NATIONAL BUREAU OF STANDARDS REPORT

10 248

TRANSIENT VIBRATION TESTS ON WOOD-JOIST FLOORS

A Report
Prepared for

Office of Research and Technology
Department of Housing and Urban Development

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Tests were made on wood-joist floors of residential structures to compare the performance of floors of conventionally-built dwelling units under transient vibration with the related criteria given in Guide Criteria for the Design and Evaluation of Operation BREAKTHROUGH Housing Systems. A total of seven dwelling units were tested. Tests were carried out on both furnished and unfurnished floors with an impact load of 75 ft-lb. The impact was induced by dropping a 25-lb bag from 3 feet above the floor.

Deflection traces were recorded and the decay characteristics of the floors were examined. The results indicated that all floors tested easily satisfied the present recommended criterion on transient vibration in the Guide. The performance of the wood-joist floors with respect to human comfort cannot be evaluated against the present state-of-the-art, as the available curves of human response to transient vibration do not seem to be representative of the conditions encountered in this limited experiment.

SI Conversion Units

In view of present accepted practice in the U.S. in this technological area, common U.S. units of measurement have been used throughout this paper. In recognition of the position of the USA as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, the authors assist readers interested in making use of the coherent system of SI units, by giving conversion factors applicable to U.S. units in this paper.

Length	1 in = 0.0254* meter
	1 ft = 0.3048* meter
Force	1 lb (lbf) = 4.448 newton
	1 kip = 4448 newton

*Exactly

1. INTRODUCTION

1.1 Purpose

The purpose of this investigation was to compare the performance of floors of conventionally-built dwelling units under transient vibration with the related criterion in the Guide for the design and evaluation of Operation BREAKTHROUGH Housing Systems (Section A.1.5.1a)(1)[1]. It is stated as follows:

> "Transient vibrations induced by human activities should decay to 0.2 of their initial displacement-amplitude within a time not to exceed 1/2 second."

1.2 Scope

The scope of this investigation was limited to impact tests of wood-joist floors commonly used in dwelling units. Tests were carried out at the site of a Washington D.C. area housing development which included detached houses of large and medium size, attached houses (townhouses) and multidwelling units (apartments).

This test program made no attempt to evaluate numerically the damping characteristics of the floors nor did it include subjective tests to establish human tolerance against transient vibration. However, the test results are

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[1] Numerals in parantheses refer to corresponding items in Reference.

compared with the curves of human response to transient vibration which are available in the literature.

1.3 Previous Work

A survey of literature indicates that while a large number of reports has been published on steady-state vibration and its effect on human comfort, only two investigations have been reported on transient vibration.

The first of these was reported by Reiher and Meister in 1932(4), subsequent to their first report on steady-state vibration (3). The second report was by Lenzen in 1966(2).

Reiher and Meister studied the effect of repeated impact vibrations. Subjective tests were conducted under repeated impact pulses at the rate of from one impact every ten seconds to six impacts per one second. It was found that the human response to impact vibration is a function of: (1) the frequency of impact; (2) the maximum peak-to-peak displacement of the initial cycle; and (3) the rise time (half period of the initial cycle). The results of impact rates of one and six per second are given in figure 1.

Lenzen reported tests on vibration of steel joist-concrete slab floors. He investigated the human response to impact vibration generated both by the dropping of an iron ball and by a man jumping on the floor. It was pointed

out in the Lenzen report that if the floor was damped to a small amplitude prior to five cycles of vibration, only the initial impact was sensed. If, however, the vibration persisted for more than 12 complete cycles, the subjects responded to the vibration as if it were a steady-state vibration. It was suggested that for vibration caused by a single impact the human response curve obtained by Reiher and Meister (3) could be used with the amplitude scale increased by a factor of 10. The selection of this factor of 10 by Lenzen appears to have been arbitrary and the curve so corrected is shown in figure 2.

The results obtained in the experiment reported here will be compared with the foregoing two curves.

2. DESCRIPTION OF TESTS

2.1 Test Program

Seven dwelling units were investigated. Four were detached houses, two were attached houses, and one was an apartment. The houses tested are designated as follows:

	Unfurnished	Furnished
House No. 1	H1	H1F
House No. 2	H2	H2F
House No. 3	H3	H3F
Apartment	A1	-

To investigate the vibration characteristics of various floors within each unit, five representative rooms were tested in each house and four rooms in the apartment. These rooms included the living room, dining room, kitchen and one or two bedrooms.

To observe the difference in the response of the floor as affected by furniture, tests were conducted in two identical houses, one furnished and the other unfurnished. Tests on the furnished houses were conducted in the display (model) houses, which were fully furnished with the usual household items including sofas, chairs, tables, decorative items, and china in the kitchen and dining areas. The floor finish was the same in both the furnished and

unfurnished houses, except house No. 2 (H2) in which the floors had no finish.

The apartment was tested as an unfurnished unit though all the rooms had a finished floor.

2.2 Test Structures

The houses were of wood-frame construction with either masonry veneer wall or wood siding. The frame structure was constructed of hemlock studs and either hemlock or fir floor joists. Prefabricated wood trusses were used for the roof framing. For subflooring, 1/2 in plywood was used in houses No. 1 and 2 and 5/8 in plywood was used in house No. 3. Schematic drawings of the floor plans for each house and the rooms tested are shown in figures 3 through 5 where the tested rooms are indicated by a circled number. The direction of spanning of floor joists of the rooms tested is indicated in these figures by a directional arrow (⟷).

The apartment was of ordinary (exterior protected) construction. All floor joists were supported by a masonry wall at one end and on wood studs at the other. The floor was constructed of hemlock joists covered with 1/2 in plywood. A schematic drawing of the apartment floor plan and the rooms tested is shown in figure 6.

2.3 Variables in Floor Framing

The test floors had five variables: joist size; joist span; joist spacing; subfloor thickness and floor finish.

The numerical values of the first four variables and the description of floor finish for each room are listed in table 1. The joist sizes given in the table are nominal dimensions, and the span is the clear distance between the faces of the supports. It should be pointed out that it is not clear to the authors whether the floor joists had simple-support or had semi-fixed support as a result of joists being continuous beyond the support.

2.4 Test Setup and Instrumentation

The test setup is shown in figure 7. It consisted of a weighted bag, a bag-release device mounted on a tripod, and a linear variable differential transformer (LVDT) for deflection measurement.

Filled with sand and lead shot to a weight of 25 lb, the bag was suspended 3 ft above the floor surface. This test setup produced an impact energy of 75 ft-lb, which was sufficient to induce measurable vibratory motion of the floors found in residential structures. This level of impact energy is also considered to be approximately the amount of the energy induced by a 150-lb person moving rapidly across a floor.

The LVDT had a gage length of ± 1.0 in and was calibrated to read increments of ± 0.0001 in. The LVDT was attached to a beam of adjustable-length which was positioned to span between two opposite walls. Both the

loading device and the LVDT were placed as close to the center of the room as possible. The plunger of the LVDT was secured to the floor surface to eliminate rebound. The output of the LVDT was recorded by a recording oscillograph equipped with a 600-cps-response galvanometer.

Each floor was tested under four different arrangements as shown in figure 8, the arrangements differing from one another in both the location of the LVDT and the impact point with respect to the joist location.

2.5 Test Procedure

The impact load on the floor was induced by dropping the 25-lb bag from a height of 3 ft. Subsequent to the drop, the bag remained on the floor and vibrated with the floor. To eliminate possible damping provided by the presence of people in the room, the bag-release mechanism was triggered from the adjacent room by means of a string.

To examine reproducibility of the response of floors, two impact tests were conducted for each test arrangement. Thus, eight tests were conducted for each floor, two tests for each of the four different arrangements.

Traces of the response of all the floors were recorded on the photosensitive paper fed through the oscillograph at a rate of 4 in per second.

3. TEST RESULTS AND DISCUSSION

3.1 Visual Observations During Test

All observations by test personnel were recorded during the tests on the furnished houses. Typical observations included the rattling of china and glassware and the shaking of furniture.

A common phenomenon noted was a violent rattling of cups and glasses on tables in the dining room and kitchen when the impact load was induced to the floor. Occasionally, pieces of tableware fell off the table. Then it was noted that a person merely walking across the room caused table settings to rattle. Another phenomenon observed was the vibration of upright furniture.

These were casual observations and no attempt was made to relate these to the rating of the floor.

3.2 Vibration Data

Response to the impact loading for each floor is given in tables 2 through 8. The numerical values listed in the tables are obtained from the deflection traces which are shown in figures 9 through 15 for test setup A.

The first column of the tables describes the house designation, room number and test setup. The second column lists the first half cycle amplitude (y_1) and the next

column lists the rebound of the first cycle (y_2). The fourth column gives the duration of the peak-to-peak rise time of the first cycle (t_1). The fifth and the sixth columns show the duration (t_2 and t_3) for the amplitude to decay to 20 and 10 percent of the initial amplitude (y_1), respectively. The last column gives the approximate frequency of the floor as deduced from the deflection traces.

The tabulated values show that the initial amplitude varied with the test setup. These variations resulted primarily from the orthotropic nature of the wood-joist floors wherein two main modes of vibration exist, one parallel to the joist and the other perpendicular to the joist. Therefore, the deflection traces obtained are the superposition of these two main modes of vibrations. The averages of the four observations corresponding to arrangements A, B, C and D were used for the analysis and comparison of test results.

One of the important findings from these tests is that all floors easily met the transient vibration criterion given in the guide for the design and evaluation of Operation BREAKTHROUGH Housing Systems (refer to sec. 1.1). The test results (t_2) are listed in column 5 of tables 2 through 8. It is seen that all initial amplitudes decayed to 20 percent of the initial value within 0.5 sec. In fact,

for most floors the initial amplitude decayed to 20 percent of the initial value within 0.2 sec and to 10 percent within 0.3 sec.

The influence of furniture on the response of the floor can be examined from the data obtained from the furnished and unfurnished houses No. 1 and No. 2. The pertinent data for these houses are tabulated in columns 2 and 6 of tabels 2 through 5 and the corresponding deflection traces are shown in figures 9 through 12. It is seen that no consistent relationship exists between the initial amplitudes of the floors of the furnished and unfurnished houses. However, both the values listed in column 6 (t_3) and the deflection traces indicate, in general, that the vibration of the floors of the furnished rooms decayed faster than those of the unfurnished rooms. The traces further show that in the furnished rooms the vibration damped out almost completely at 0.5 sec, whereas in the unfurnished rooms the vibration persisted at least 1.0 sec or more with small amplitudes. The above observations indicate that the presence of furniture does provide some increase in the decay rate; i.e., increase in damping.

As mentioned earlier the floors had five variables in their construction, namely, joist size, joist span, joist spacing, thickness of subfloor and type of floor finish. However, a systematic study of these variables is not

possible, since these were not controlled variables. Furthermore, since most floors had joists of one size (2 in x 10 in) spaced predominantly at 16 in center-to-center and had 1/2 in plywood subfloor, a study of the response of the floor as affected by joist size, joist spacing and thickness of subfloor is not meaningful. However, some distinctive results for the other two variables are worth noting. It is seen in tables 2 through 7 that all floors, which had a span of less than 13 ft-6 in, had a frequency of approximately 20 cps. For floors which had a span of 20 ft-6 in the frequency was about 13 cps and 14 cps for the unfurnished and furnished cases (H1-4 and H1F-4), respectively. In addition to having a lower frequency, the floor of 20 ft-6 in span had a slower decay rate.

Four different types of floor finishes on the plywood subfloor were found in the dwelling units tested. They were: oak strips nailed on subfloor; vinyl asbestos tiles glued on subfloor; carpet with padding on subfloor; and 1 5/8 in lightweight concrete poured on subfloor. The first three types were used in the houses and the last type was used in the apartment. In addition, those floors which had the lightweight concrete had either carpet with padding or vinyl asbestos tiles on the concrete surface.

A comparison was made of the response of floors of unfurnished houses in figure 16 using the corresponding

tabulated data given in tables 2, 4 and 6. This reveals that while no significant difference in the initial impact deflection was observed between the floors finished with oak strip and vinyl asbestos tiles, respectively, a substantial difference in the initial deflection was observed between the floors covered with vinyl asbestos tiles and those finished with carpet. For otherwise similar floors, the initial deflection of the carpeted floors (H3-2) was between 27 and 52 percent less than that of the floors finished with vinyl asbestos tiles (H3-3). Of the three finishes, namely oak strip, vinyl asbestos tile and carpets, the carpet provided somewhat greater damping than the other two.

When all of these three types of finish are compared with the floor which had lightweight concrete, the latter floor showed a greater damping than the other three. Figure 15 shows the response of the floors which had the lightweight concrete. It is seen that most of the vibration damped out within 5 cycles.

3.3 Comparison of the Results with Human Response Curves

The test results are plotted on the human response curves for transient vibration as suggested by Lenzen in figure 17. Because the test points are clustered in a small area, the region which encompasses all the test points is cross hatched. The test data indicated that most floors

tested fall in Zone 5 and 6 with most of the test points in Zone 6, suggesting that for an impact of 75 ft-lb the floor response would greatly disturb and be injurious to the occupant.

In figure 18 the test results are plotted on Reiher and Meister's human response curves for one impact per second. As in the previous figure, the test results are grouped by the cross hatched region. It is seen that all test results lie well above the uppermost zone, II_b, indicating that the 75 ft-lb impact would not only induce unpleasant vibration but also would endanger the occupant.

It is questionable, however, whether these descriptions are applicable to the floors of the dwelling units tested. Some modification should be made on the classification of human response since the floors tested did not appear to belong to the categories identified by these curves. Until further studies are made to examine human tolerance of transient vibration, no specific comments can be made on the floors tested as to their level of performance with respect to human comfort.

4. SUMMARY AND CONCLUSION

4.1 Summary

This investigation examined the response of wood-joist floors subjected to transient vibration. The purpose of this investigation was to compare the performance of floors of conventionally-built dwelling units under transient vibration with the related criterion in the guide for the design and evaluation of Operation BREAKTHROUGH Housing Systems. The experiments involved on-the-site testing of actual houses and an apartment. The transient vibration was induced to the floor by an impact of 75 ft-lb.

Deflection traces were recorded and the decay characteristics of the floors were examined. Results of the experiments were compared with the curves of human response for transient vibration obtained by others.

4.2 Conclusions

The following conclusions may be drawn from the experimental results presented in this report:

1. All floors tested easily met the criterion that the amplitude should decay to 20 percent of its initial value within 0.5 second. In fact, the amplitude of most floors decayed to 20 percent of the initial amplitude within 0.2 sec and 10 percent within 0.3 sec. This indicates that the

wood-joist floors have relatively high damping capacity. The results further indicated that the damping capacity of wood-joist floors are improved by adding a lightweight concrete finish.

2. Comparison of the test results with the available curves of human response to transient vibration shows that the description of human tolerance given in the curves do not seem to be representative of the conditions encountered in this limited experiments. No conditions were noted which would be injurious to humans, although the available curves of human response would indicate that a large number of responses would be "definitely dangerous" or "injurious."

In view of the last conclusion and the scanty amount of information available on the human response to transient vibration, extensive experimental studies should be undertaken to clarify the subjective aspects. Such a study program should consider not only the physical characteristics of the floors but also a choice of the dynamic test load which can realistically represent the actual dynamic loads encountered in residential structures.

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5. ACKNOWLEDGMENTS

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The tests were performed by Messrs. J. Raines and E. Tuma of the Structures Laboratory, Building Research Division. Their assistance is appreciated.

6. TABLES AND FIGURES

House \ Variables	Joist Size (in x in)	Joist Span (ft-in)	Joist Spacing (in)	Subfloor	Type of Wood	Floor Finish
H1(FH1)-1	2 x 10	13-6	16	1/2 in plywood	Fir or Hemlock	Oak Strip[1]
-2	2 x 10	13-6	16		Fir or Hemlock	Oak Strip
-3	2 x 10	13-6	24		Fir or Hemlock	Vinyl Asbestos Tile
-4	2 x 12	20-6	12		Fir or Hemlock	Oak Strip
-5	2 x 10	13-6	24		Fir or Hemlock	Oak Strip
H2(FH2)-1	2 x 10	13-6	16	1/2 in plywood	Hemlock	Oak Strip
-2	2 x 10	13-0	16		Hemlock	Oak Strip
-3	2 x 10	13-1	16		Hemlock	Vinyl Asbestos Tile
-4	2 x 10	12-0	24		Fir or Hemlock	Oak Strip
-5	2 x 10	13-0	24		Fir or Hemlock	Oak Strip
H3(FH3)-1	2 x 10	12-6	16	5/8 in plywood	Hemlock	Carpet
-2	2 x 10	12-2	16		Hemlock	Carpet
-3	2 x 10	12-2	16		Hemlock	Vinyl Asbestos Tile
-4	2 x 10	12-6	16		Hemlock	Carpet
-5	2 x 10	12-6	16		Hemlock	Carpet
A1 -1	2 x 10	14-6	16	1/2 in plywood	Hemlock	Carpet + L.W.C.[2]
-2	2 x 10	11-5	16		Hemlock	Carpet + L.W.C.
-3	2 x 10	11-5	16		Hemlock	Vinyl Asbestos Tile + L.W.C.
-4	2 x 10	10-3	16		Hemlock	Carpet + L.W.C.

[1] Dimension of Oak Strip = 25/32 in x 2 1/2 in

[2] 1 5/8 in Lightweight Concrete

TABLE 1 Details of Floor Framing and Finish

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H1-1-A	0.065	0.039	0.019	0.080	0.350	22
B	.086	.041	.019	.060	.310	22
C	.090	.049	.022	.110	.330	22
D	.119	.049	.016	.060	.270	22
H1-2-A	0.154	0.075	0.027	0.070	0.280	20
B	.159	.075	.024	.090	.270	20
C	.171	.089	.022	.070	.270	20
D	.154	.086	.023	.060	.260	20
H1-3-A	0.114	0.041	0.020	0.190	0.340	20
B	.090	.043	.025	.170	.210	20
C	.096	.049	.021	.190	.350	20
D	.077	.043	.022	.230	.420	20
H1-4-A	0.108	0.058	0.045	0.150	0.470	12.5
B	.111	.046	.040	.160	.470	13.5
C	.106	.049	.046	.150	.390	12.5
D	.104	.050	.043	.150	.390	12.5
H1-5-A	0.118	0.056	0.038	0.200	0.410	18
B	.159	.064	.031	.190	.390	18
C	.137	.055	.038	.190	.260	18
D	.130	.062	.046	.200	.260	18

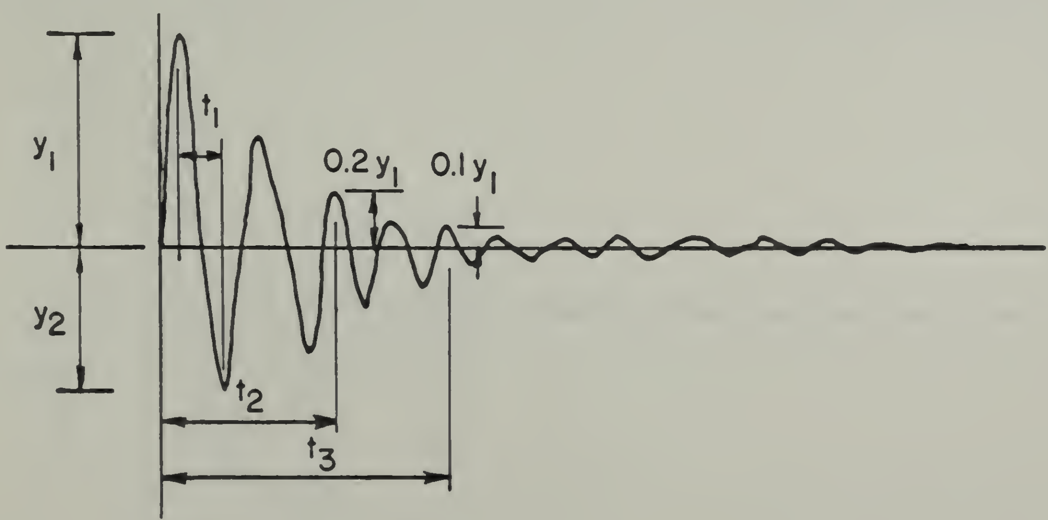


TABLE 2 Test Results of House No. 1
(Unfurnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H1F-1-A	0.074	0.058	0.018	0.179	0.243	26
B	.085	.053	.020	.141	.234	26
C	.107	.066	.019	.118	.162	23
D	.086	.062	.019	.130	.237	22
H1F-2-A	0.098	0.033	0.024	0.139	0.220	20
B	.104	.035	.023	.122	.184	20
C	.104	.030	.027	.147	.271	26
D	.100	.028	.025	.139	.230	22
H1F-3-A	0.110	0.057	0.022	0.116	0.182	19
B	.140	.051	.024	.095	.255	20
C	.095	.044	.021	.158	.239	20
D	.124	.045	.024	.165	.251	19
H1F-4-A	0.070	0.033	0.047	0.221	0.306	14
B	.076	.033	.043	.182	.379	14
C	.075	.033	.049	.123	.380	14
D	.075	.035	.047	.146	.278	14
H1F-5-A	0.119	0.058	0.036	0.159	0.250	17
B	.123	.068	.039	.118	.234	20
C	.132	.044	.034	.135	.276	19
D	.105	.064	.036	.188	.284	19

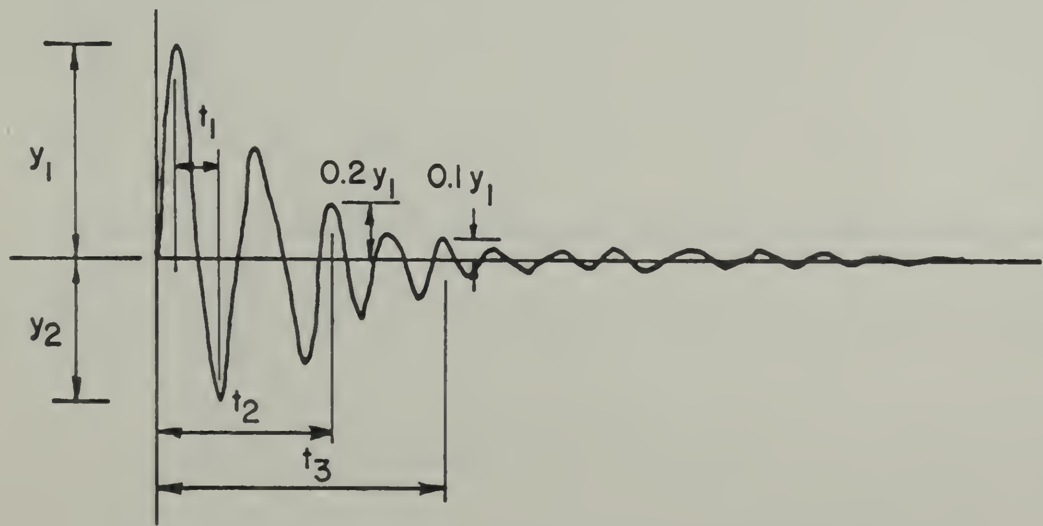


TABLE 3 Test Results of House No. 1 (Furnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H2-1-A	0.096	0.060	0.019	0.110	0.170	21
B	.118	.066	.026	.060	.140	21
C	.123	.066	.024	.140	.170	22
D	.094	.063	.026	.140	.180	22
H2-2-A	0.125	0.052	0.024	0.090	0.140	20
B	.125	.063	.027	.090	.200	20
C	.131	.053	.026	.100	.160	19.5
D	.127	.058	.019	.090	.170	19.5
H2-3-A	0.149	0.075	0.022	0.060	0.190	21
B	.154	.075	.019	.060	.180	22
C	.140	.079	.022	.070	.170	20
D	.139	.092	.021	.060	.100	19.5
H2-4-A	0.094	0.040	0.026	0.150	0.200	19
B	.094	.030	.031	.150	.200	19.5
C	.109	.053	.033	.120	.180	19.5
D	.078	.036	.031	.170	.300	19.5
H2-5-A	0.081	0.034	0.018	0.100	0.140	23
B	.094	.040	.019	.090	.120	26
C	.125	.035	.020	.110	.160	22
D	.115	.060	.023	.090	.140	22

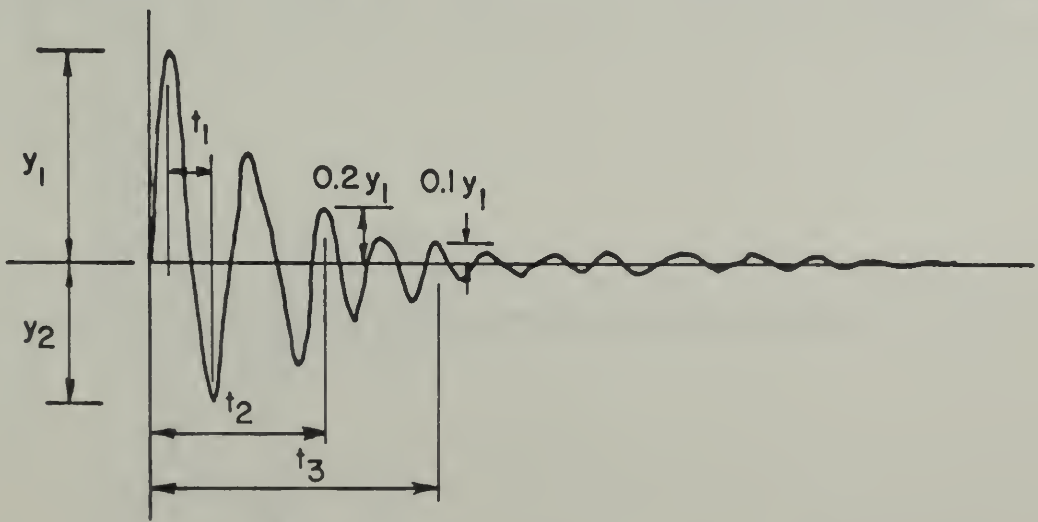


TABLE 4 Test Results of House No. 2
(Unfurnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H2F-1-A	0.142	0.069	0.023	0.084	0.173	20
B	.147	.068	.025	.078	.184	21
C	.146	.064	.020	.139	.228	20
D	.141	.065	.024	.127	.197	20
H2F-2-A	0.110	0.031	0.024	0.090	0.141	20
B	.127	.033	.030	.099	.147	20
C	.124	.033	.024	.108	.201	21
D	.119	.032	.028	.112	.208	20
H2F-3-A	0.138	0.028	0.030	0.075	0.134	19
B	.134	.033	.032	.099	.144	19
C	.145	.040	.028	.087	.144	18
D	.131	.035	.028	.090	.139	19
H2F-4-A	0.161	0.060	0.024	0.156	0.308	20
B	.140	.054	.026	.110	.183	20
C	.225	.109	.022	.074	.149	21
D	.195	.085	.028	.087	.148	21
H2F-5-A	0.053	0.028	0.028	0.057	0.076	24
B	.050	.029	.024	.063	.071	25
C	.074	.038	.021	.084	.128	24
D	.056	.022	.023	.067	.125	24

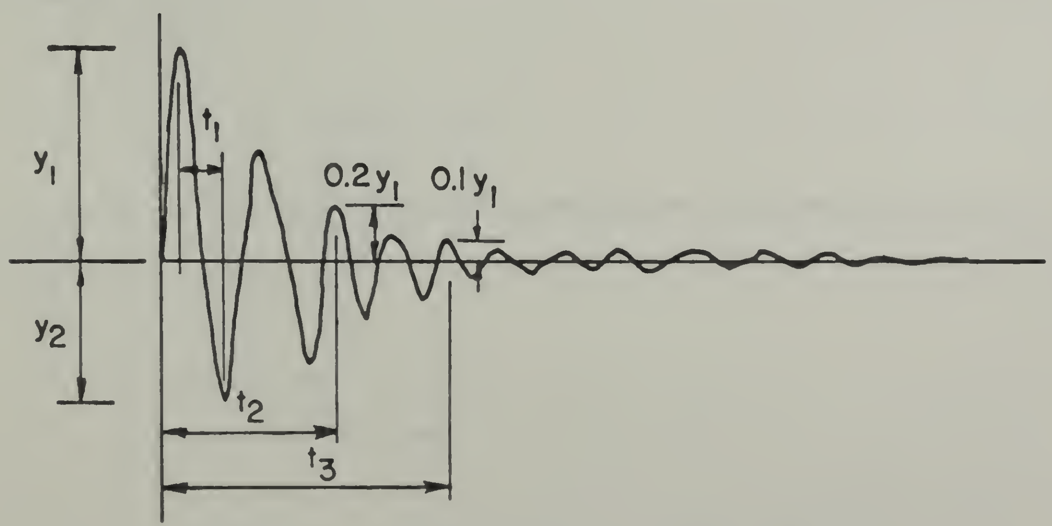


TABLE 5 Test Results of House No. 2
(Furnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H3-1-A	0.150	0.083	0.024	0.168	0.253	23
B	.133	.089	.C20	.132	.212	22
C	.120	.079	.017	.160	.210	22
D	.154	.087	.023	.156	.205	22
H3-2-A	0.097	0.045	0.020	0.070	0.080	25
B	.077	.043	.020	.070	.080	25
C	.100	.061	.019	.070	.090	25
D	.058	.044	.018	.120	.090	24
H3-3-A	0.132	0.064	0.020	0.095	0.137	24
B	.121	.054	.023	.095	.170	26
C	.148	.068	.020	.087	.128	28
D	.120	.056	.020	.090	.150	24
H3-4-A	0.119	0.067	0.021	0.132	0.191	26
B	.061	.051	.016	.144	.203	25
C	.049	.042	.022	.262	.304	25
D	.119	.071	.020	.198	.243	22
H3-5-A	0.143	0.073	0.018	0.165	0.284	25
B	.123	.083	.018	.104	.181	28
C	.163	.090	.029	.137	.198	26
D	.133	.076	.022	.054	.122	26

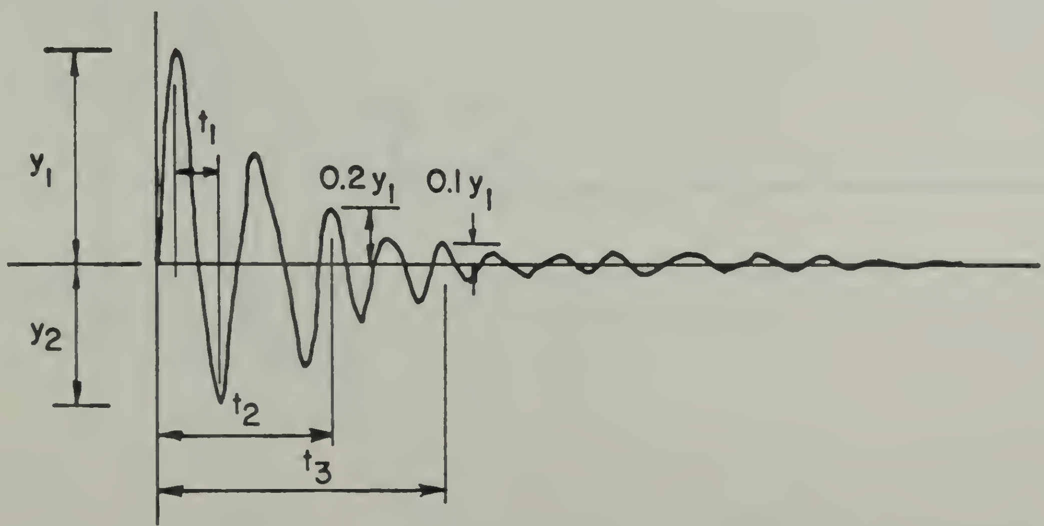


TABLE 6 Test Results of House No. 3
(Unfurnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
H3F-1-A	0.182	0.092	0.018	0.076	0.102	24
B	.186	.081	.018	.087	.287	25
C	.209	.086	.016	.058	.227	28
D	.201	.071	.017	.056	.189	27
H3F-2-A	0.079	0.044	0.019	0.071	0.125	27
B	.122	.042	.016	.057	.294	24
C	.127	.063	.017	.056	.184	25
D	.088	.067	.016	.072	.179	24
H3F-3-A	0.133	0.040	0.014	0.072	0.153	26
B	.182	.034	.016	.156	.234	24
C	Data not available					
D	.163	.043	.014	.135	.218	24
H3F-4-A	0.154	0.063	0.021	0.063	0.228	25
B	.179	.058	.023	.138	.268	27
C	.173	.058	.022	.094	.254	27
D	.158	.057	.024	.116	.248	27
H3F-5-A	0.130	0.065	0.015	0.061	0.088	35
B	.146	.067	.015	.134	.254	33
C	.121	.049	.016	.055	.132	32
D	.133	.061	.016	.056	.072	33

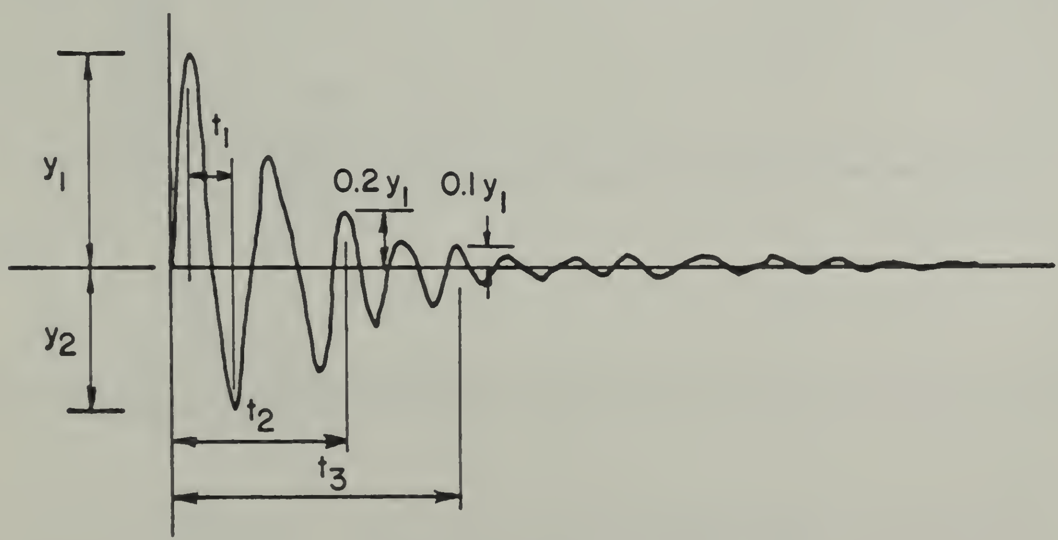


TABLE 7 Test Results of House No. 3
(Furnished)

	y_1 (in)	y_2 (in)	t_1 (sec)	t_2 (sec)	t_3 (sec)	f (cps)
A1-1-A	0.060	0.023	0.040	0.110	0.240	17
B	.046	.023	.042	.130	.240	15
C	.034	.018	.037	.140	.220	15
D	.066	.026	.037	.110	.230	--
A1-2-A	0.081	0.041	0.045	0.150	0.270	15
B	.106	.054	.043	.170	.220	16
C	.078	.036	.043	.180	.250	17
D	.080	.044	.043	.190	.240	18
A1-3-A	0.056	0.025	0.038	0.060	0.070	19
B	.055	.022	.039	.060	.070	19
C	.065	.023	.041	.070	.080	--
D	.059	.022	.041	.080	.090	--
A1-4-A	0.063	0.038	0.034	0.130	0.210	16
B	.065	.035	.037	.140	.200	16
C	.072	.043	.035	.110	.230	16
D	.067	.039	.035	.170	.240	16

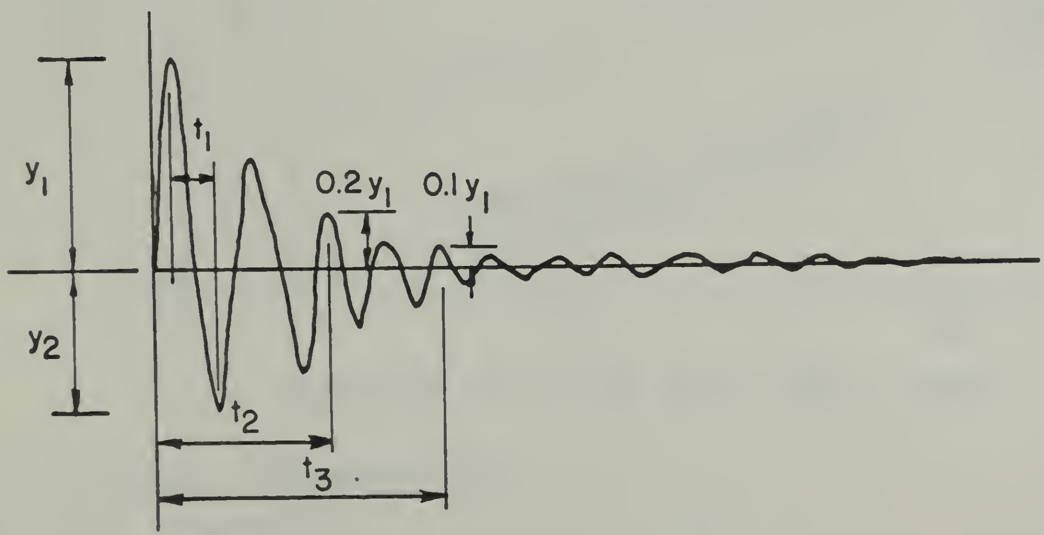
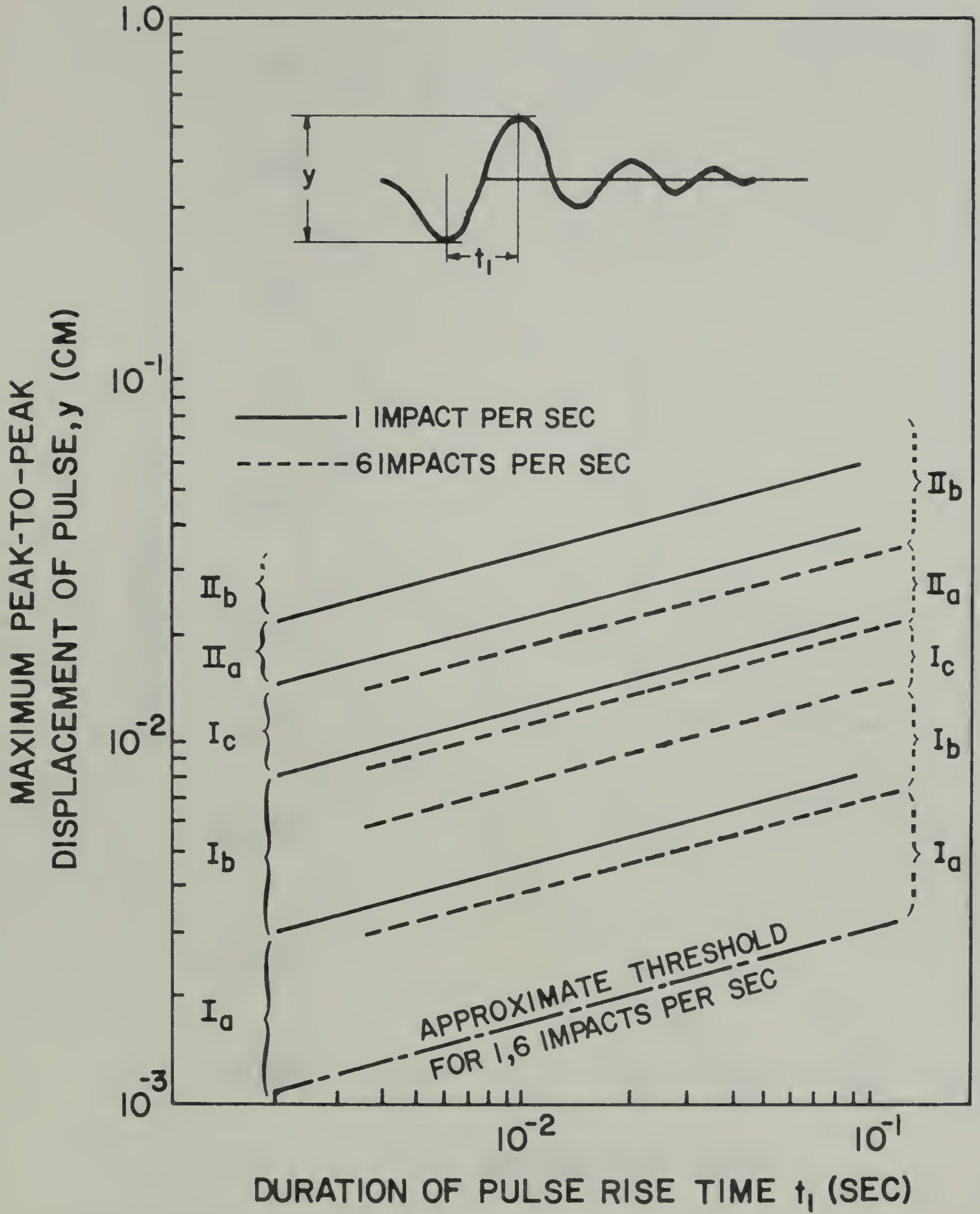


TABLE 8 Test Results of Apartment (Unfurnished)



I_a : THRESHOLD OF PERCEPTION

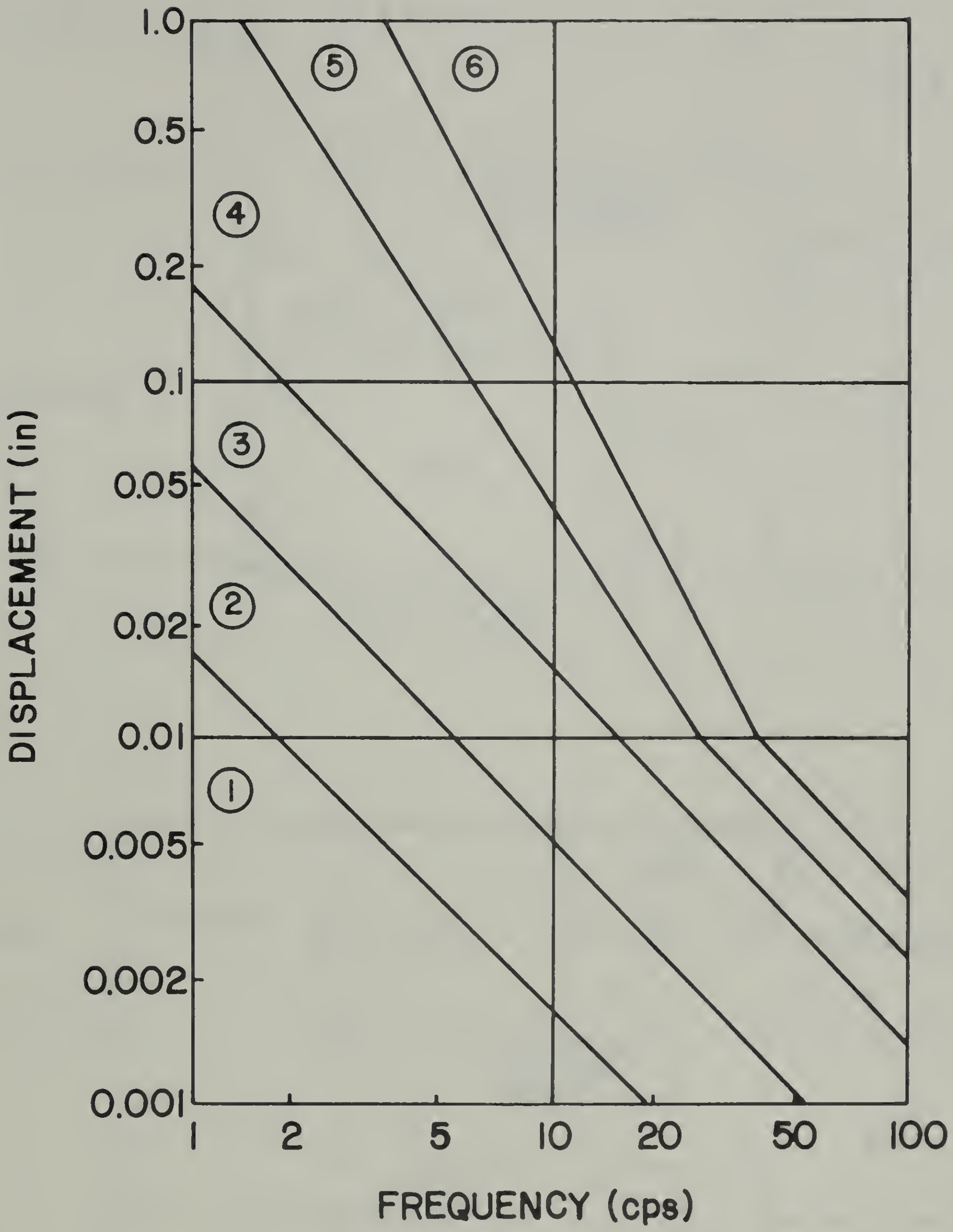
I_b : EASY PERCEPTION

I_c : STRONG PERCEPTION, ANNOYING

II_a : VERY UNPLEASANT, POTENTIAL DANGER FOR LONG EXPOSURES

II_b : EXTREMELY UNPLEASANT, DEFINITELY DANGEROUS

FIGURE 1 TOLERANCE OF HUMANS SUBJECTED TO REPEATED IMPACT (DUE TO REIHER AND MEISTER, REF. 4)



ZONE 1 : NOT PERCEPTIBLE
ZONE 2 : SLIGHTLY PERCEPTIBLE
ZONE 3 : DISTINCTLY PERCEPTIBLE
ZONE 4 : STRONGLY PERCEPTIBLE
ZONE 5 : DISTURBING
ZONE 6 : VERY DISTURBING, INJURIOUS

FIGURE 2 GRAPH OF REDUCED HUMAN RESPONSE
(DUE TO REIHER AND MEISTER, REF. 3 AND MODIFIED BY LENZEN, REF. 2)

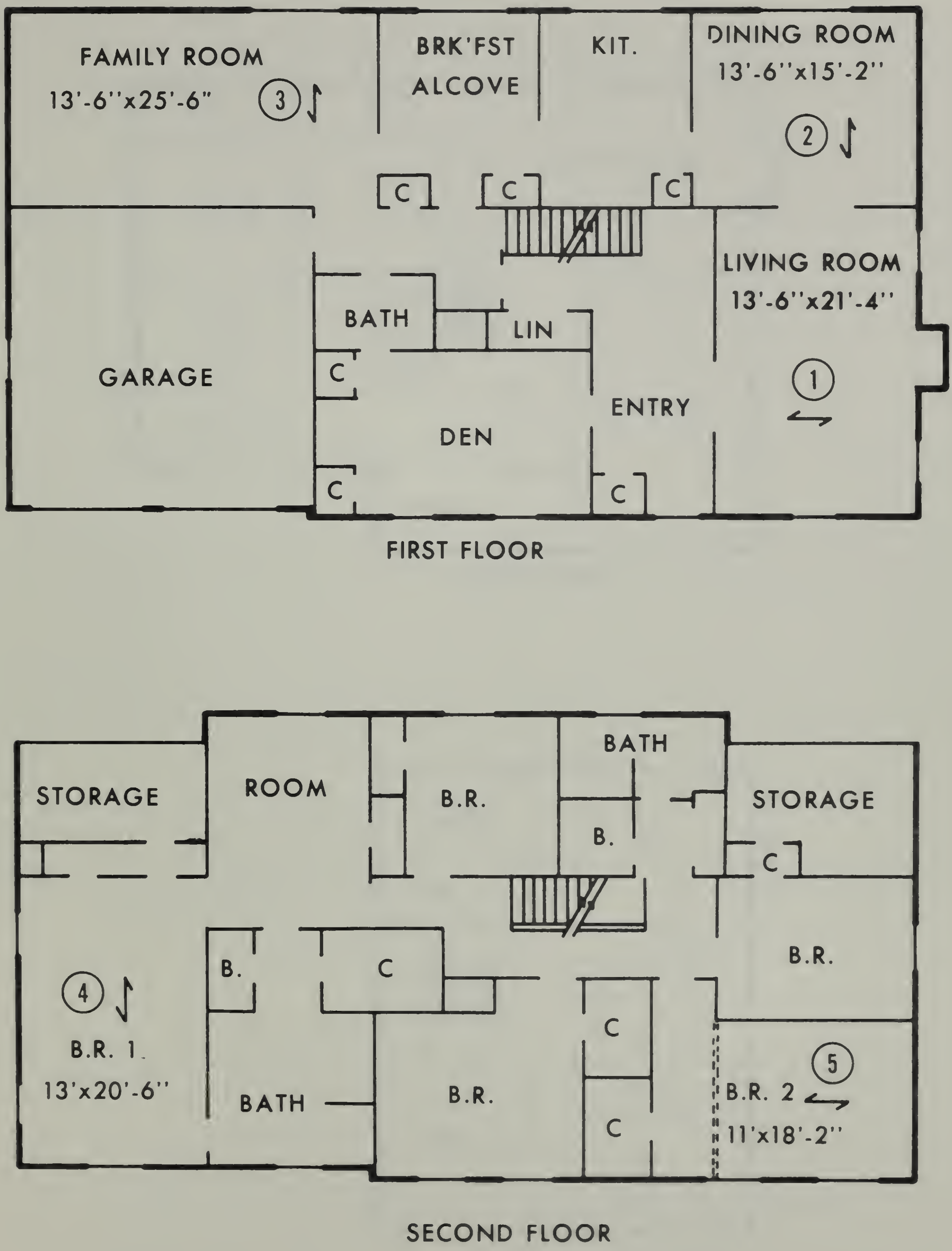
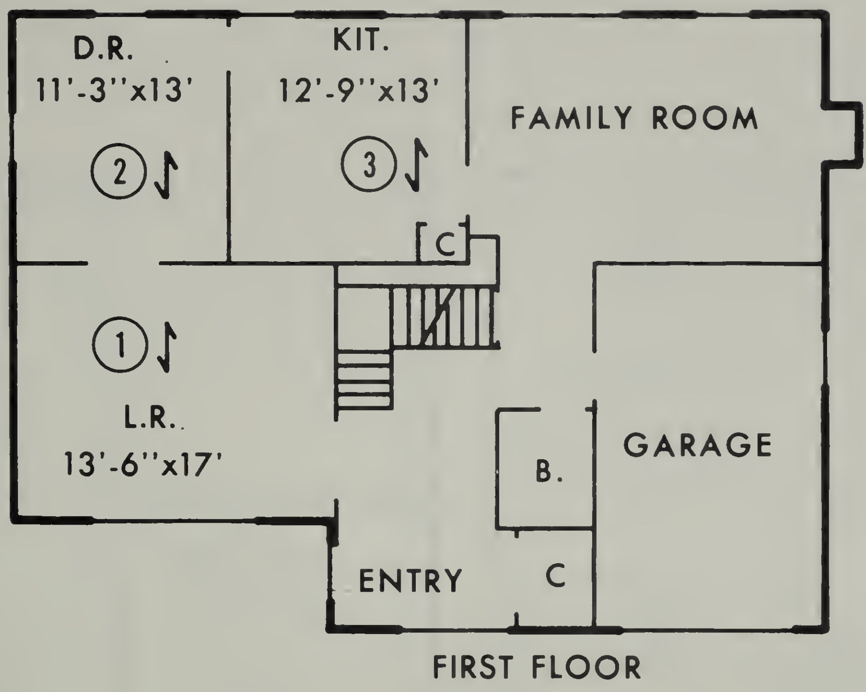


FIG. 3 FLOOR PLAN OF HOUSE NO. 1



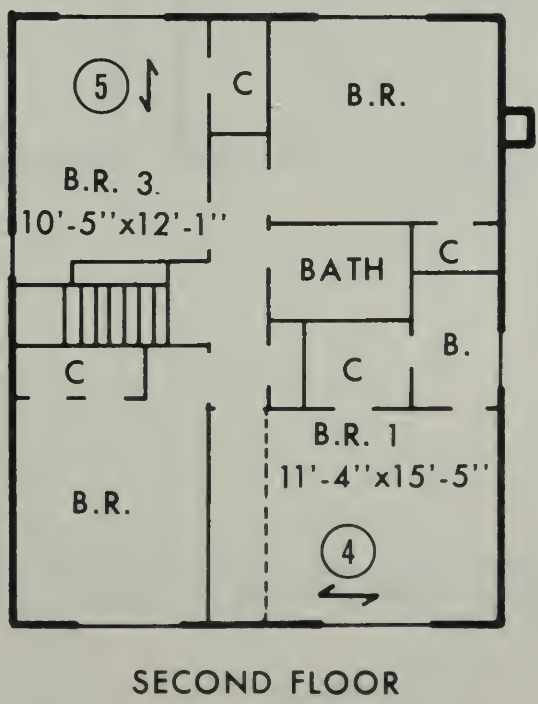


FIG. 4 FLOOR PLAN OF HOUSE NO. 2

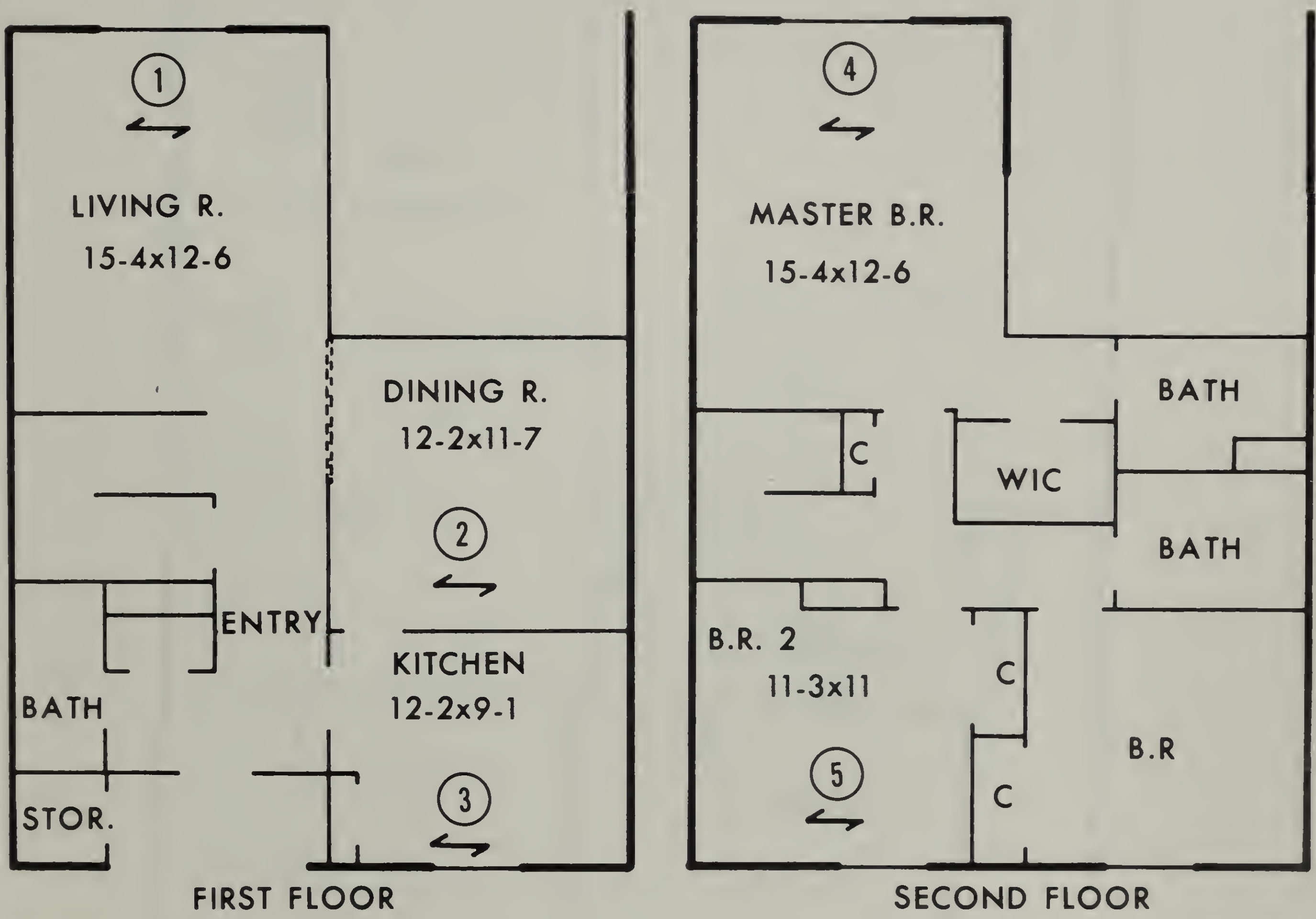


FIG. 5 FLOOR PLAN OF HOUSE NO. 3

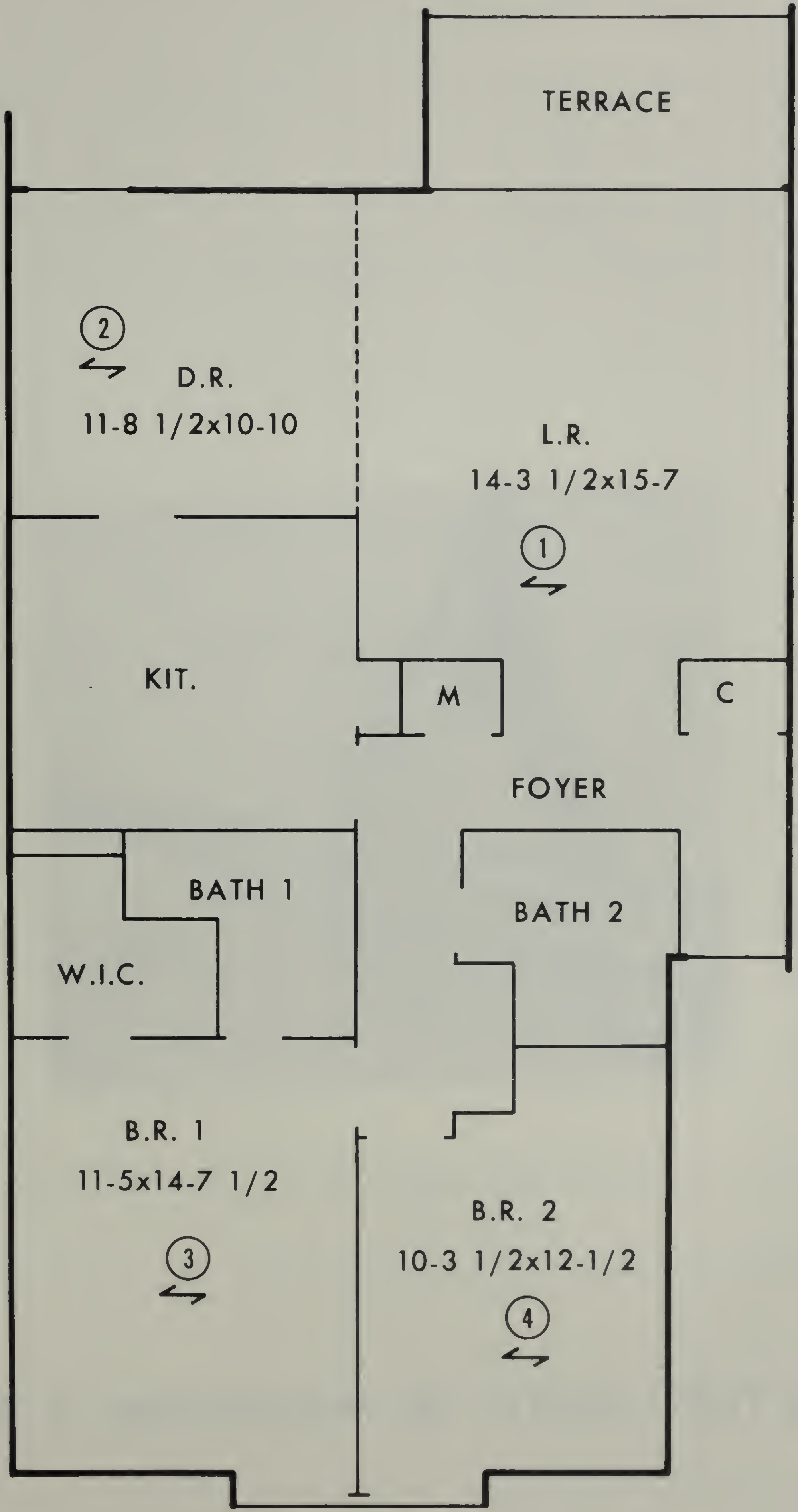


FIG. 6 FLOOR PLAN OF APARTMENT

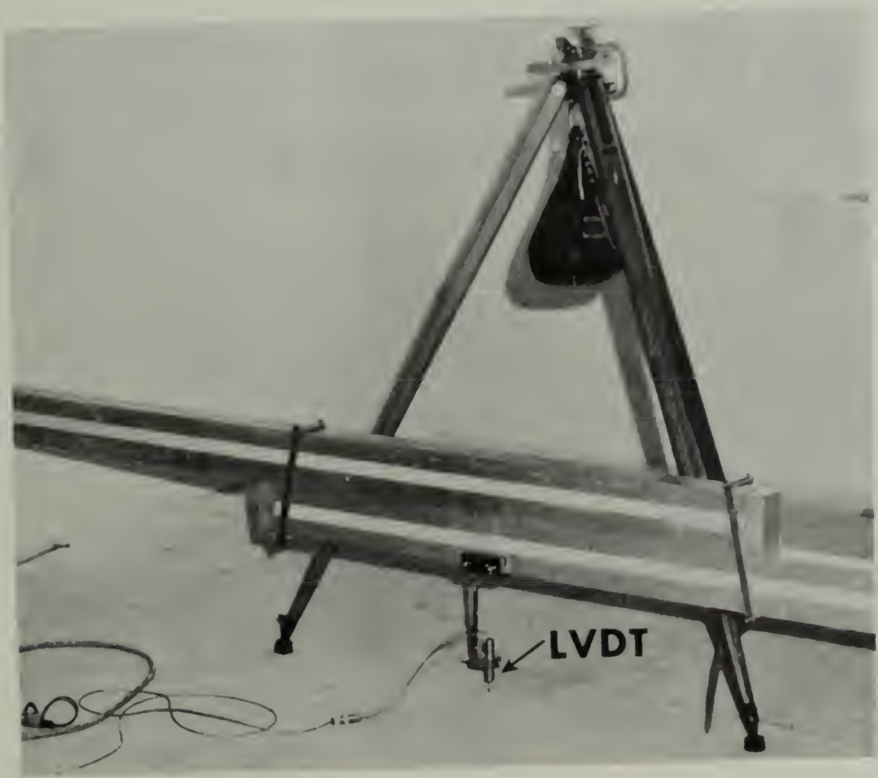


FIGURE 7 PHOTOGRAPH OF TYPICAL TEST SETUP

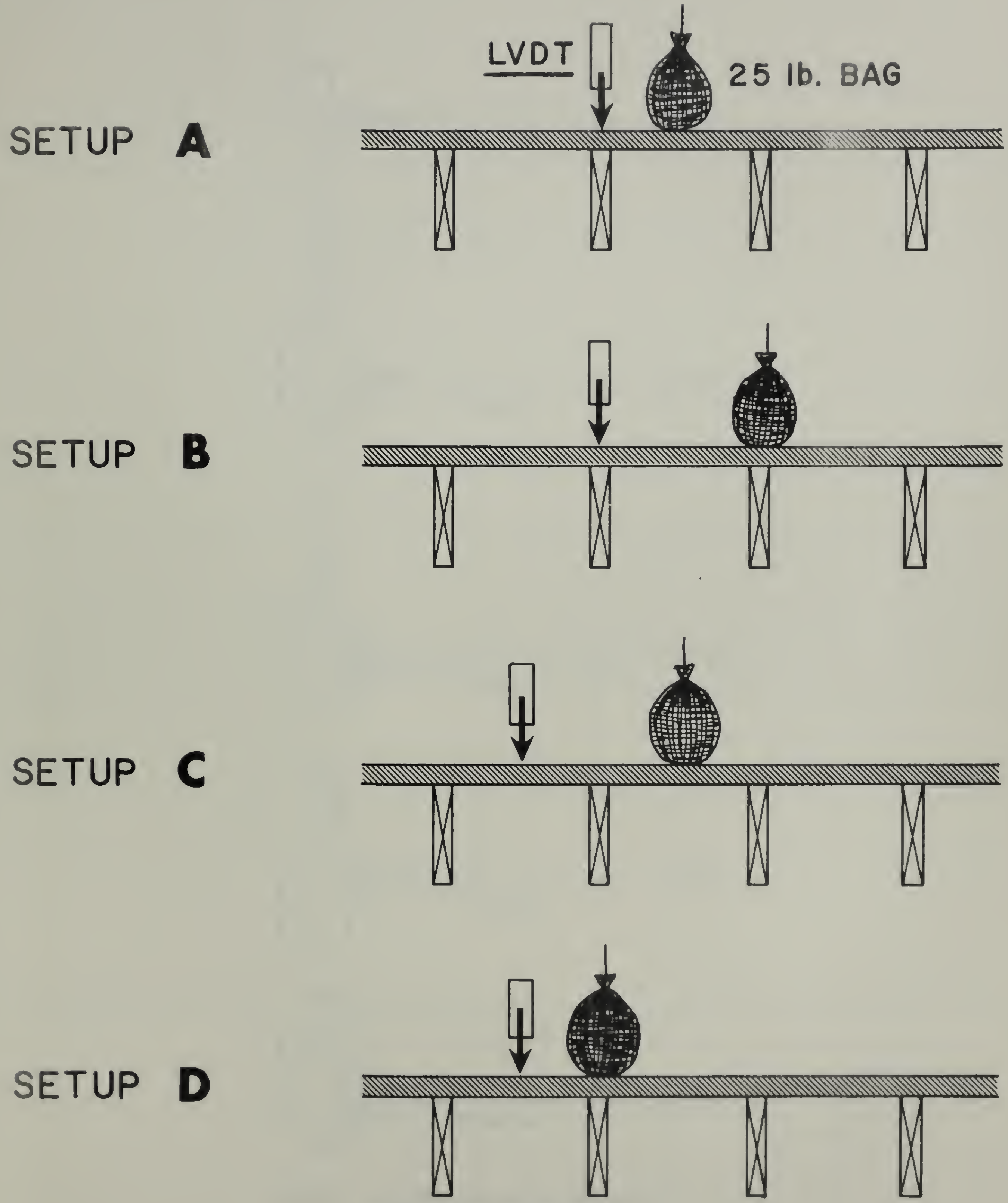


FIG. 8 TEST SETUP AND SEQUENCE

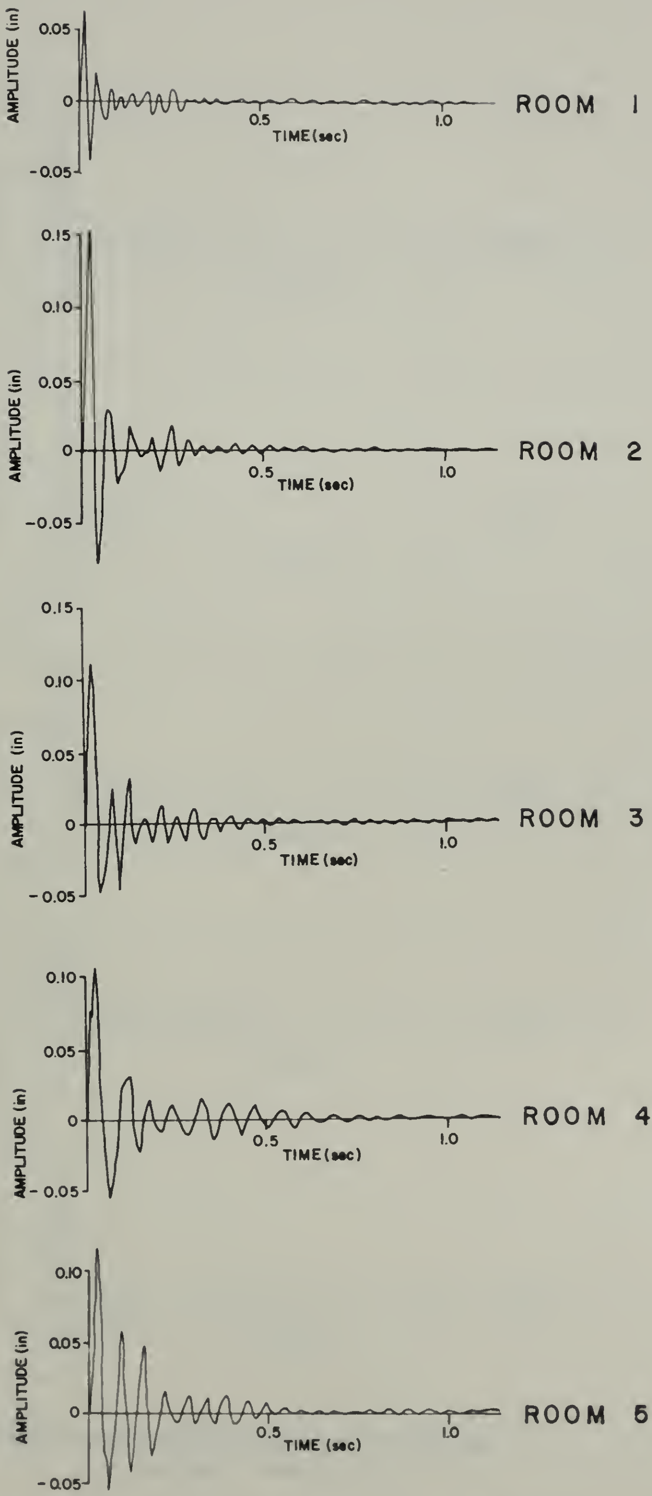


FIGURE 9 DEFLECTION TRACES OF HOUSE NO. 1 UNFURNISHED - TEST SETUP A.

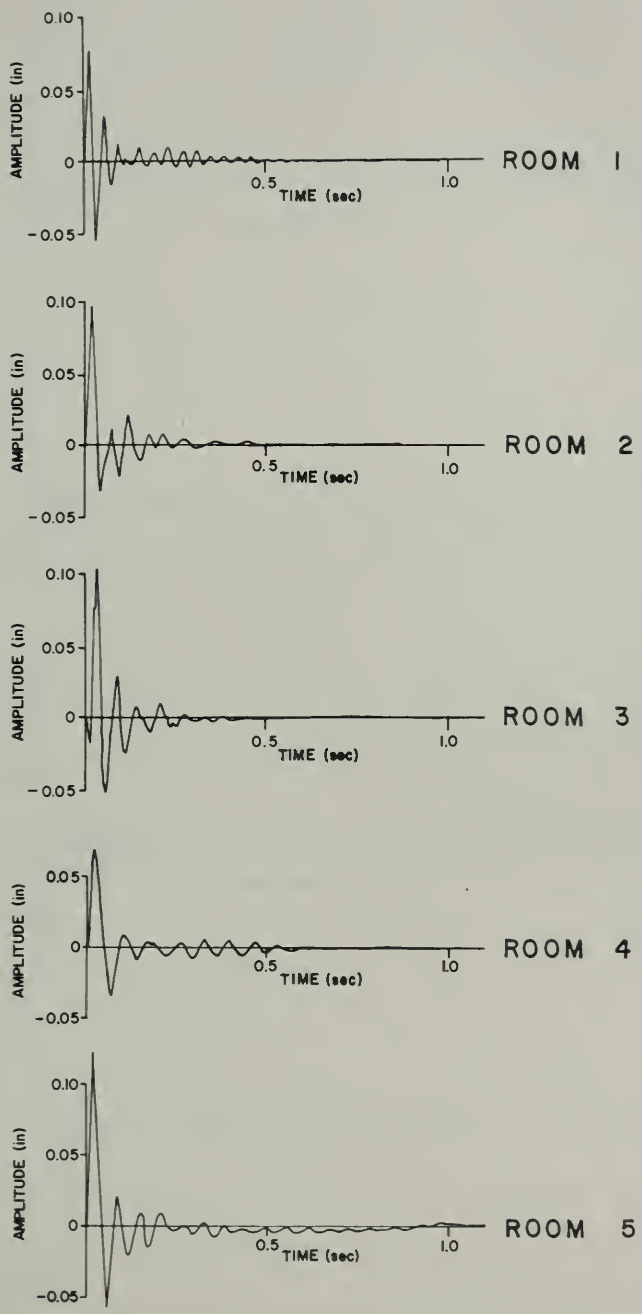


FIGURE 10 DEFLECTION TRACES OF HOUSE NO. 1 FURNISHED - TEST SETUP A.

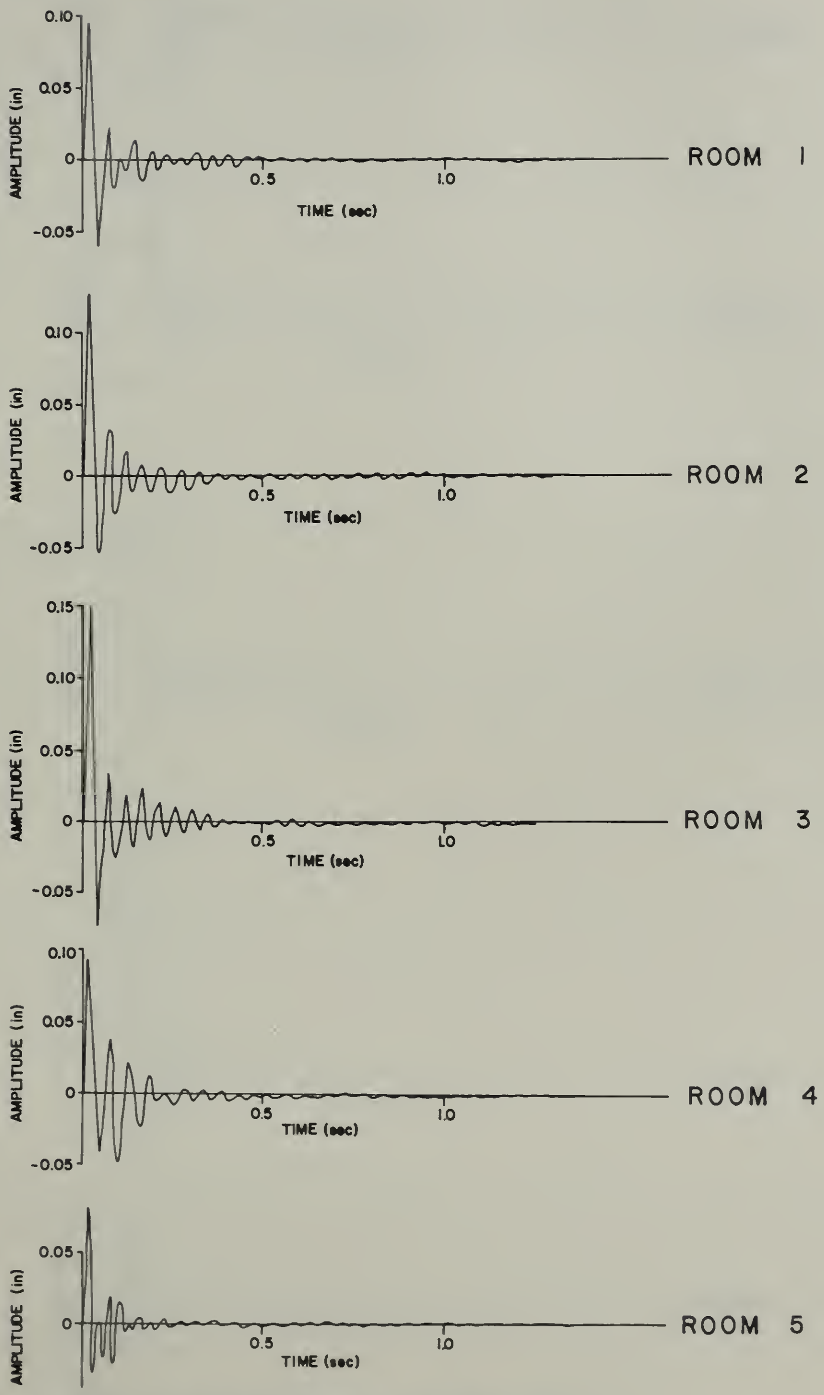


FIGURE 11 DEFLECTION TRACES OF HOUSE NO. 2 UNFURNISHED - TEST SETUP A.

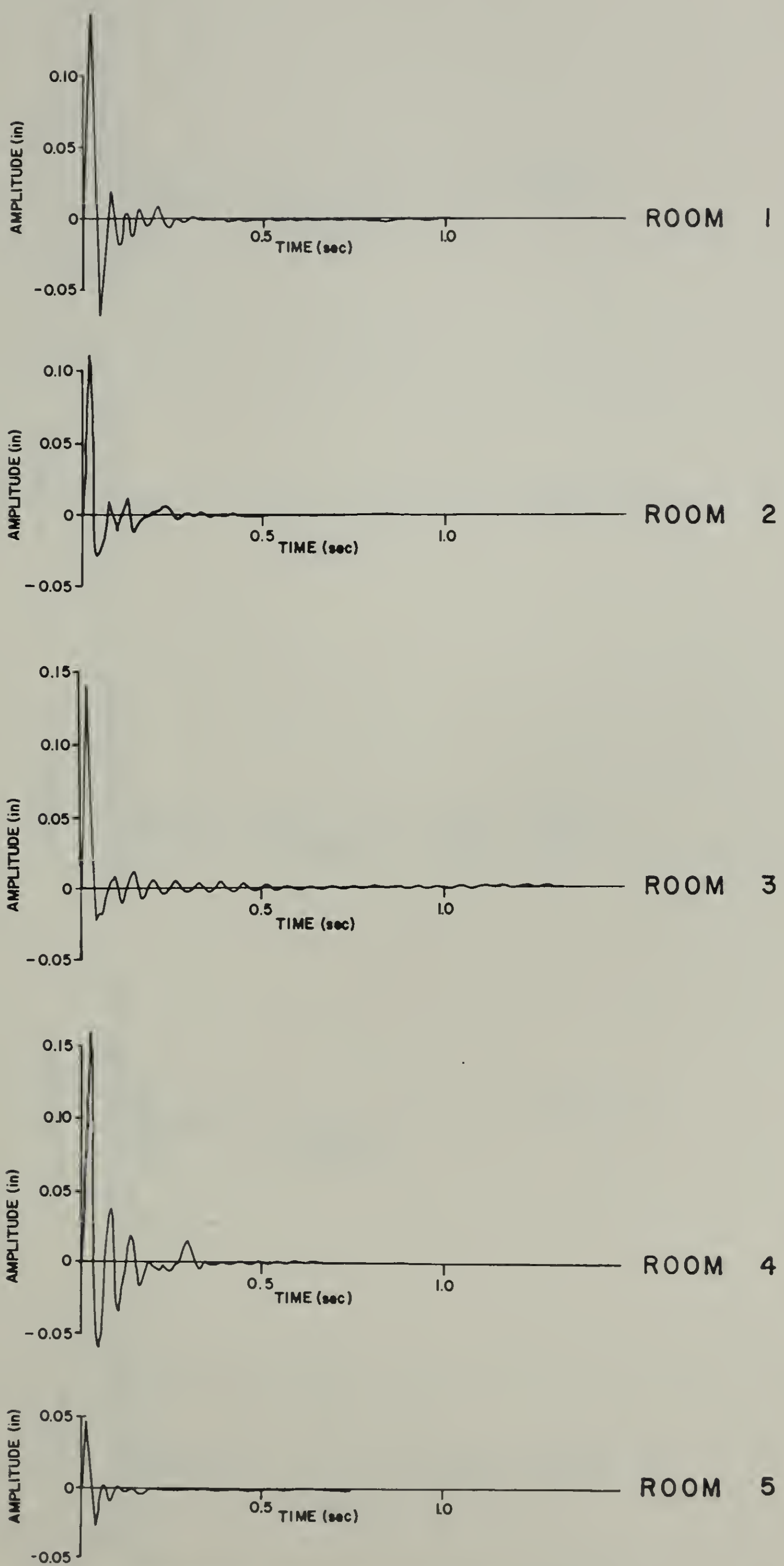


FIGURE 12 DEFLECTION TRACES OF HOUSE NO. 2
FURNISHED - TEST SETUP A.

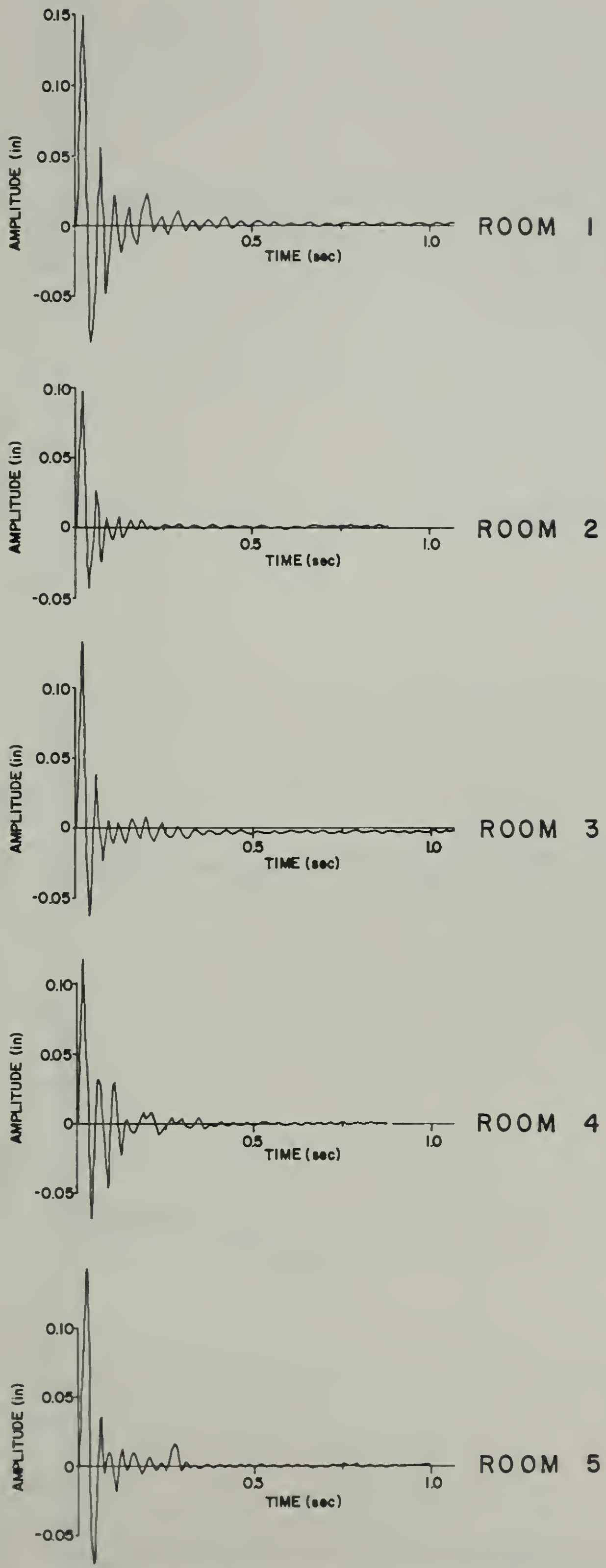


FIGURE 13 DEFLECTION TRACES OF HOUSE NO. 3 UNFURNISHED - TEST SETUP A.

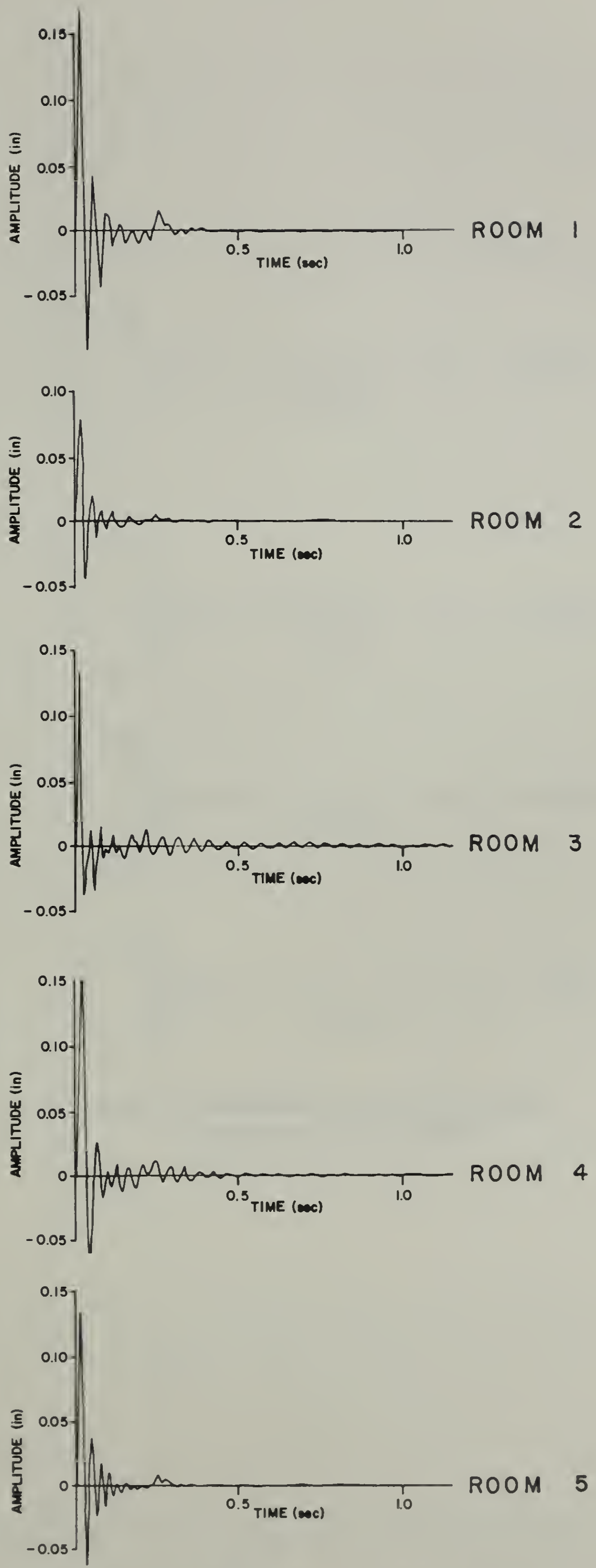


FIGURE 14 DEFLECTION TRACES OF HOUSE NO. 3 FURNISHED - TEST SETUP A.

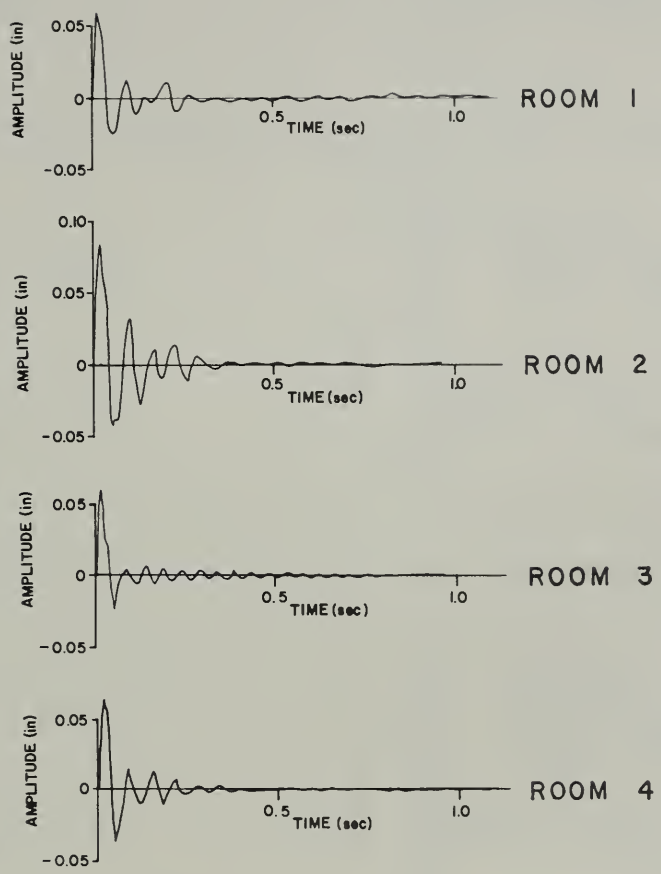
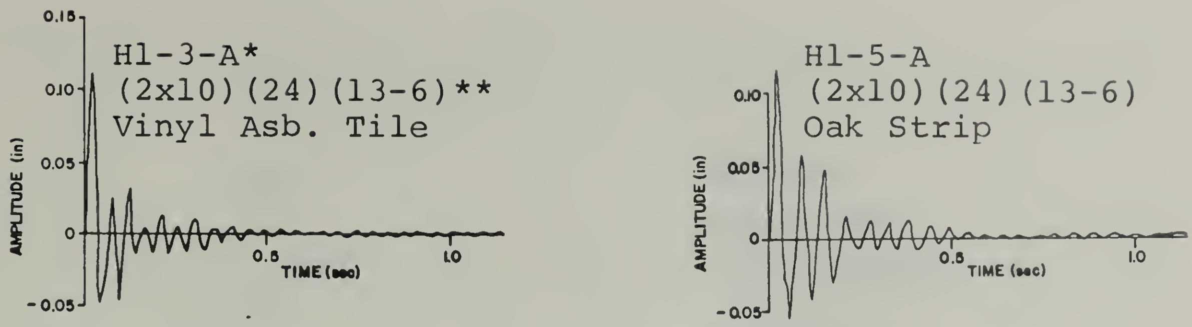
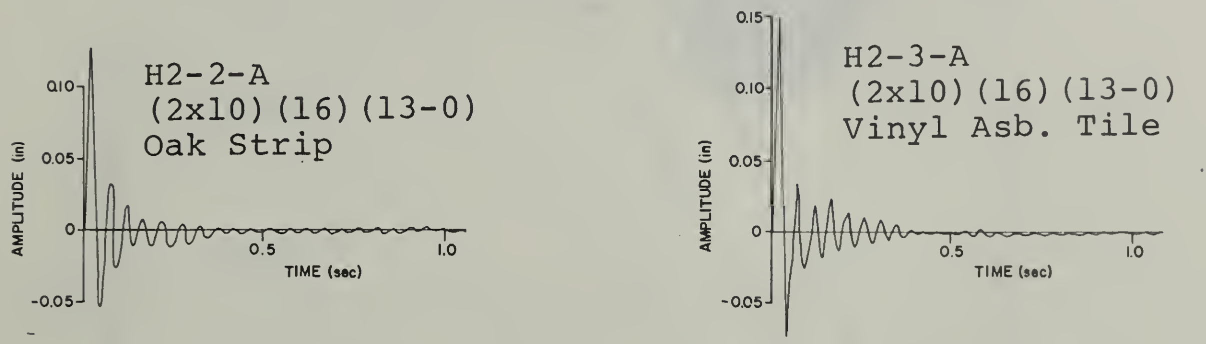


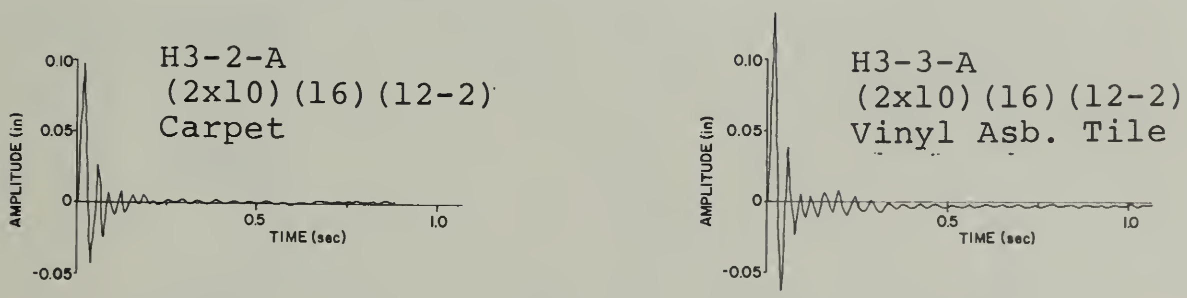
FIGURE 15 DEFLECTION TRACES OF APARTMENT UNFURNISHED - TEST SETUP A.



(a) Vinyl Asbestos Tile vs. Oak Strip



(b) Vinyl Asbestos Tile vs. Oak Strip

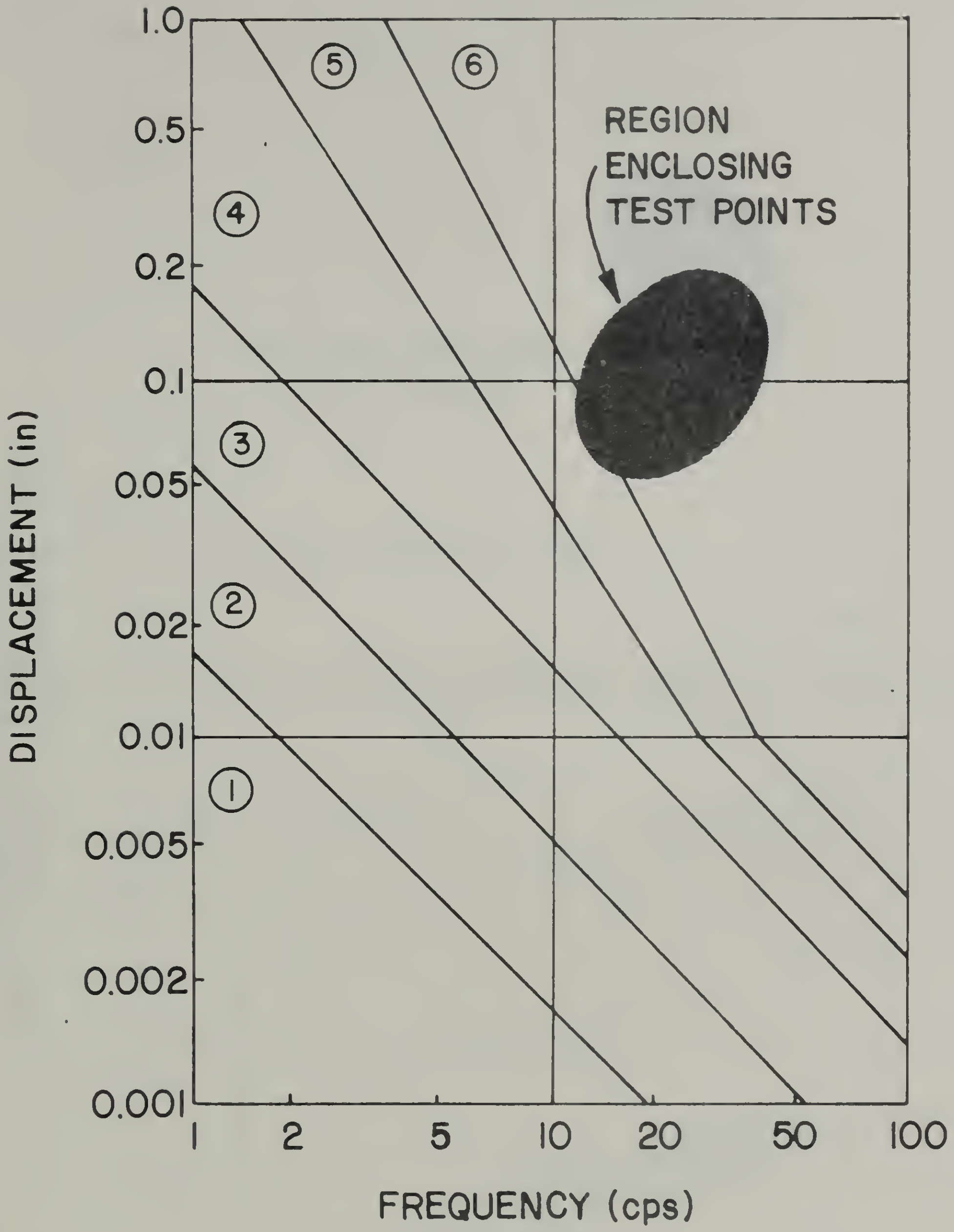


(c) Vinyl Asbestos Tile vs. Carpet

* House No. - Room No. - Test Setup

** (Joist Size)(Joist Spacing)(Joist Span)

FIGURE 16 COMPARISON OF FLOOR RESPONSES AS AFFECTED BY FLOOR FINISH



ZONE 1 : NOT PERCEPTIBLE
ZONE 2 : SLIGHTLY PERCEPTIBLE
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ZONE 4 : STRONGLY PERCEPTIBLE
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FIGURE 17 GRAPH OF REDUCED HUMAN RESPONSE (DUE TO REIHER AND MEISTER, REF. 3 AND MODIFIED BY LENZEN, REF 2)

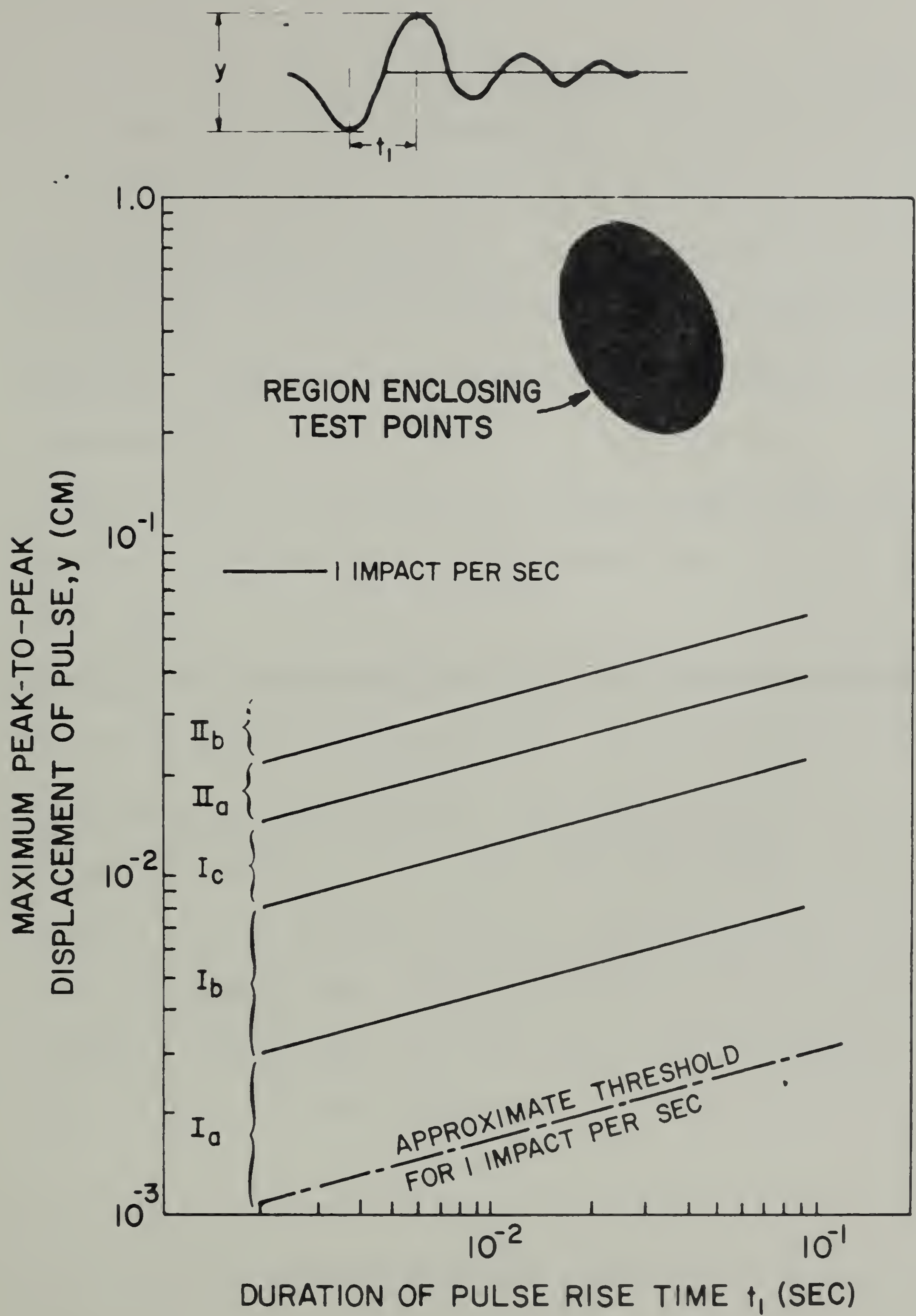

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FIGURE 18 TOLERANCE OF HUMAN SUBJECTED TO REPEATED IMPACT (DUE TO REIHER AND HEISTER - REF. 4)

7. REFERENCES

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2. Lenzen, K. H., "Vibration of Steel Joist-Concrete Slab Floors," Engineering Journal, AISC, vol. 3, no. 3, July 1966
3. Reiher, H. and Meister, F. J., "Die Empfndlichkeit des Menschen gegen Erschutterungen (The Effect of Vibration on People)," Forschung auf dem Gebeite des Ingenieurwesens, vol. 2, pp. 381-386, 1931
4. Reiher, H. and Meister, F. J., "Die Empfindlichkeit des Menschen gegen StaBe (The Sensitivity of Human Against Impact)," Forschung auf dem Gebeite des Ingenieurwesens, vol. 3, pp. 177-180, 1932

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