testing Materials, Philadelphia, Pa., 1968.

[8] ASTM Designation D 2394-69 Tests for Simulated Service Testing of Wood and Wood-Base Finish Flooring, American Society for Testing Materials, Philadelphia, Pa., 1969.

[9] Federal Housing Administration, Minimum Property Standards for One and Two Living Units., Washington, D.C. Nov. 1966, as subsequently amended.

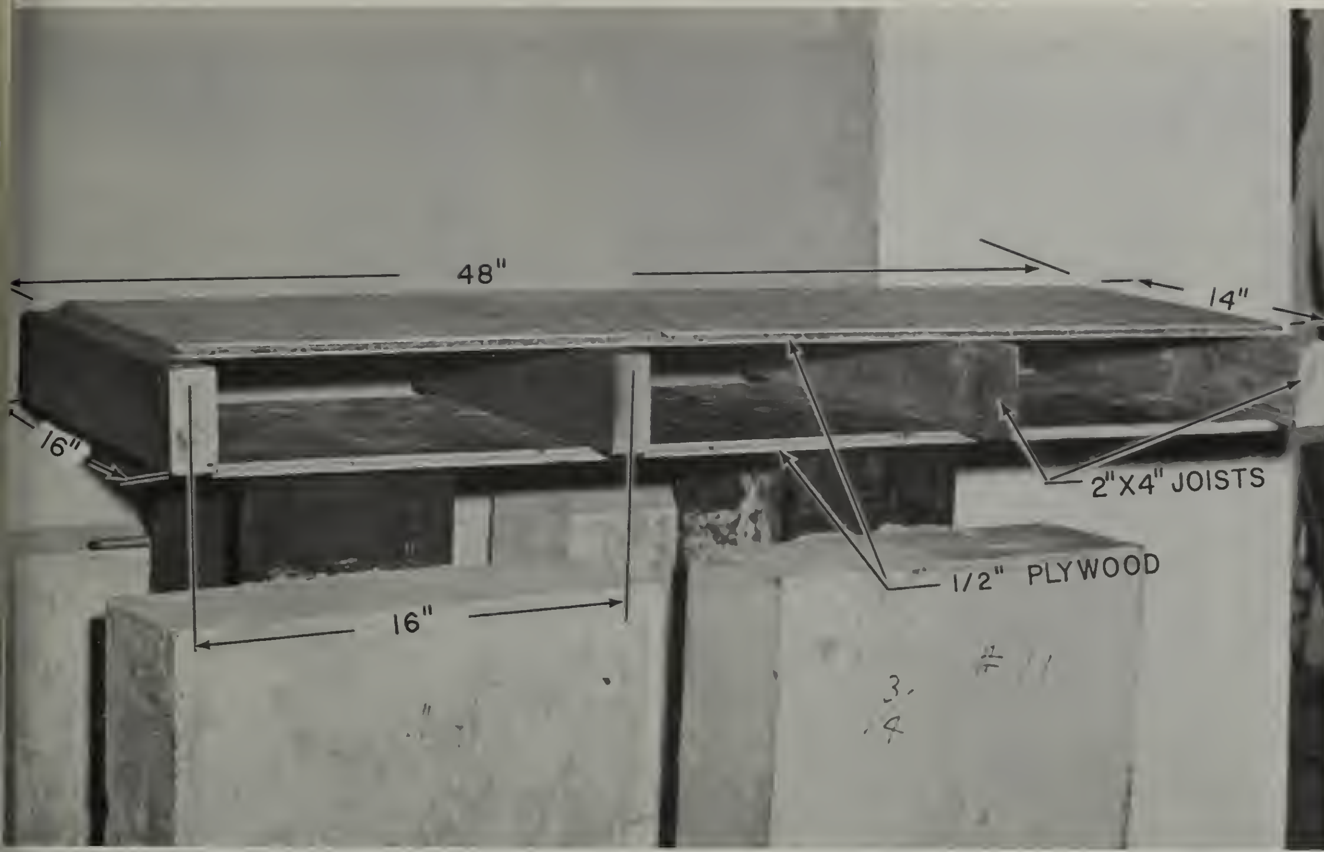

FIGURE 1 STANDARD SPECIMEN WITHOUT UNDERLAYMENT

FIGURE 2 STANDARD SPECIMEN WITH UNDERLAYMENT

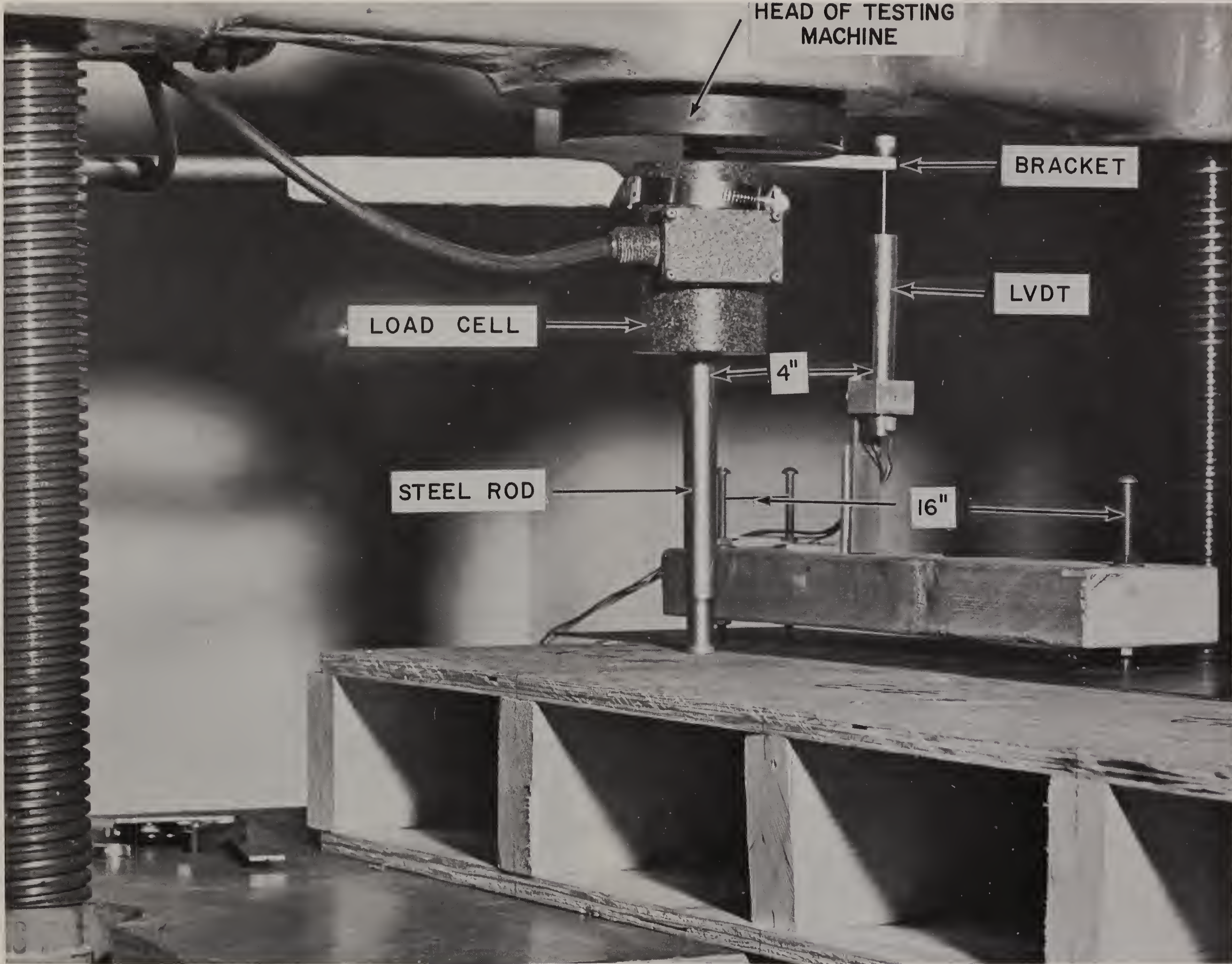

FIGURE 3 TEST SET UP
CONCENTRATED LOAD,

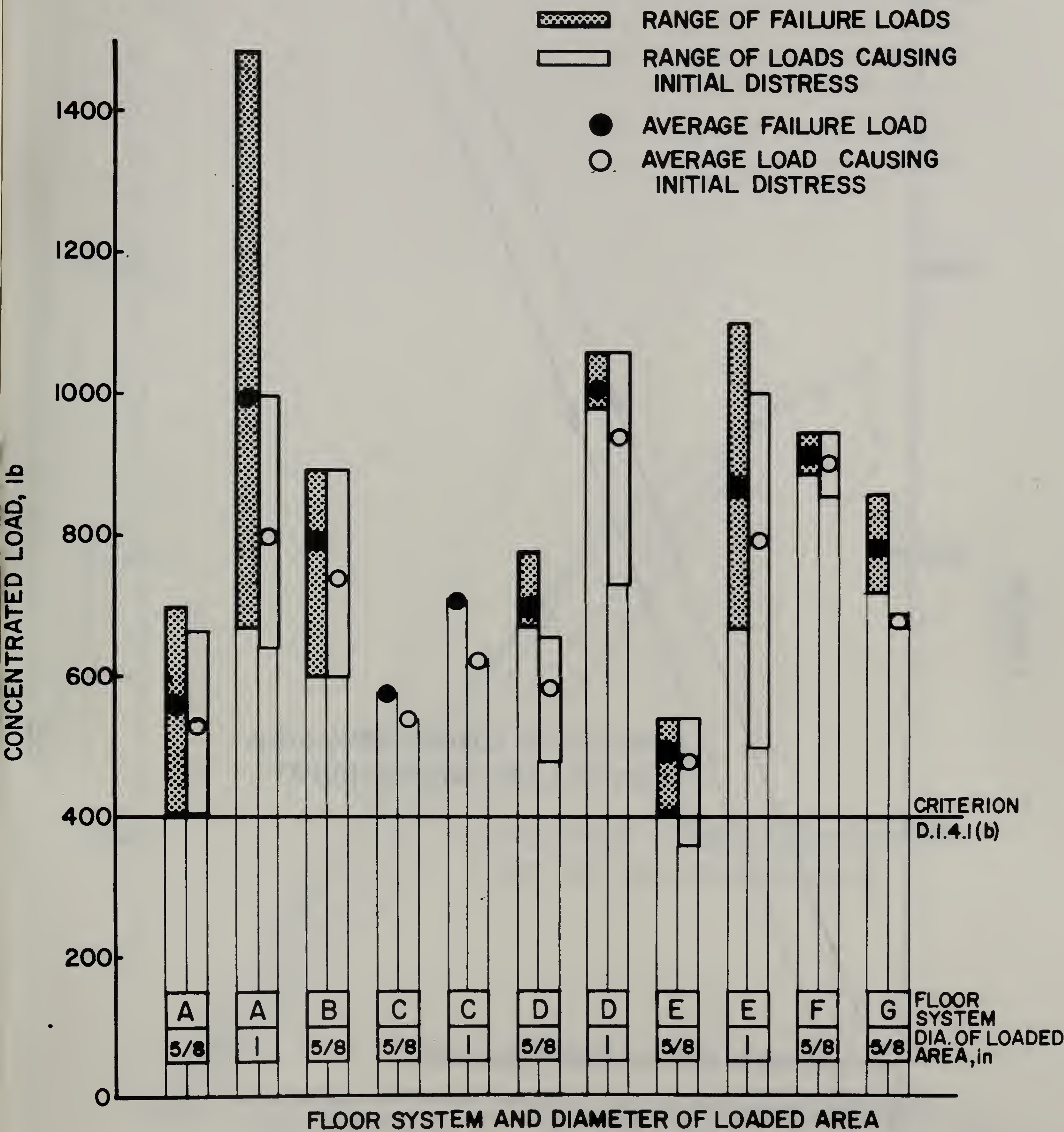

FIGURE 4. RANGE AND AVERAGES OF TEST RESULTS FOR TEST LOCATIONS 1 AND 1u

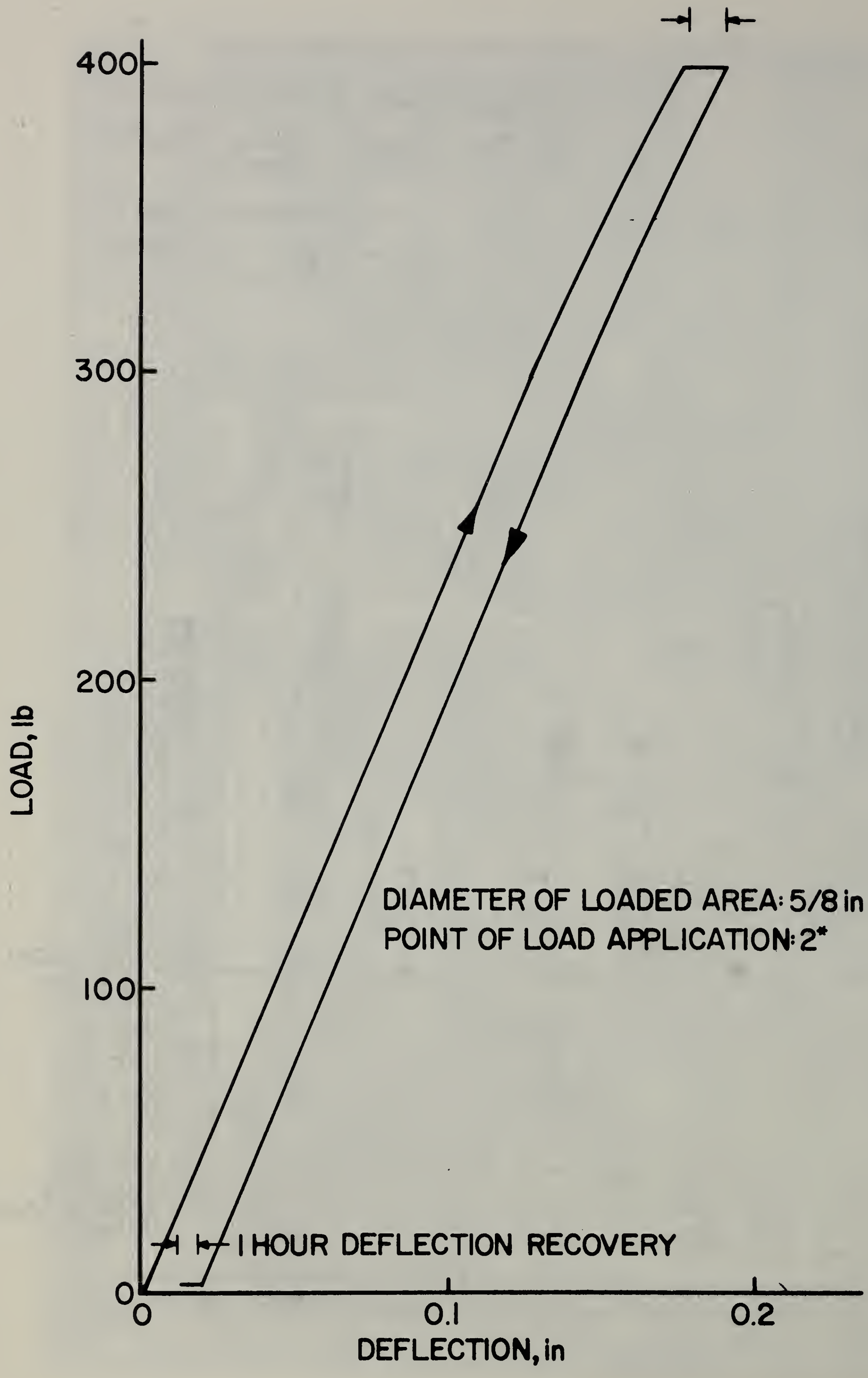

FIGURE 5 COMPLIANCE OF FLOOR SYSTEM C WITH BREAKTHROUGH CRITERION D.1.4.1(B)

* SEE FIGURE 5.1

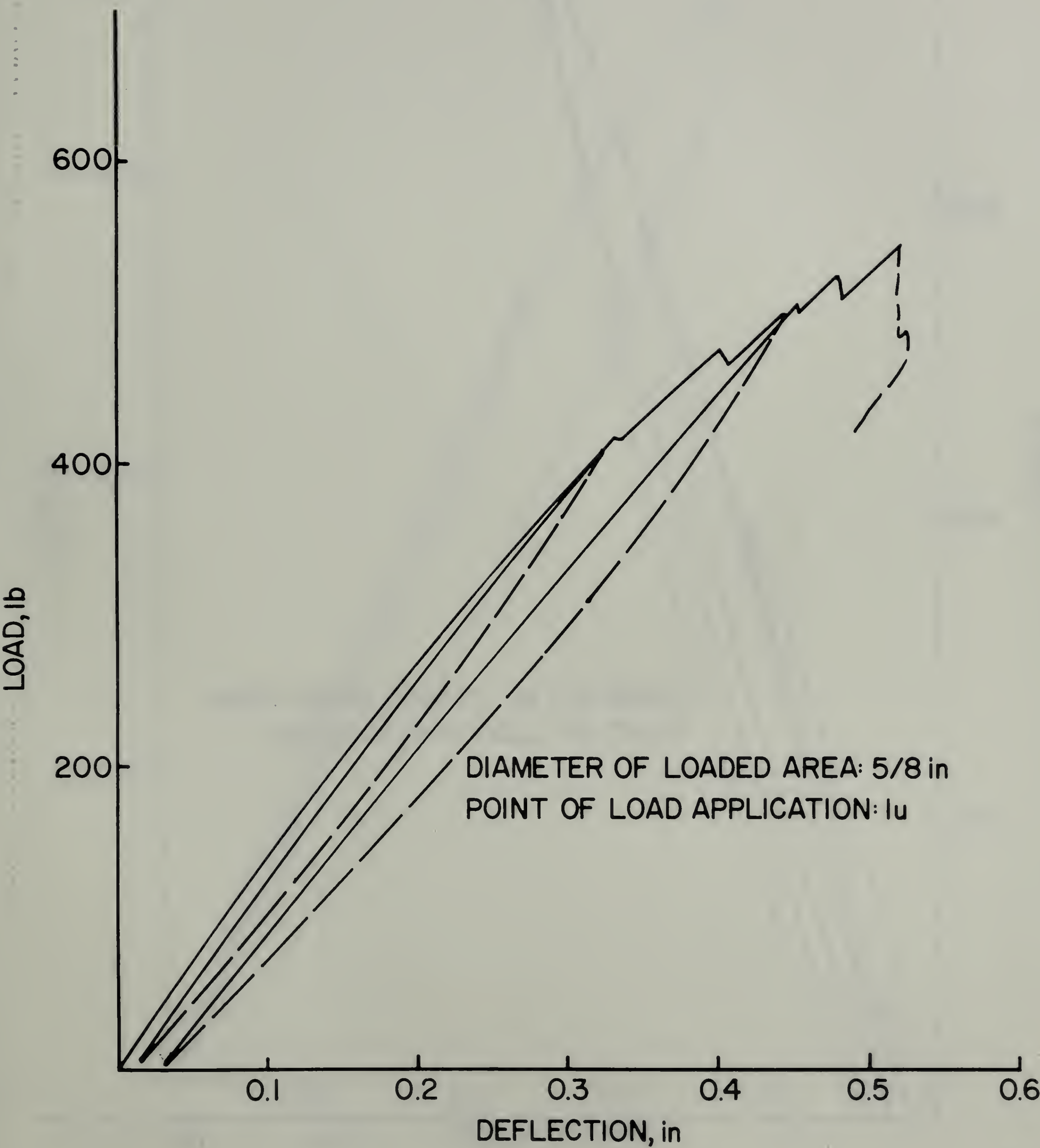

FIGURE 6 DEFLECTION RECOVERY CHARACTERISTICS OF FLOOR SYSTEM A

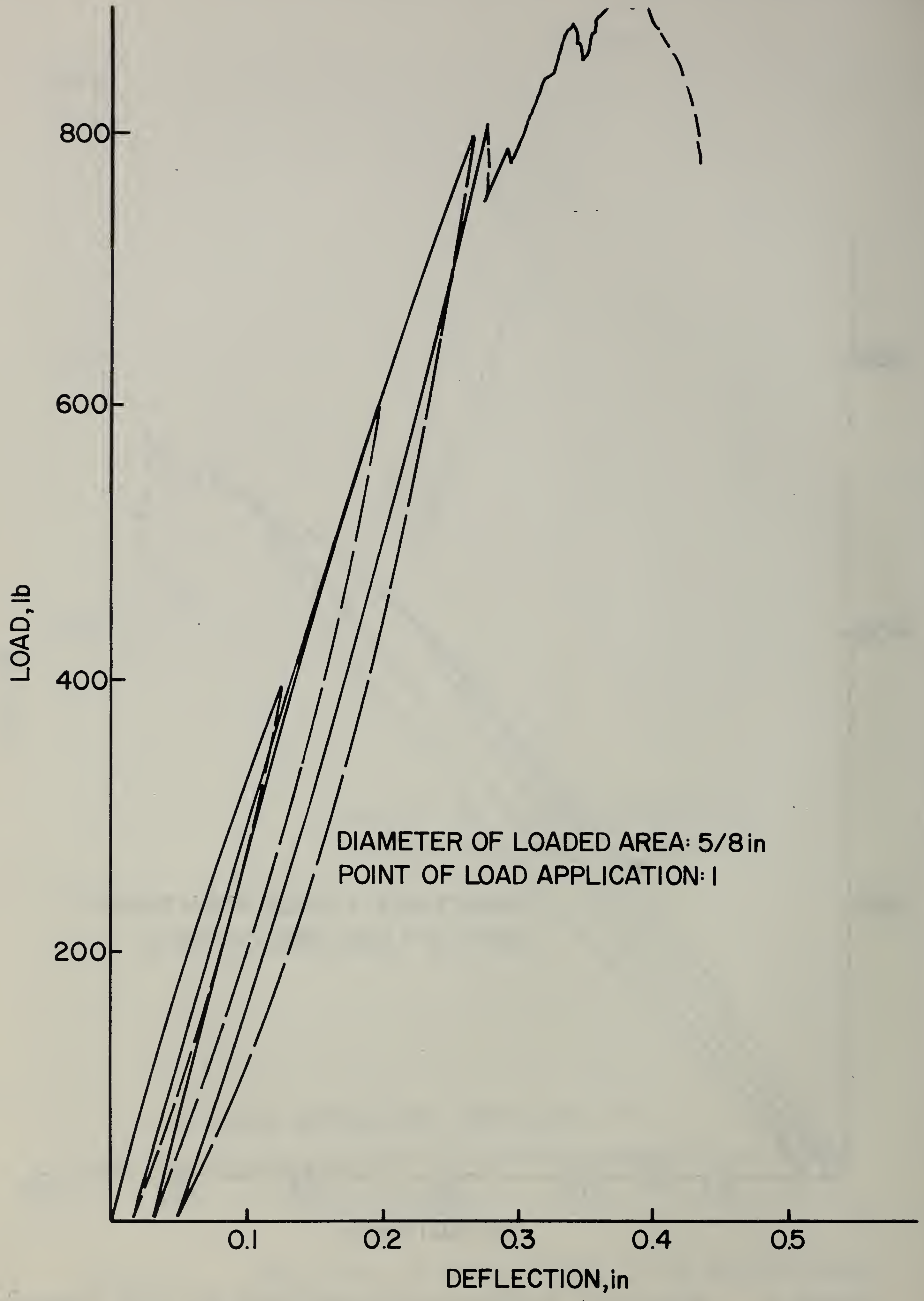

FIGURE 7 DEFLECTION RECOVERY CHARACTERISTICS OF FLOOR SYSTEM

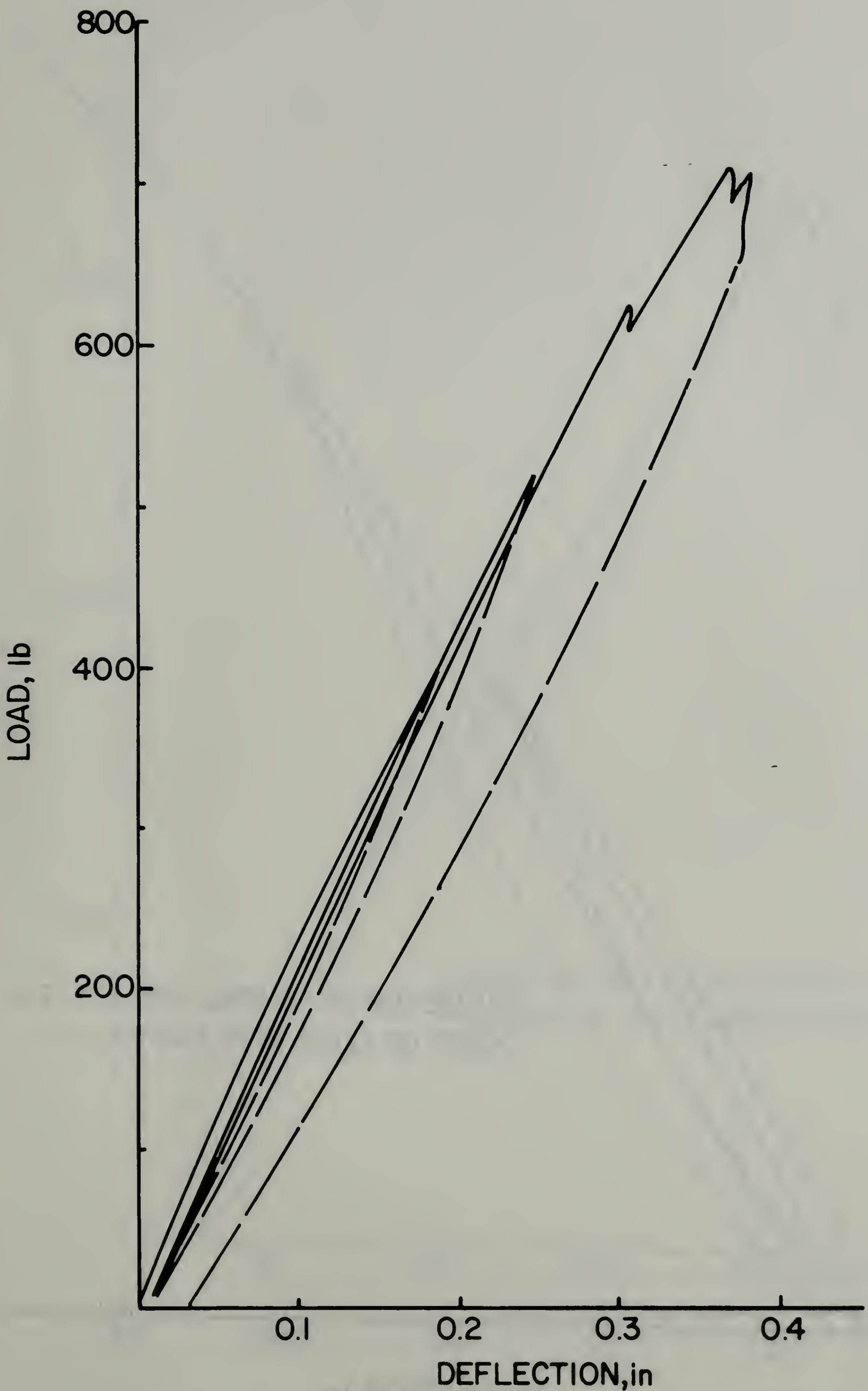

FIGURE 8 DEFLECTION RECOVERY CHARACTERISTICS OF FLOOR SYSTEM C

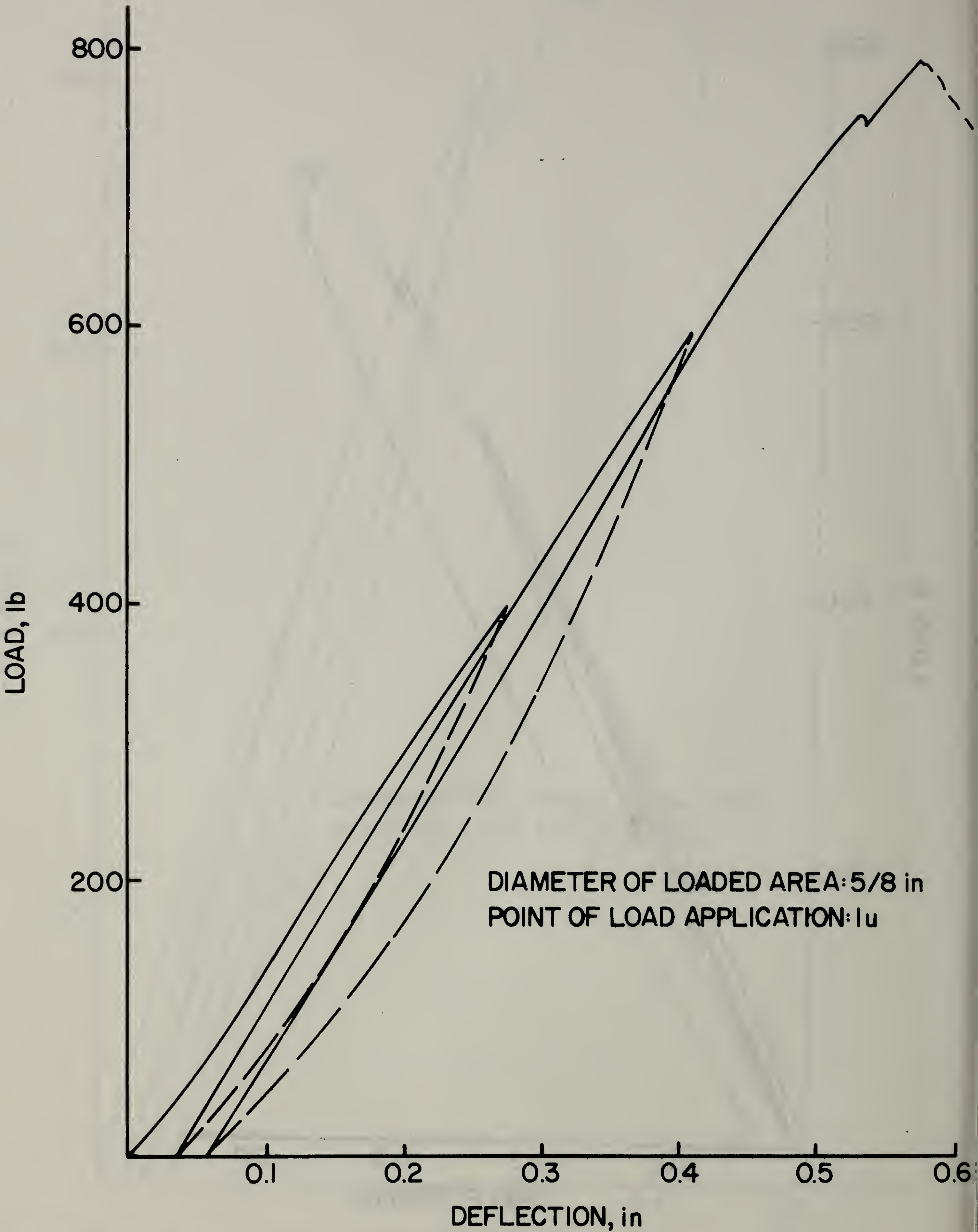

FIGURE 9. DEFLECTION RECOVERY CHARACTERISTICS OF FLOOR SYSTEM F

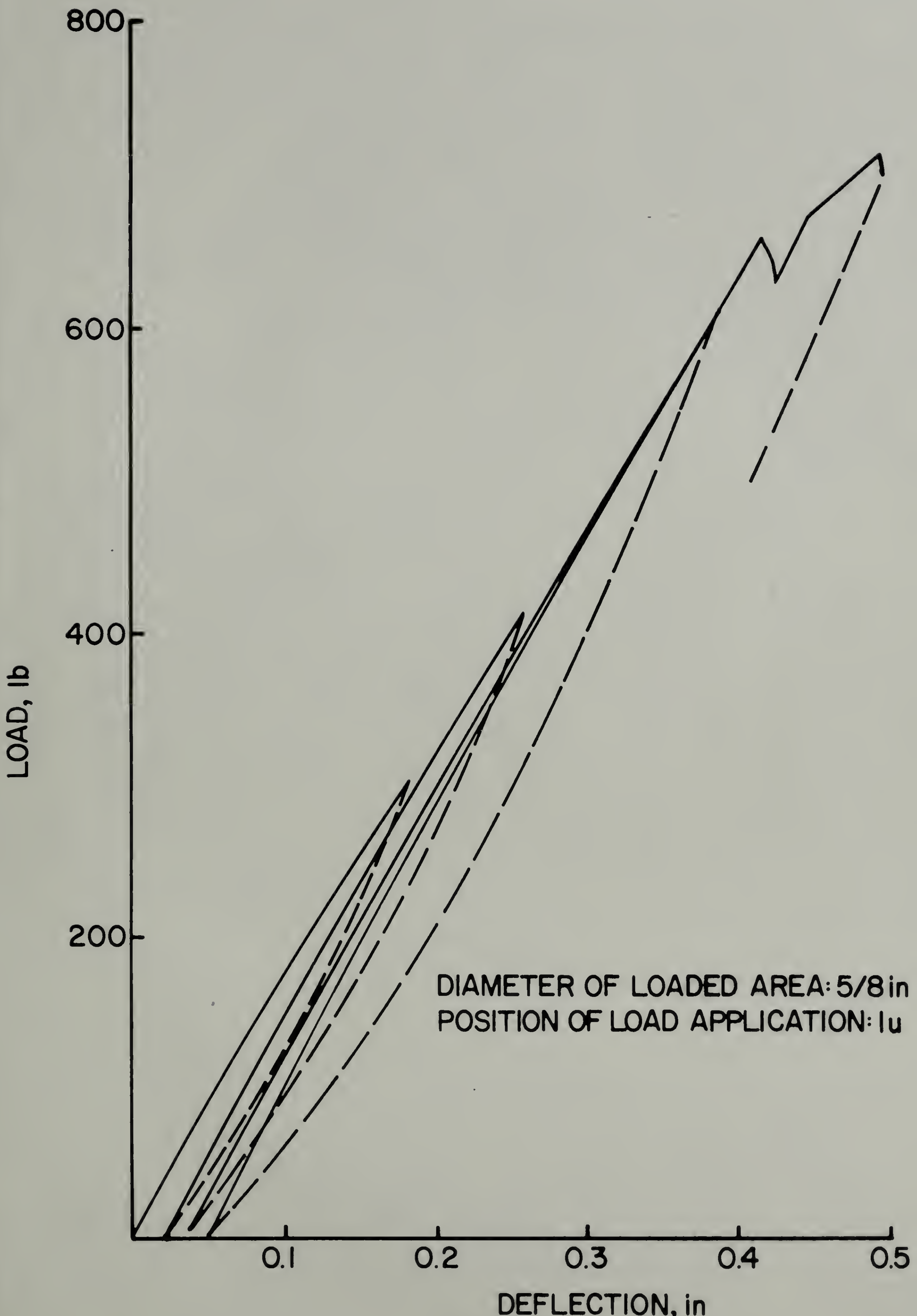

FIGURE 10 DEFLECTION RECOVERY CHARACTERISTICS OF FLOOR SYSTEM G

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