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The Effect of Impact Loadings on the Performance of Wood Joist Subflooring Systems

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SI Conversion Units

In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units, the author assists readers interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 metre (exactly)
1 ft = 0.3048 metre (exactly)

Area

1 in^2 = 6.5416 x 10^{-4} $metre^2$ (exactly)

Mass

1 lb (lbm) - 0.4536 kilogram

Energy

1 ft-lb (ft-lb force) - 1.356 joule

Glossary

Hardboard: A dense panelboard manufactured primarily of wood fibers with the natural lignin in the wood reactivated to serve as a binder for the wood fibers.

Subfloor: The structural material or surface which supports floor loads and the finish flooring. If the subfloor material posses sufficient density, smoothness, stiffness, dimensional stability, and adequate bonding properties, finish flooring may be applied directly on it without the use of underlayment.

Underlayment: A mastic or panelboard material installed over the subfloor to provide a suitable base for the finish flooring when the subfloor does not possess the necessary properties for direct application of the finish flooring.

The Effect of Impact Loadings on the Performance of Wood Joist Subflooring Systems

H. S. Lew

This report presents the results of an experimental study of wood-joist subflooring systems subjected to impact load. Six different types of subflooring systems were tested following the test method described in the ASTM Standard Methods (ASTM Designation E-72). The magnitude of impact load was varied by dropping a 60-lb bag from different heights.

A concentrated static load of 400 lb was applied to the subfloor after it was exposed to impact load. It is suggested that the deflection under this concentrated load be used as a measure of the impact resistance of the subfloor.

Key Words: Concentrated load; deflection; floor; hardboard; housing; impact energy; Operation BREAKTHROUGH; plywood; subfloors; underlayment; wood; wood joists.

1. Introduction

1.1 Background

Performance criteria need both descriptive and quantified limits to adequately define their intent. It became apparent, in the course of the development of the Guide Criteria [1][1/] for the Operation BREAKTHROUGH program, that no reliable test data for conventional wood floors of dwelling construction are available to establish quantified limits relative to impact resistance. For this reason, the experimental program presented in this report was undertaken.

1.2 Scope

Because wood joist floor construction is widely used and has shown a generally acceptable level of performance, it was decided that the impact strength of wood-joist floors would provide an appropriate datum for comparison. The tests reported herein were carried out on wood-joist floors with several combinations of plywood subflooring.

1.3 Test Program

From the user's point of view, one feature of the serviceability of the floor is considered to be impaired when the local deformation of the floor is excessive under static loads. When an impact load causes damage to the floor, application of a static load on that part of the floor can produce a larger deflection than that produced by the same load on the undamaged floor at the same location. If this deflection under the static load is greater than a tolerable limit, the performance of this floor can become objectionable to the user. The serviceability of the floor would then be impaired.

1/ Figures in brackets indicate the literature references on page 28.

The incidents which produce impact load in dwellings may range from accidental dropping of household items and furniture to a person falling from a ladder. The magnitudes of these impact loads on the floor have not been documented. Therefore, the resistance of floor systems to specific levels of impact loads associated with specific causes cannot be determined at present. On the other hand, deflection of the floor under a given static concentrated load can be determined experimentally relative to the stiffness reduction of the floor that might be caused by the application of impact load. Thus, for a limiting deflection under a given static concentrated load, the corresponding impact energy could be obtained for a specific floor system. Conversely, after being subjected to this maximum level of impact energy, the floor should not deflect more than a set limit under the same concentrated static load.

A series of tests were made to establish a relationship between the impact load and the deflection at the impacted area under a concentrated static load. In each test, an impact load was applied to the specimen and subsequently the static deflection was measured under a concentrated load of predetermined magnitude applied to that area. The magnitude of the concentrated load and the size of the loaded area will be discussed in section 1.4.

The impact was delivered to the specimen by dropping a 60-lb bag from a given height. For simplicity, the energy delivered to the specimen is measured by the product of the weight of the bag and the height of drop. Thus, the energy is expressed in terms of the potential energy rather than the kinetic energy delivered to the specimen. In this test program, the magnitude of impact energy is expressed in "ft-lb."

1.4 Concentrated Load and Loaded Area

When concentration of load is considered for design, both the load and the loaded area should be taken into account. A study by Boyd [2] shows that typical concentrated loads found in houses are as follows:

1. A person carrying a heavy load . . . . . 350-400 lb
2. A crowded sofa (per front caster). . . . 300-350 lb
3. An upright piano (per caster). . . . . 200 lb
4. A player-piano (per caster). . . . . 280 lb
5. A hand-truck carrying an upright piano (per wheel) . . . . 250-350 lb
6. A hand-truck carrying a player-piano (per wheel). . . . . 350-450 lb

Since the frequency of occurrence of a large load produced by such items as a player-piano is low, Boyd concluded that it would be inappropriate to design for such an extreme load. He suggested that it would not be unreasonable to consider a short-term load of 400 lb for a duration of a few seconds over an area of 1.5 in^2. The magnitude of such a load appears reasonable to consider as a design load. However, the bearing pressure produced by this loading condition is substantially less than a maximum bearing pressure that could be expected from stiletto heels. It has been observed that due to a small contact area, stiletto heels can produce a bearing pressure as high as 1,400 psi.

A test program that deals with evaluation of the performance of floors under concentrated load must consider both high magnitude loads and corresponding pressures that reflect what the floor would experience in practice. For this test program, it was decided to use a concentrated load of 400 lb applied over a 5/8-in dia. disc. This results in about 1,300 psi of bearing pressure which is close to the upper range of bearing pressures that could occur in practice.

2.0 Description of Tests

2.1 Test Specimens

Four different groups of plywood subflooring were tested. Two groups consisted of a single sheet of plywood and two groups of a sheet of plywood overlayed with a sheet of underlayment (see glossary). To examine the effect of discontinuous edges of subflooring on the impact strength, the specimens with underlayment had both spliced sheets as well as full continuous sheets of plywood. Figure 1 illustrates the layout of the test specimens and table 1 gives a description of the specimens and the number of tests for each group.

All materials were typical of those presently used in conventional wood-frame house construction and were purchased from building material suppliers in the Washington, D. C. area. The plywood used for the specimens had five piles and met the Federal Product Standard PS 1-66 for soft plywood [3]. Designations used to describe grades of the plywood used in this test program are given in the appendix. The hardboard underlayment satisfied the Federal Specification LLL-B-810a [4].

All specimens were constructed in accordance with the provisions in FHA "Minimum Property Standards" (FHA-MPS) Sections 817.3 and 815.4 [5]. As shown in table 1, groups 1, 2, 3a and 4a specimens were constructed using full-size (4 ft x 8 ft) sheets nailed on a frame made of 2 x 8[2/] wood members. For group 3b and 4b specimens, a full-size sheet of plywood was first split into two halves of 2 ft x 8 ft and then nailed on the frame. A full-size (4 ft x 8 ft) sheet of underlayment was nailed on top of the plywood for all group 3 and 4 specimens.

As specified in FHA-MPS, 8d common nails were used for nailing the plywood. Six-inch spacing was used for interior and 10-in spacing for exterior joists. The underlayments were nailed directly on the plywood using 4d annular-threaded nails spaced 6 inches on center in each perpendicular direction.

For all test specimens, 2 x 8 joists were spaced at 16 inches on center, thus providing 6 equally spaced test panels (see fig. 1). The joists were end-nailed to the 2 x 8 edge members. The plywood sheet was oriented with the grain of the outer ply perpendicular to the axis of the joists.

The letter designations A, B, C, and D shown in figure 1 indicate the test panels of each specimen on which the test load was applied. In all cases, tests were made on panels A and B first. If the test on these two

[2/] 2 x 8 is designation in nominal dimensions of wood joist whose actual cross-sectional dimensions are 1-1/2 in by 7-1/2 in.

panels produced damage to either the plywood subflooring or the underlayment, the specimen was discarded. On the other hand, if no damage to the specimen was observed, additional tests were made on panels C and D.

2.2 Test Setup

The test setup was essentially the same as the one described in ASTM E-72 [6] and is shown in figure 2. However, the test panel assembly was placed directly on the floor of the laboratory instead of placing it on steel roller supports as described in the ASTM test. This support condition minimized flexing action of the joist, thus providing a rigid support condition for impact loading. This also created a more severe test than if the joists were allowed to respond in flexure and hence, corresponded to a more critical situation in actual floors. The material and size of the 60-lb sandbag shown in figure 3 conformed to the specifications of ASTM E-72. The bag was dropped from a release-mechanism as shown.

The setup for the concentrated load test is shown in figure 4. The test load was applied by a single-acting hydraulic ram of 20,000-lb capacity. The load applied at a rate of one lb/sec and was monitored by a load cell of 500-lb capacity. All deformations under the concentrated load were measured using a rig shown in figure 5. The rig consisted of a 16-in long reference beam that spanned between two adjacent joists and a dial gage graduated to read 0.001 inch.

2.3 Test Procedure

Each group of the specimens described in table 1 was tested following two different test procedures. Part of the specimens of each group were tested under impact load only and the remaining specimens were subjected to both impact load and the static load of 400 lb. The significance of the static load test was described in section 1.3. The number of tests conducted under each test procedure for each group of specimens is given in table 2.

For the specimens that were subjected only to impact load, residual deflection was measured at the center of the impacted area. The magnitude of impact, as defined by the product of the weight of the bag and the height of drop, was increased in increments of either 60 ft-lb or 120 ft-lb until breaking and/or splintering of the plywood subfloor was noted at the underside. For group 1 specimens, the test started from 60 ft-lb load and for other groups the test started from 120 ft-lb load. After the bag was removed from the specimen, residual deflections were measured on the top with respect to the top surface of test specimen as shown in figure 3.

Impact was repeated on a panel as long as distress was not observed anywhere in that panel. It should be pointed out that this procedure assumes that, as long as no breakings or splinterings are observed, the previous impact loads would not have damaged the test panel for the subsequent test, provided that the magnitude of the loads in the preceding tests were less than the subsequent test. This assumption is reasonable as it will be shown subsequently that no statistically significant difference was observed in residual deflections between those from successive impact load tests on the same test panel and those from single impact load tests where each increment of impact load was applied on a new test panel.

For those specimens which were subject to impact and the 400-lb static load, the following procedure was used. Prior to any load application, a reference deflection, designated as d1, was taken with the device shown in figure 5. Next, a concentrated load of 400 lb was applied. After maintaining the load for one minute, a deflection reading, designated as d2, was taken while the load being applied on the top surface. After unloading and waiting for five minutes the top surface deflection, designated as d3, was again measured. The concentrated load was again applied, and maintained for one minute, and then the deflection, designated as d4, was measured under the load. The purpose of applying two cycles of loading was to minimize the indentation produced by the concentrated load. The deflection at the beginning of the second load cycle, d3, was used as a datum for all subsequent deflection measurements. Following the two static loading cycles, an impact load was applied on the same area which had received two cycles of static loading.

Deflections were measured before and after the impact, designated as d5 and d6, respectively, with the device shown in figure 3. The static load of 400 lb was again applied. As before, deflection measurements were taken before loading, while the load was being applied on the test panel and after unloading. They are designated as d7, d8 and d9, respectively. Subsequent impact loading was applied in increments of either 60 or 120 ft-lb. The deflection measurements d5 and d6 were taken with each application of impact load. Immediately following each application of impact load, the concentrated load of 400 lb was applied, and the deflection measurements d7, d8 and d9 were taken. This sequence was repeated until damage to the test panel was noted.

2.4 Single versus Successive-Impact Tests

Under the previously described scheme of testing, it was considered desirable to show that successive impact loading would not cause substantial cumulative damage to the subflooring. In order to verify this, two series of tests were performed on group 2 specimens. In one series of tests impact load was applied successively on the same panel until it broke. In another series of tests, each impact load was applied on a separate panel. The magnitude of impact load was increased and the residual deflections were measured after impact load in both series.

The residual deflection measurements of the two series of tests are compared at 360 ft-lb, 420 ft-lb, and 480 ft-lb levels in table 3. The measurements of single-impact tests are listed under column A and the measurements of successive-impact tests under column B.

A two-sided statistical t-test was made to determine whether or not the averages of residual deflections of the two schemes differed significantly. It is necessarily assumed that the variances of the residual deflection measurements of the two schemes are not known and are not equal; and hence, the means are not equal. The t-test procedure is described in reference 7. The statistical quantities computed at a five-percent significance level corresponding to the 360 ft-lb, 420 ft-lb, and 480 ft-lb levels are given in table 4.

In comparing the means from each of the two testing schemes, a hypothesis is set up such that it is possible to discredit it from the facts. The hypothesis, in this case, is that the two sample means may be regarded as means of samples from the same population. The hypothesis is examined by testing whether the difference between the two means, $\overline{X}_A - \overline{X}_B$, is significant.

The computed statistics are compared with the absolute difference between the two means in the last row of table 4. It is seen here that, in all three levels of impact energy, the computed statistic, u, is greater than the actual difference between the mean from the single-impact tests and the mean from the successive-impact tests. The conclusion is that the hypothesis is true, i.e., the two schemes of testing do not differ significantly.

3. Test Results and Discussions

3.1 Deflection From Concentrated Static Load Prior to Impact Loading

As described previously in section 2.3, two cycles of a static concentrated load of 400 lb were applied to the test panel prior to impact loading. Static deflections from the second cycle of loading, d4, are given in table 5. It is seen that deflection measurements are reasonably consistent even though there were noted a number of defects such as knotholes and bore holes in the plywoods used in the specimens. The ranges of the deflection for each group are depicted in figure 6. They varied from 0.017 in for group 2 specimens to 0.060 in for group 1 specimens. A large range of variation of data for the group 1 specimens is reasonable because of the use of A-D grade plywood.

Average values of deflections show that a single layer subflooring of 5/8-in C-C plywood (group 2) deflected about 30 percent less than the subfloors which had 1/2-in C-D plywood with either 1/4-in A-A plywood or 1/4-in hardboard underlayment (groups 3a and 4a, respectively). It is also apparent that the specimens which had discontinuous plywood subflooring (groups 3b and 4b) showed approximately 1.5 times average deflections of the specimens which had continuous subflooring (groups 3a and 4a). These results suggest that discontinuous edges in plywood subflooring may lead to excessive deflections.

3.2 Impact Load Versus Floor Deflection from Concentrated Static Load

Figures 7 through 12 show a plot of static deflections against impact energy for each group of specimens. The deflections plotted were measured under a concentrated load of 400 lb which was applied after each impact load. In the figures the ordinate is the potential energy of the bag and the abscissa is the deflection d8 for each level of impact energy as described in section 2.3. It should be noted that the deflection d4 was used at zero impact energy. Thus, the offset from the origin of each figure indicates the amount of static deflection produced by the second cycle of the 400-lb load applied on a 5/8-in disc prior to impact loading.

In each figure, the mean of the test points at each impact energy level is shown as an open circle. The means for each group of specimens are given in table 6. Because there were an inadequate number of test panels of the group 1 and 3a specimens that sustained 600 ft-lb impact, the mean of these groups at this level was not determined. Most specimens of these groups were damage at this level of impact to such an extent that the deflection measurements were not possible.

For ease of comparison, the average deflections given in table 6 are plotted in figure 13. The initial position of each curve indicates relative stiffness of the subflooring from the concentrated load of 400 lb applied prior to impact loading. Except for groups 1 and 3b specimens, the static deflection from the 400-lb concentrated load increased linearly with increasing impact energy up to about 360 ft-lb. Above this level the group 2 specimens began to show increasing deformation and the remaining three groups of specimens remained linear up to 600 ft-lb. It is interesting to note that there is little difference in the deflection resistance of two different kinds of underlayment used in this study; namely, 1/4-in A-A plywood or 1/4-in hardboard in combination with 1/2-in C-D plywood. However, for subflooring which had a discontinuous edge under the impact area, the 1/4-in hardboard underlayment showed greater deflection resistance than the 1/4-in A-A plywood underlayment.

A limiting level of impact energy could be obtained from figure 13 for a specific floor system provided that an acceptable deflection limit under the 400-lb concentrated load is established. At present, no such limit is found in the design specifications and standards used in the U.S. Based on results of tests conducted on 1/2-inch plywood subfloors with wood joists spaced at 16 inches o.c., the Canadian National Building Code - CAS 0152 [8] has a requirement for a maximum deflection limit for plywood subfloors. The deflection limit is 1/180 of the span under a static concentrated load of 175 lb. An extrapolated value of the deflection of 1/2-inch plywood subfloor supported at 16 inches o.c. under a 400-lb concentrated load is about 0.2 inch. If this value is taken as a maximum allowable deflection, figure 13 gives a limiting impact energy for group 1, group 4a, group 3a and group 2 specimens of about 60, 300, 360 and 520 ft-lb, respectively. Thus, if an expected maximum impact energy in dwelling is known, from a figure such as this, a practical choice of subflooring can be made for a limiting deflection.

4. Conclusions

4.1 Conclusions

An investigation was conducted to determine the effect of impact load on the static deflection resistance of plywood subfloors nailed to wood joists. The following conclusions are based on the results of this investigation:

1. The plywood subfloors tested showed that deflection resistance under a concentrated load of 400 lb decreased gradually as impact energy increased. Except for group 1 and group 3b specimens, the increase in the deflection under the concentrated load with increase in the impact energy remained linear up to an impact energy level of 360 ft-lb. For group 3a, 4a and 4b specimens, the linearity extended up to 600 ft-lb. Groups 3a and 4a specimens showed about the same rate of increase in deflection.

2. It was shown that a limiting impact energy for the floor could be obtained from a relationship between impact energy and static deflection under a concentrated load applied to the impacted area. However, an acceptable limit of the static deflection under the concentrated load needs to be established prior to obtaining such a limiting value of impact energy from the relationship.

3. Static deflections from a static concentrated load of 400 lb applied after impact loading indicate that increasing the thickness of plywood subflooring is more effective in increasing the deflection resistance of the subfloor than adding a layer of underlayment over the subfloor for about the same total thickness of subflooring. It was shown that the average deflection of a single layer 5/8-inch C-C plywood subfloor was about 30 percent less than that of the subfloor comprised of 1/2-inch C-D plywood with 1/4-inch A-A plywood or 1/4-inch hardboard underlayment.

4. It was shown that for the specimens which had a layer of underlayment over the subflooring, the subflooring with discontinuous edge of plywood deflected approximately 1.5 times the subflooring with continuous sheet of plywood.

5. Acknowledgements

The tests reported herein were performed by Mr. James Seiler, engineering technician of the Structures Laboratory and Mr. Bruce Bean, a graduate student at University of New Hampshire, who was a student summer worker in 1971. Mr. Bean also analyzed the test data. The author wishes to thank them for their contributions to this investigation.

Constructive criticisms of Dr. Robert Crist, Assistant Chief of Structures Section and careful review of the report by Dr. Norman F. Somes, Chief of the Structures Section are gratefully acknowledged.

6. Tables and Figures

TABLE 1. Description of Test Specimens

Group		Component of Specimens	No. of Tests
1		1/2 in. A-D INT, Group 1*	56
2		5/8 in. Underlayment C-C Plugged	44
3	a	1/2 in. C-D Plugged INT with 1/4 in. A-A Underlayment	25
	b+	1/2 in. C-D Plugged INT with 1/4 in. A-A Underlayment	28
4	a	1/2 in. C-D Plugged INT with 1/4 in. Hardboard Underlayment	36
	b+	1/2 in. C-D Plugged INT Split with 1/4 in. Hardboard Under-layment.	28

*For designations of plywood, refer to Appendix.

+These specimens had splitted sheets of plywood panel thus providing discontinuous edge at the center of test panel.

TABLE 2 Distribution of Tests

Group	Impact Test Only	Impact & Static-Load Test	Total No. of Tests
1	46	10	56
2	36	8	44
3a	18	7	25
3b	22	6	28
4a	30	6	36
4b	24	4	28

TABLE 3 Single and Successive Drop Test Data for Group 2 Specimens

No. of Tests	Residual Deflection (in)					
	360 ft-lb*		420 ft-lb*		480 ft-lb*	
	A	B	A	B	A	B
1	0.003	0.008	0.011	0.004	0.012	0.014
2	0.004	0.008	0.013	0.007	0.022	0.016
3	0.005	0.010	0.018	0.009	0.026	0.018
4	0.005		0.020	0.018	0.027	0.022
5	0.005		0.036	0.024		0.024
6	0.011		0.040	0.054		0.031
7	0.011					0.034
8	0.012					0.055
9	0.016					
10	0.019					
11	0.029					

A = Single Drop Test on different test panel
B = Successive Drop Test on the same test panel
* = 60 lb bag x height of Drop

Note: Data have been rearranged for convenience of comparison in increasing order of residual deflection.

TABLE 4 Two-Side t-Tests*

Statistical Measures	Impact Energy					
	360 ft-lb		420 ft-lb		480 ft-lb	
	B	A	B	A	B	A
$\overline{X}$	0.0087	0.0109	0.0193	0.0230	0.0268	0.0218
s^2	1.33×10^{-6}	63.49×10^{-6}	34.49×10^{-5}	14.72×10^{-5}	17.91×10^{-5}	4.69×10^{-5}
V	4.44×10^{-7}	57.71×10^{-7}	57.31×10^{-6}	24.53×10^{-6}	22.38×10^{-6}	11.73×10^{-6}
f	13		10		12	
u	0.0054		0.0201		0.0127	
$\lvert\overline{X}_A-\overline{X}_B\rvert$	0.0046		0.0037		0.0050	
Conclusion	$u > \lvert\overline{X}_A-\overline{X}_B\rvert$ A and B do not differ		$u > \lvert\overline{X}_A-\overline{X}_B\rvert$ A and B do not differ		$u > \lvert\overline{X}_A-\overline{X}_B\rvert$ A and B do not differ	

*: $\alpha = 0.05$ (level of significance)

$\overline{X}$: Sample mean

s^2: Sample estimate of variance

V: Unbiased estimate of the true variance of sample mean

f: degree of freedom

A: Single-drop test

B: Successive-drop test

u: $t_{1-\alpha/2} \times S_D$

t: Student's Distribution

S_D: Estimated Standard Error of the Difference Between Two Means

TABLE 5 Initial Static Deflection Under 400 lb

No. of Test	Static Deflection (in)					
	Group 1	Group 2	Group 3a	Group 3b	Group 4a	Group 4b
1	0.162	0.089	0.154	0.248	0.151	0.210
2	0.167	0.110	0.158	0.251	0.150	0.217
3	0.170	0.100	0.153	0.242	0.151	0.201
4	0.191	0.102	0.158	0.234	0.164	0.205
5	0.222	0.102	0.157	0.205	0.149	
6	0.193	0.099	0.154	0.200	0.129	
7	0.192	0.109	0.139			
8	0.168	0.117				
9	0.199	0.114				
10	0.200	0.108				
Avg.	0.186	0.104	0.153	0.230	0.149	0.208

TABLE 6 Mean Deflections Under 400-lb Static Load

Impact Energy (ft-lb)	Static Deflection (in.)					
	Group 1	Group 2	Group 3a	Group 3b	Group 4a	Group 4b
0	0.186	0.104	0.153	0.230	0.149	0.208
60	0.193					
120	0.212	0.111	0.161	0.254	0.161	0.227
180	0.240					
240	0.304	0.117	0.174	0.294	0.186	0.262
300	0.331					
360	0.363	0.132	0.198	0.363	0.210	0.244
480	0.442	0.170	0.222	0.416	0.228	0.318
600	---	0.245	0.251	---	0.247	0.347

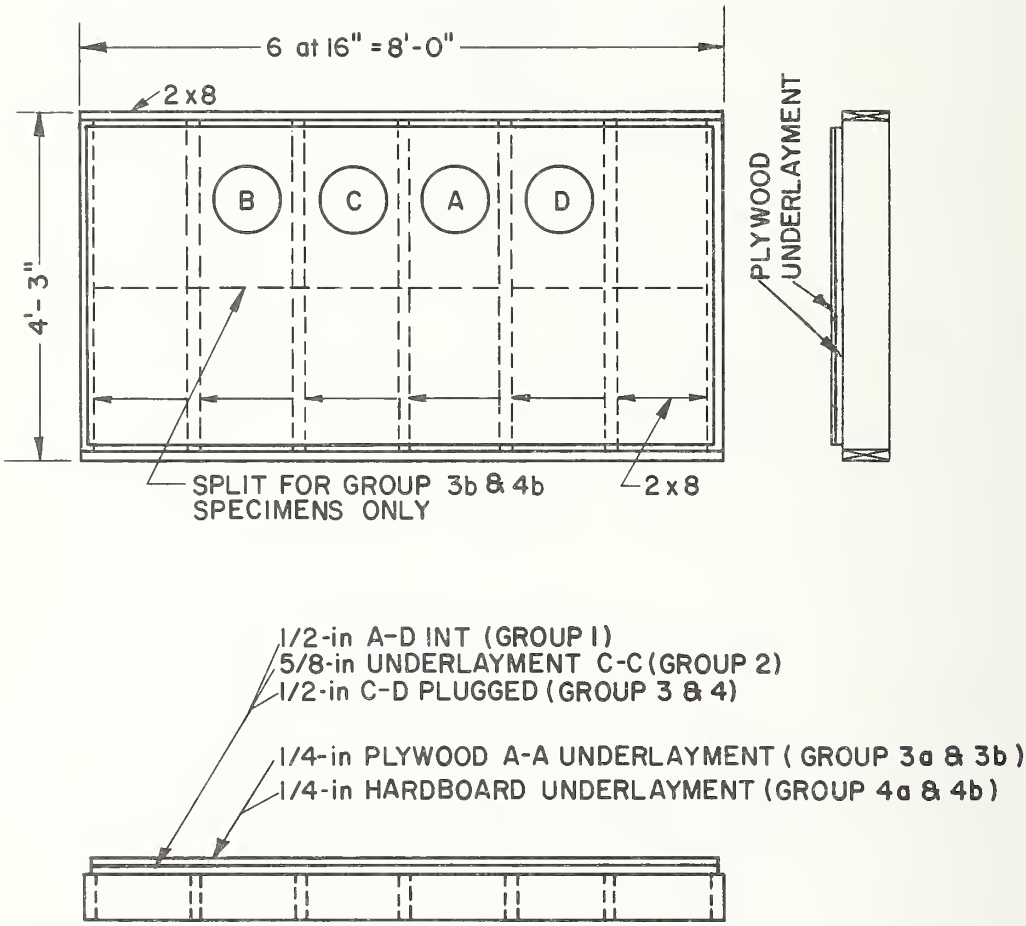

FIGURE 1 Test Specimen

FIGURE 2 Impact Test Setup

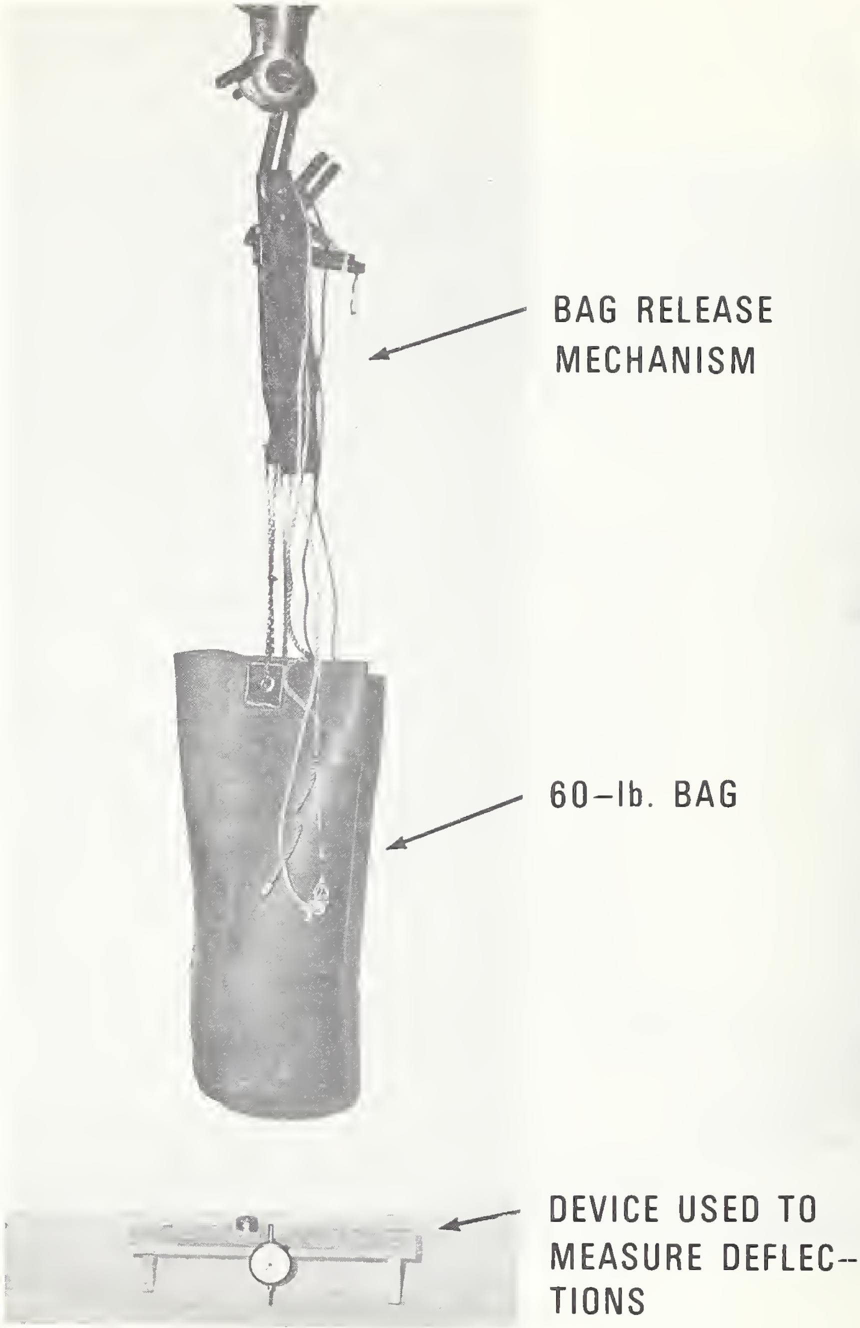

FIGURE 3 60-lb Sandbag, Bag Release Mechanism and Device Used to Measure Deflections

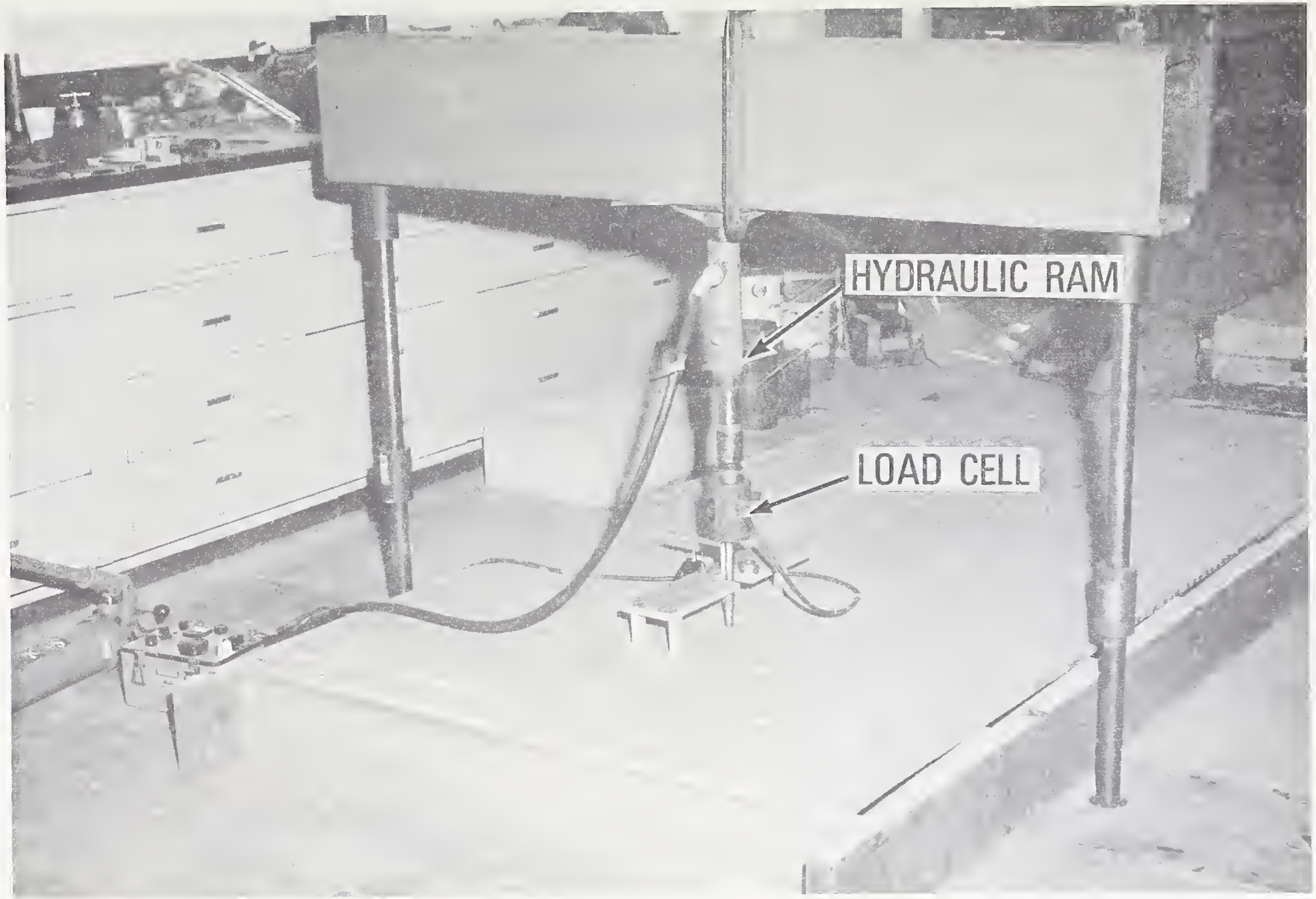

FIGURE 4 Concentrated Load Test Setup

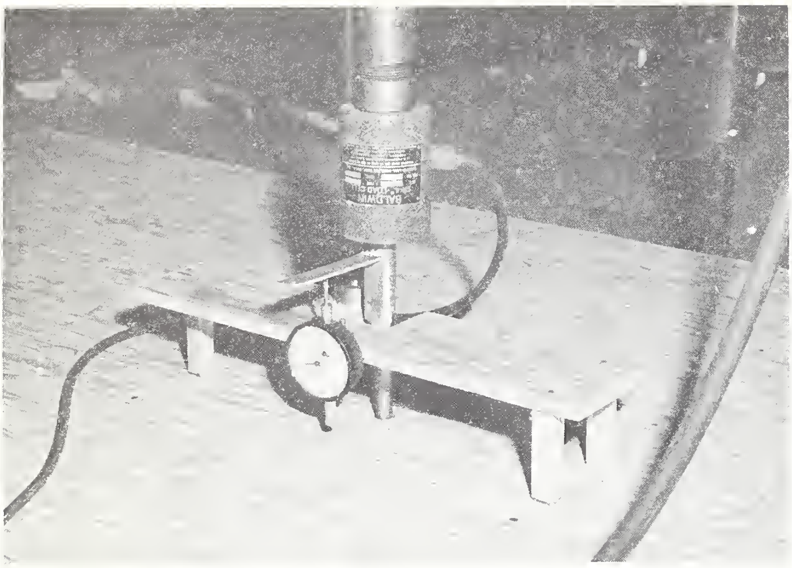

FIGURE 5 Rig Used for Deflection Measurements in Static Tests

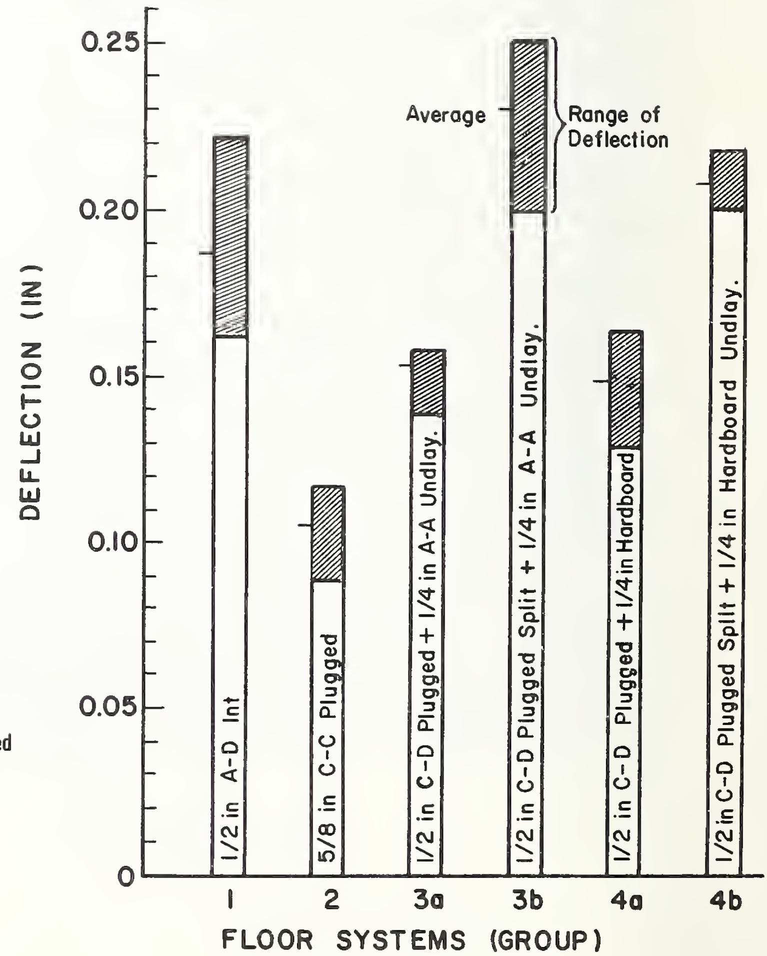

FIGURE 6 Range of Static Deflection Measured Prior to Impact Loading

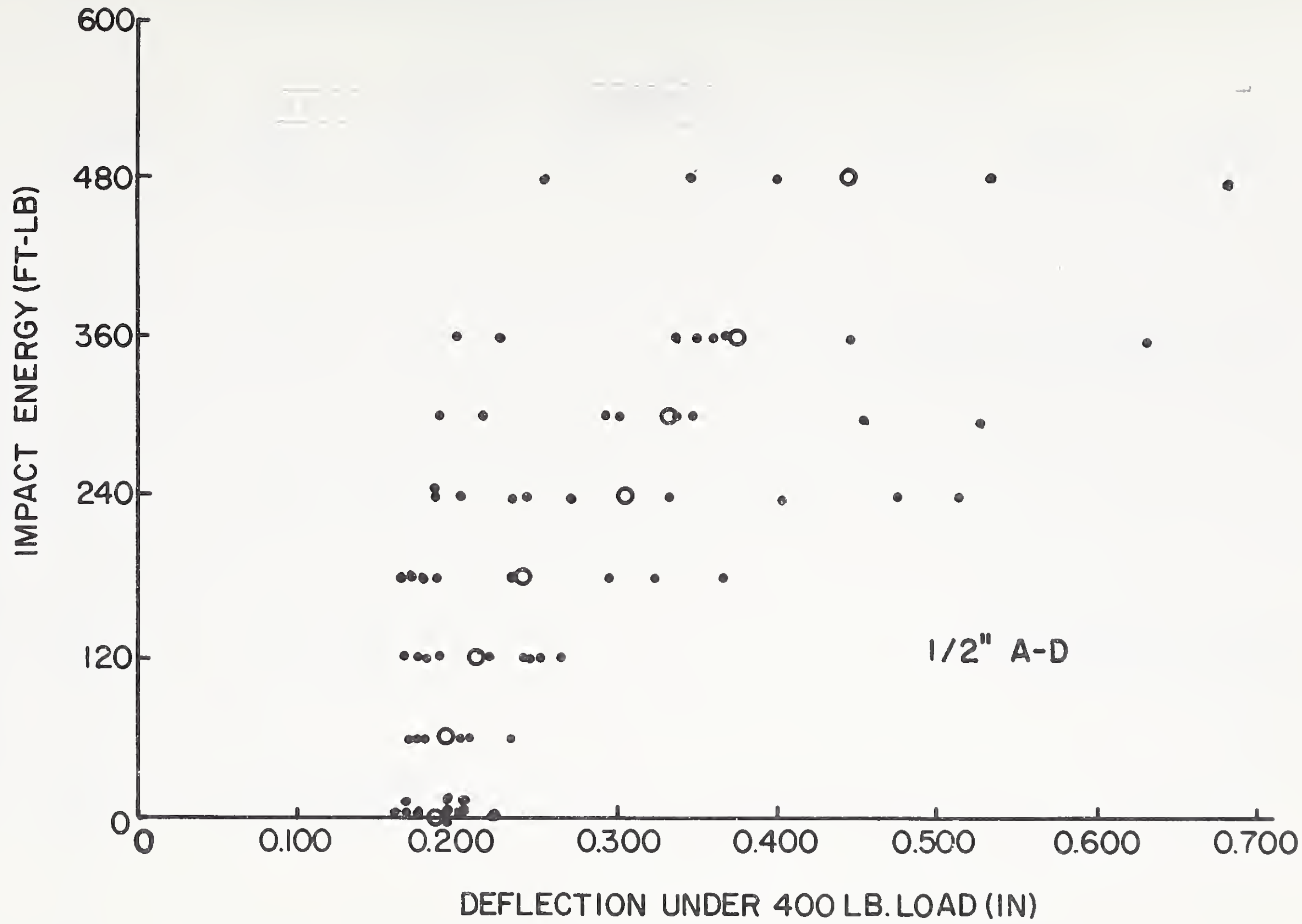

FIGURE 7 Deflection from 400 lb Concentrated Load vs Impact Energy-Group 1 Specimens

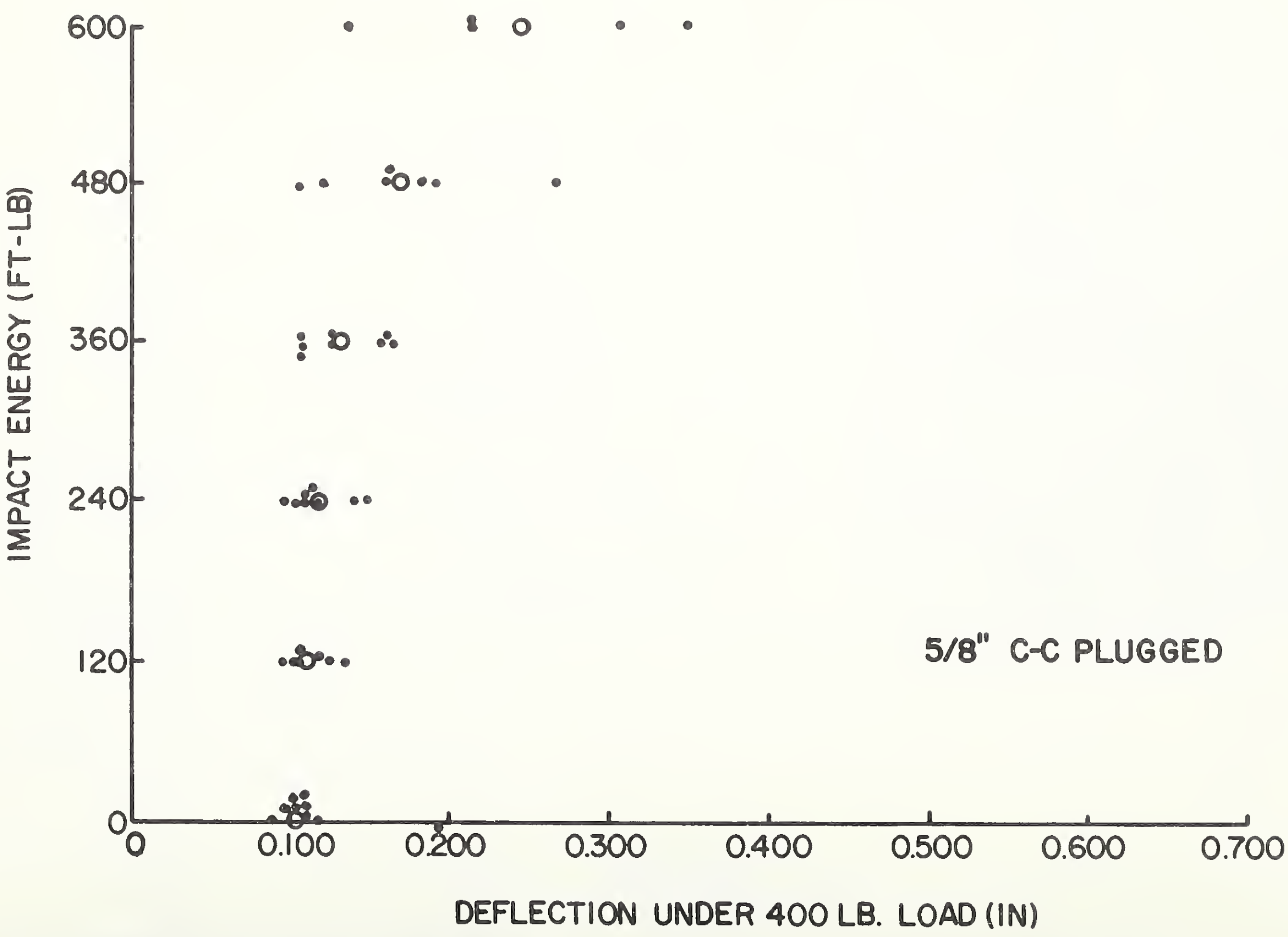

FIGURE 8 Deflection from 400 lb Concentrated Load vs Impact Energy–Group 2 Specimens

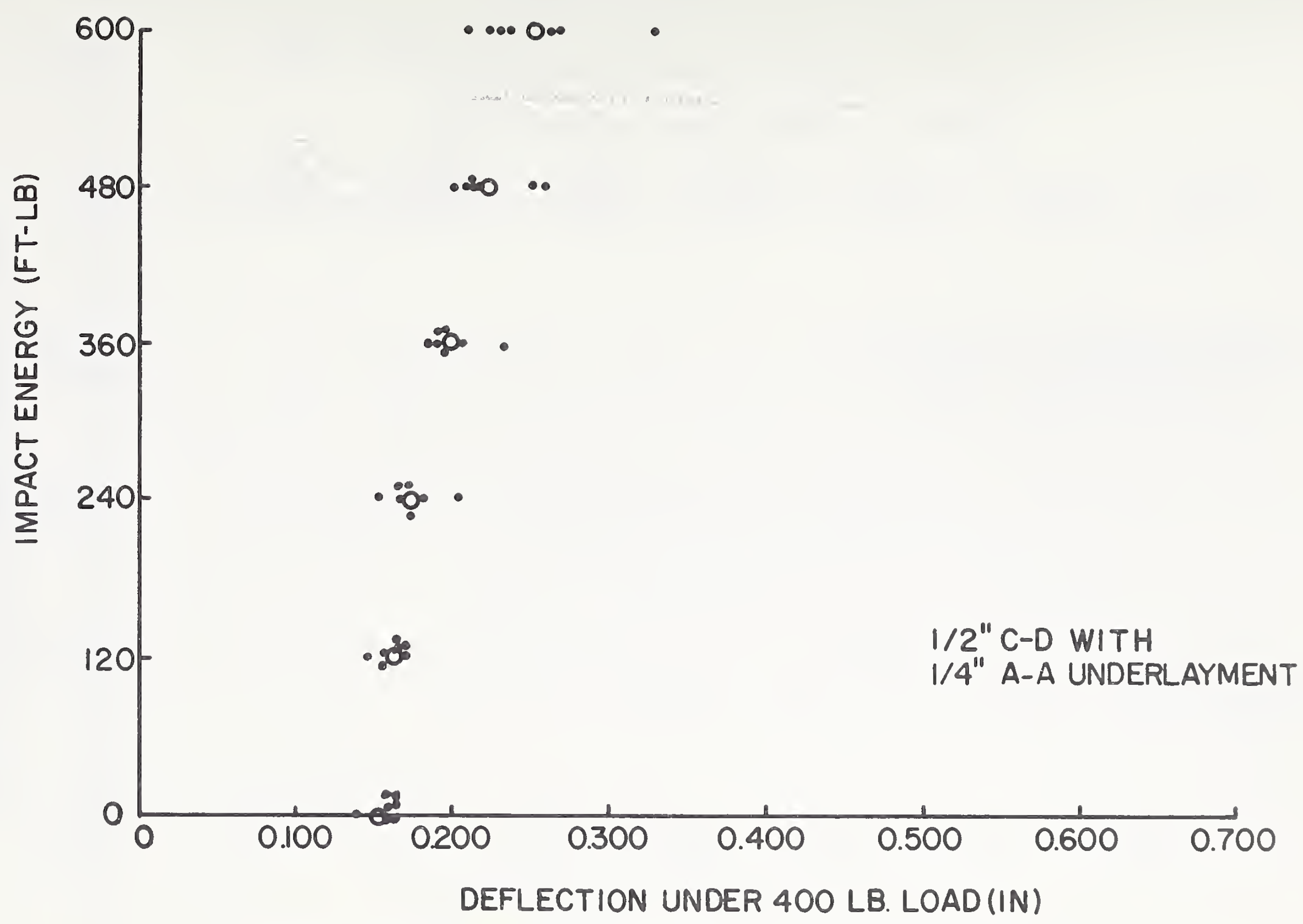

FIGURE 9 Deflection from 400 lb Concentrated Load vs Impact Energy – Group 3a Specimens

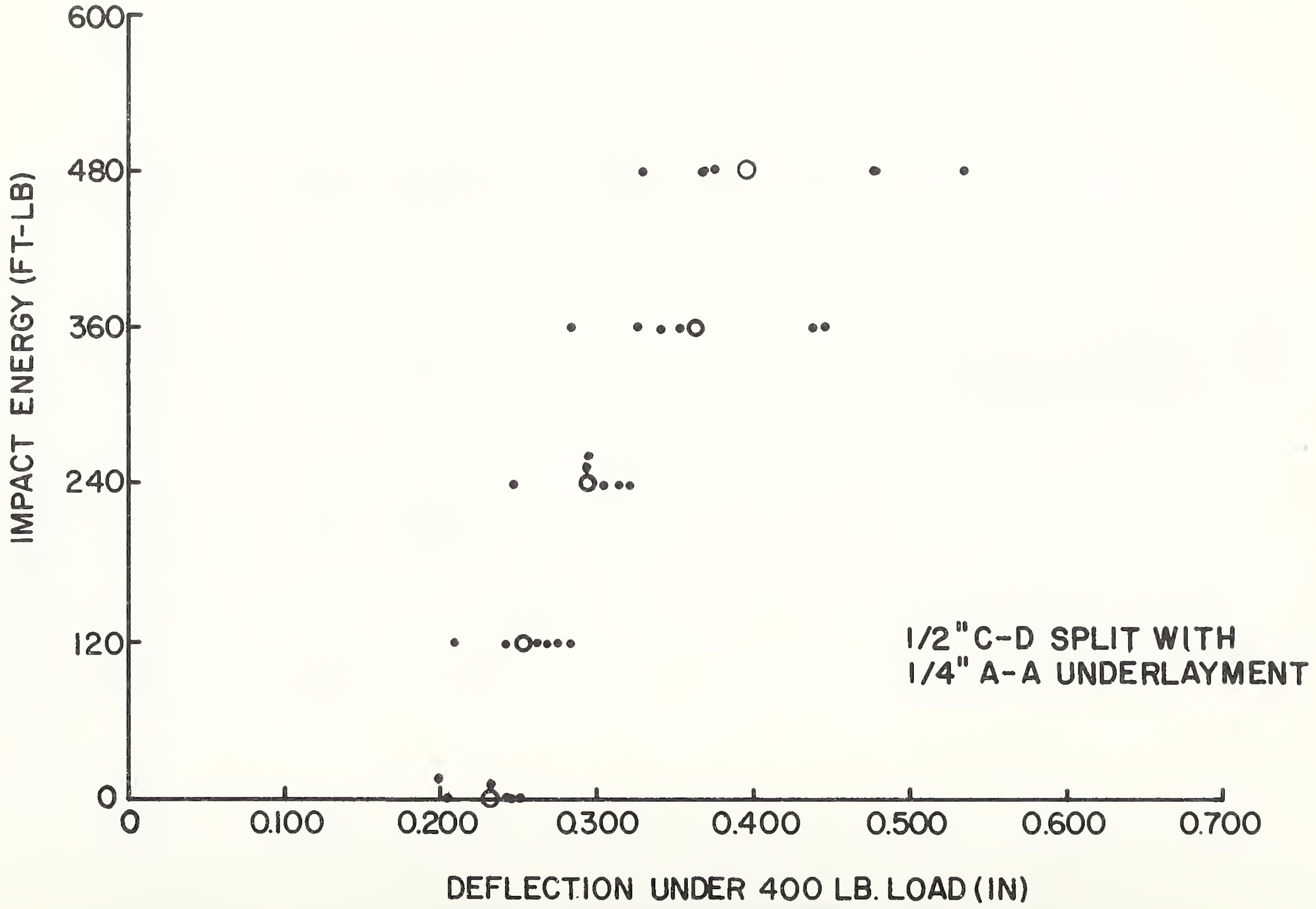

FIGURE 10 Deflections from 400 lb Concentrated Load vs Impact Energy - Group 3b Specimens

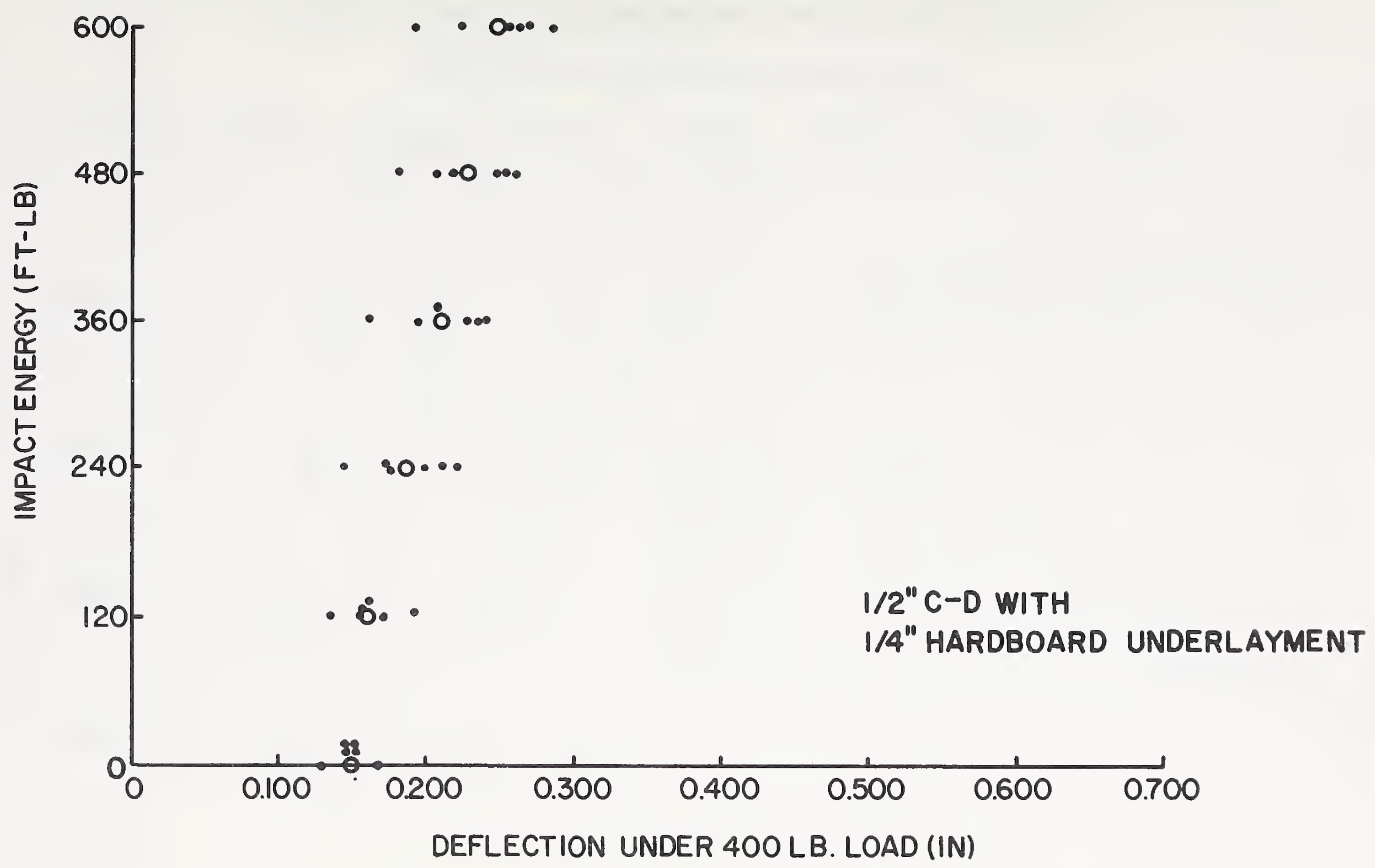

FIGURE 11 Deflection from 400 lb Concentrated Load vs Impact Energy—Group 4a Specimens

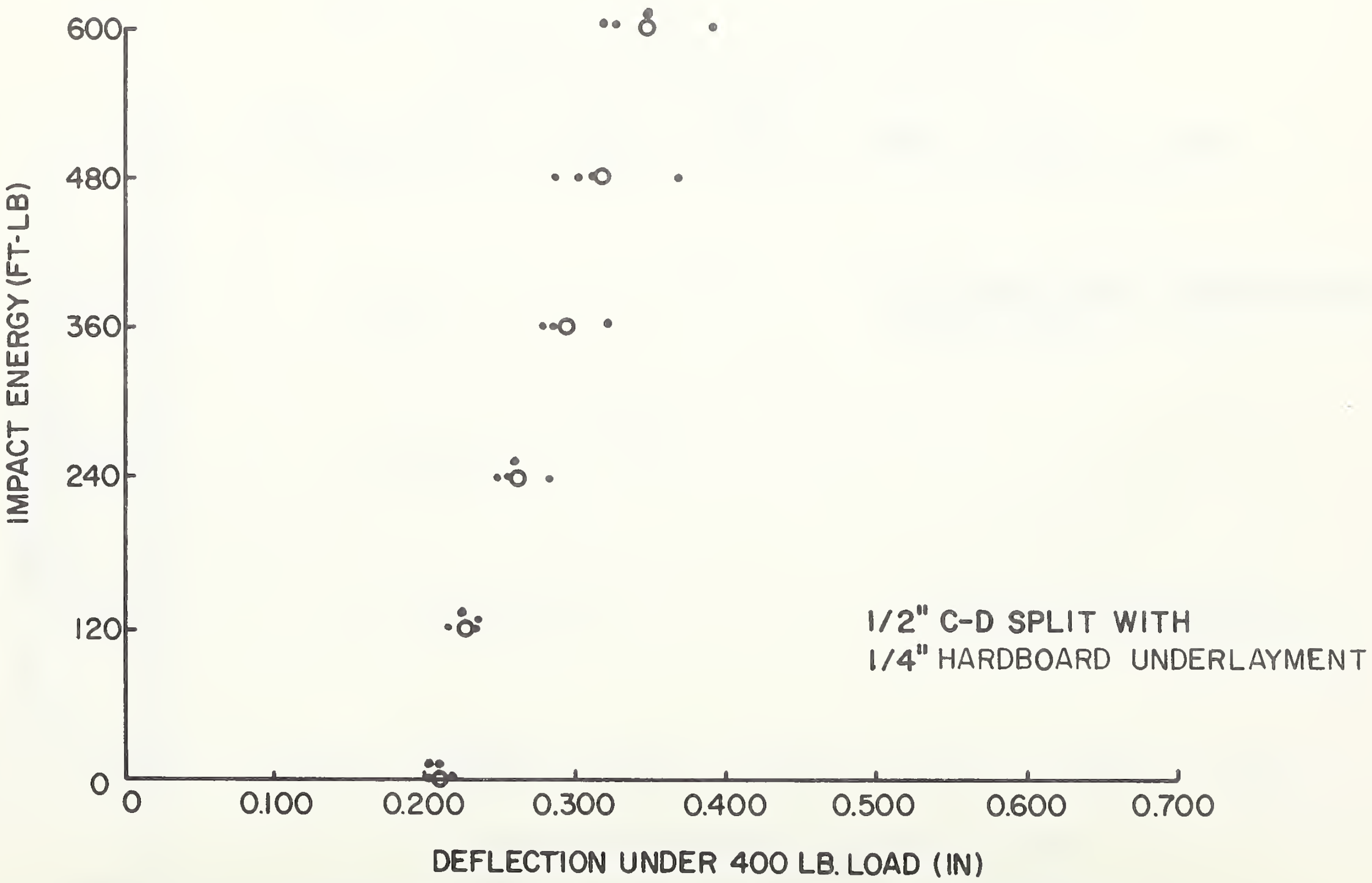

FIGURE 12 Deflections from 400 lb Concentrated Load vs Impact Energy – Group 4b Specimens

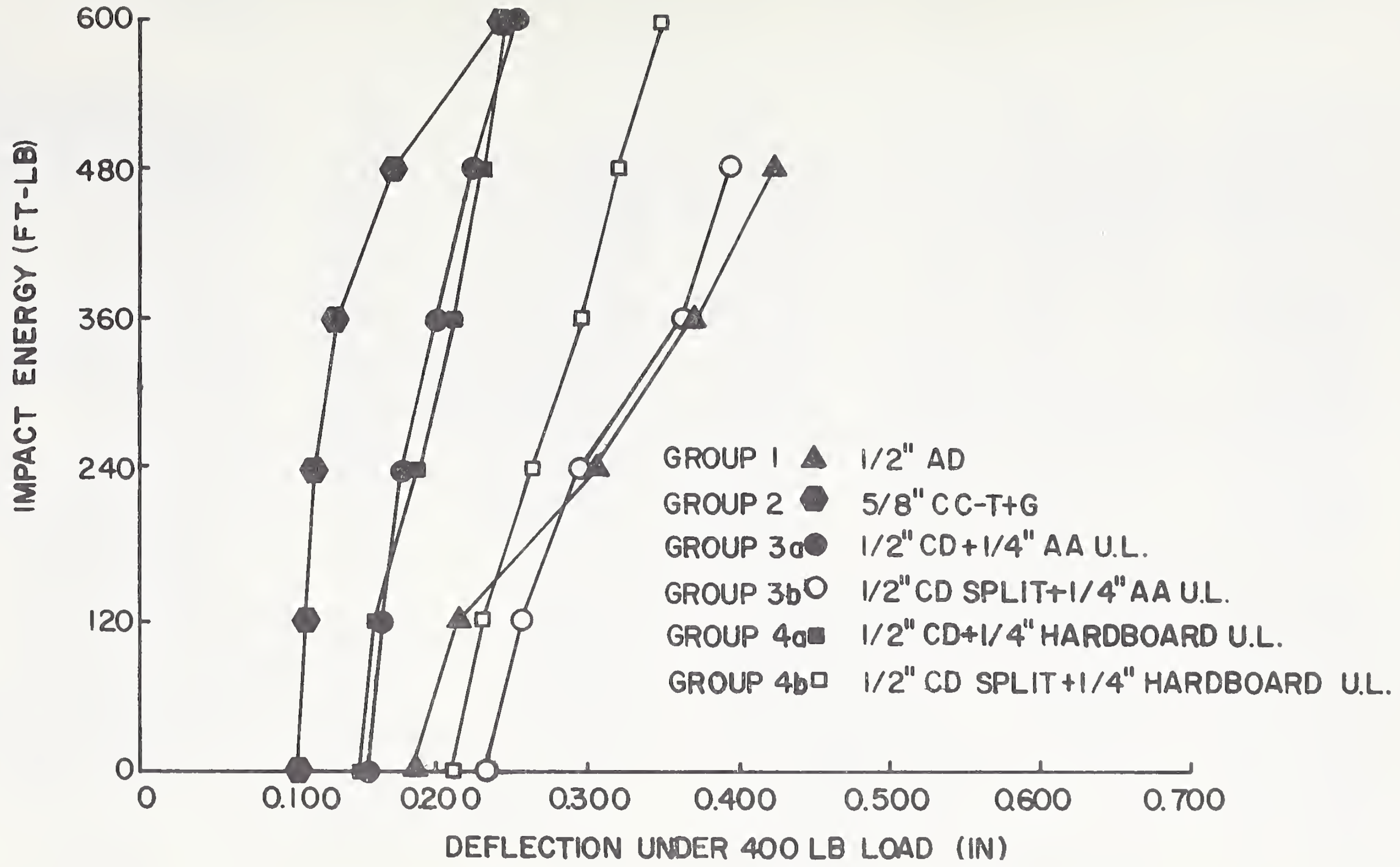

FIGURE 13 Average Deflections from 400 lb Concentrated Load Applied After Impact vs Impact Energy

7. Appendix

For reference, the following tables and grade descriptions for veneers are reproduced from NBS Voluntary Product Standard PS 1-66 "Softwood Plywood, Construction and Industrial" and from a publication of the American Plywood Association.

Interior Type Grades

Panel Grade Designations	Minimum Veneer Quality Face	Back	Inner Plys	Surface
N-N[1]	N	N	C	Sanded 2 sides
N-A[1]	N	A	C	Sanded 2 sides
N-B[1]	N	B	C	Sanded 2 sides
N-D[2]	N	D	D	Sanded 2 sides
A-A	A	A	D	Sanded 2 sides
A-B	A	B	D	Sanded 2 sides
A-D	A	D	D	Sanded 2 sides
B-B	B	B	D	Sanded 2 sides
B-D	B	D	D	Sanded 2 sides
Underlayment	C (Plugged)	D	C[3] & D	Sanded or touch-sanded as specified
C-D (Plugged)	C (Plugged)	D	D	Unsanded or touch-sanded as specified
STRUCTURAL		See Paragraph 3.4.4		Unsanded grade[4]
STANDARD	C	D	D	Unsanded grade[4]
STANDARD WITH EXTERIOR GLUE (See para. 3.4.5)	C	D	D	Unsanded grade[4]

(1) Natural finish items intended primarily for cabinet work. Available generally only in 3/4" thickness and only from certain mills.

(2) Natural finish item, intended primarily for paneling and wainscoting. Available generally only in 1/4" thickness and only from certain mills.

(3) Veneer immediately adjacent to face shall be C or better.

(4) Panels shall not be sanded, touch-sanded, or thickness sized by any mechanical means.

Exterior Type Grades[1]

Panel Grade Designations	Minimum Veneer Quality Face[2]	Back[2]	Inner Plys	Surface
Marine		See paragraph 3.4.1		
Special Exterior		See paragraph 3.4.6		
A-A	A	A	C	Sanded 2 sides
A-B	A	B	C	Sanded 2 sides
A-C	A	C	C	Sanded 2 sides
B-B (Concrete Form)		See paragraph 3.4.3		
B-B	B	B	C	Sanded 2 sides
B-C	B	C	C	Sanded 2 sides
C-C (Plugged)	C (Plugged)	C	C	Sanded or touch-sanded as specified
C-C	C	C	C	Unsanded grade[3]
A-A High Density Overlay	A	A	C (Plugged)	———
B-B High Density Overlay	B	B	C (Plugged)	———
B-B High Density Concrete Form Overlay (See para. 3.4.3)	B	B	C (Plugged)	———
B-B Medium Density Overlay	B	B	C or C (Plugged) as specified	———
Special Overlays	C	C	C	———

(1) Available also in STRUCTURAL I classification as provided in paragraph 3.4.4.

(2) For overlaid plywood, the grade designation for face and back refers to the veneer directly underlying the surface. All overlaid plywood is overlaid on two sides unless otherwise specified. When only one side is surfaced, the exposed back shall be C or better.

(3) Panels shall not be sanded, touch-sanded or thickness sized by any mechanical means.

Classification of Species

Group 1	Group 2		Group 3	Group 4	Group 5
Birch Yellow Sweet Douglas Fir 1 Larch, Western Maple, Sugar Pine, Caribbean Pine, Southern Loblolly Longleaf Shortleaf Slash Tanoak	Cedar, Port Orford Douglas Fir 2 Fir California Red Grand Noble Pacific Silver White Hemlock, Western Lauan Red Tangile White Almon Bagtikan	Maple, Black Meranti Mengkulang Pine Pond Red Western white Spruce, Sitka Sweet Gum Tamarack	Alder, Red Cedar Alaska Pine Jack Lodgepole Ponderosa Spruce Redwood Spruce Black Red White	Aspen Bigtooth Quaking Birch, Paper Cedar Incense Western Red Fir, Subalpine Hemlock, Eastern Pine Sugar Eastern White *Poplar, Western Spruce, Engelmann	Fir, Balsam Poplar, Balsam

* Black Cottonwood

Veneer grades used in plywood

Veneer Grade	Limiting Characteristics	
N Intended for Natural Finish	Presents smooth surface. Veneer shall be all heartwood or all sapwood free from knots, knotholes, open splits, pitch pockets, other open defects, and stain, but may contain pitch streaks averaging not more than 3/8" wide blending with color of wood. If joined, not more than two pieces in 48" width; not more than three pieces in wider panels. Joints parallel to panel edges and well-matched for color and grain. Repairs shall be neatly made, well-matched for color and grain, and limited to a total of six in number in any 4' x 8' sheet.	• Maximum of three "router" patches not exceeding 3/4" x 3-1/2" admitted. No overlapping. • Shims admitted not exceeding 12" in length but may occur only at ends of panel. (Examples of permissible combinations: 3 router patches and 3 shims, 2 router patches and 4 shims, 1 router patch and 5 shims, or 6 shims). Suitable synthetic fillers may be used to fill 1/32" wide checks, splits up to 1/16" x 2", and chipped areas or other openings not exceeding 1/8" x 1/4".
A	Presents smooth surface. Admits—Pitch streaks blending with color of wood and averaging not more than 3/8" in width. —Sapwood. —Discolorations. Veneer shall be free from knots, knotholes, splits, pitch pockets and other open defects. If of more than one piece, veneer shall be well joined. Repairs shall be neatly made, parallel to grain, and limited to 18 in number in any 4' x 8' sheet, excluding shims; proportionate limits on other sizes.	Patches of "boat," "router," and "sled" type only, not exceeding 2-1/4" in width, and may be die-cut if edges are cut clean and sharp. Radius of ends of boat patches shall not exceed 1/8". • Multiple patching limited to 2 patches, neither of which may exceed 7" in length if either is wider than 1". • Shims admitted except over or around patches or as multiple repairs. Suitable synthetic fillers may be used to fill 1/32" wide checks, splits up to 1/16" x 2", and chipped areas or other openings not exceeding 1/8" x 1/4".
B	Presents solid surface. Admits—Knots up to 1" across the grain if both sound and tight. —Pitch streaks averaging not more than 1" in width. —Discolorations. —Slightly rough but not torn grain, minor sanding and patching defects, including sander skips not exceeding 5% of panel area. Veneer shall be free from open defects except for splits not wider than 1/32", vertical holes up to 1/16" in diameter if not exceeding an average of one per square foot in number, and horizontal or surface tunnels up to 1/16" in width and 1" in length not exceeding 12 in number in a 4' x 8' sheet (proportionately on other sizes). Repairs shall be neatly made and may consist of patches, plugs, synthetic plugs and shims.	• Patches may be "boat," "router," and "sled" type not exceeding 3" in width individually when used in multiple repairs or 4" in width when used as single repairs. • Plugs may be "circular," "dog-bone," and "leaf-shaped," not exceeding 3" in width when used in multiple repairs or 4" in width when used as single repairs. • Synthetic plugs shall present a solid, level, hard surface not exceeding above dimensions. Suitable synthetic fillers may be used to fill small splits or openings up to 1/16" x 2", and chipped areas or other openings not exceeding 1/8" x 1/4".
C	Admits—Tight knots up to 1½" across the grain. —Knotholes not larger than 1" across the grain. Also an occasional knothole not more than 1½" measured across the grain, occurring in any section 12" along the grain in which the aggregate width of all knots and knotholes occurring wholly within the section does not exceed 6" in a 48" width, and proportionately for other widths. —Splits ½" by one-half panel length; 3/8" by any panel length if tapering to a point; ¼" maximum where located within 1" of parallel panel edge. —Worm or borer holes up to 5/8" x 1½". —Open pitch pockets not wider than 1".	Repairs shall be neatly made and may consist of patches, plugs, and synthetic plugs. Patches ("boat," including die-cut) not exceeding 3" in width individually when used in multiple repairs or 4" in width when used as single repairs. Plugs may be circular, "dog-bone" and leaf-shaped. Synthetic plugs shall present a solid, level, hard surface not exceeding above dimensions.
C (plugged)	Admits—Knotholes, worm or borer holes, and other open defects up to ¼" x ½". —Sound tight knots up to 1½" across the grain. —Splits up to 1/8" wide.	—Ruptured and torn grain. —Pitch pockets if solid and tight. —Plugs, patches and shims.
D	D veneer used only in Interior type plywood and may contain plugs, patches, shims, worm or borer holes. Backs: Admits tight knots not larger than 2½" measured across the grain and knotholes up to 2½" in maximum dimension. An occasional tight knot larger than 2½" but not larger than 3" measured across the grain or knothole larger than 2½" but not larger than 3" maximum dimension, occurring in any section 12" along the grain in which the aggregate width of all knots and knotholes occurring wholly within the section does not exceed 10" in a 48" width and proportionately for other widths. Inner Plys: Permits tight knots. Knotholes limited as for backs. —In sanded panels, knotholes not larger than 2½" maximum dimension in veneer thicker than 1/8".	—Knotholes not exceeding 3½" maximum dimension in center ply of 5-ply STANDARD and C-D Plugged grades. All Plys: Pitch pockets not exceeding 2½" measured across the grain. Splits up to 1" except in backs only not more than one exceeding ½"; not exceeding ¼" maximum width where located within 1" of parallel panel edge; splits must taper to a point. White pocket in inner plys and backs, not exceeding three of the following characteristics in any combination in any area 24" wide by 12" long. (a) 6" width heavy white pocket. (b) 12" width light white pocket. (c) One knot or knothole or repair 1½" to 2½", or two knots or knotholes or repairs 1" to 1½".

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report presents the results of an experimental study of wood-joist subflooring systems subjected to impact load. Six different types of subflooring systems were tested following the test method described in the ASTM Standard Methods (ASTM Designation E-72). The magnitude of impact load was varied by dropping a 60-lb bag from different heights.

A concentrated static load of 400 lb was applied to the subfloor after it was exposed to impact load. It is suggested that the deflection under this concentrated load be used as a measure of the impact resistance of the subfloor.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Concentrated load; deflection; floor; hardboard; housing; impact energy; Operation BREAKTHROUGH; plywood; subfloors; underlayment; wood; wood joists.

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