The Wood-Frame House as a Structural Unit

MSC

TECHNICAL REPORT 5

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Presented at the 1965 Meeting
of the Wood Engineering Division
of the
FOREST PRODUCTS RESEARCH SOCIETY
New York, New York
June 26 - July 1

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Summary

A full-scale house, 28' x 36', was structurally evaluated as a unit, by subjecting it to various combinations of simulated wind and gravity loads while continuously recording deflections at 29 points. Rigidity, attributable to members, components, and such structural elements as sheathing, flooring, and sheetrock, was also evaluated. Floor deflections and vibrations were recorded for 14 stages of construction, and racking tests were conducted at 7 stages of dismantling.

Floor deflection and vibration were reduced by adding several components and structural elements, of which partitions were the most effective. Average floor deflection in partitioned areas ranged from 33% to 40% of span/360, while in non-partitioned areas it ranged from 59% to 70% of span/360.

Hardwood flooring was the next most effective reducer of deflection. It also significantly reduced vibration amplitude and duration, especially in non-partitioned areas, but had little effect on frequency. Scabbing joists with 1 x 8's across the center support made little difference in vibration, but significantly reduced deflection.

A foundation failure, within one minute after 20 psf were applied to all exterior surfaces, complicated this part of the study because the house could move on its foundation, in spite of strong anchorage and guys on the "up-wind" side. The ½-inch sheetrock ceiling, in combination with $^3/_8$-inch plywood wall sheathing, appeared to be very effective in resisting horizontal movement. However, other combinations, such as $^3/_8$-inch plywood wall sheathing and partitions with sheetrock in place, could be expected to show more resistance if the ceiling had been removed first.

Crown and chord movements of the roof structure were approximately the same. Both increased with removal of partitions, and they resisted simulated gravity load better than wind load.

Introduction

The primary objective of this study was to evaluate the structural performance of a complete, conventional, three-bedroom, full-scale house, by subjecting it to various combinations of static and dynamic loading, while continuously recording deflections and deformations throughout the house.

Part I of the study was concerned with the deflection of floors under simulated gravity loading. Part II was devoted to floor vibrations induced by dynamic loading. Part III was concerned primarily with the overall structural performance of the house, as indicated by movements of walls, ceilings and roof surfaces, when subjected to combinations of simulated gravity and dynamic loading at various stages of construction. The floor plan of the selected design is shown in Figure 1.

It is generally recognized that the conventional method of designing houses on the piece-by-piece basis, and ignoring the interaction of major structural elements, provides only a rough approximation of the total performance, and can cause excessive waste of building materials. Until quantitative information on such interaction is provided, engineers and architects, as well as regulatory agencies, are tied to tradition and the present rule-of-thumb methods which control home building.

It seemed logical to start with a complete, full-scale house and evaluate it as a structural unit, and to compile quantitativedesign information on the structural contribution by the various major elements such as roofs, walls, partitions and floors. The objective also included compiling quantitative data on the interaction of the various parts that comprise the major elements.
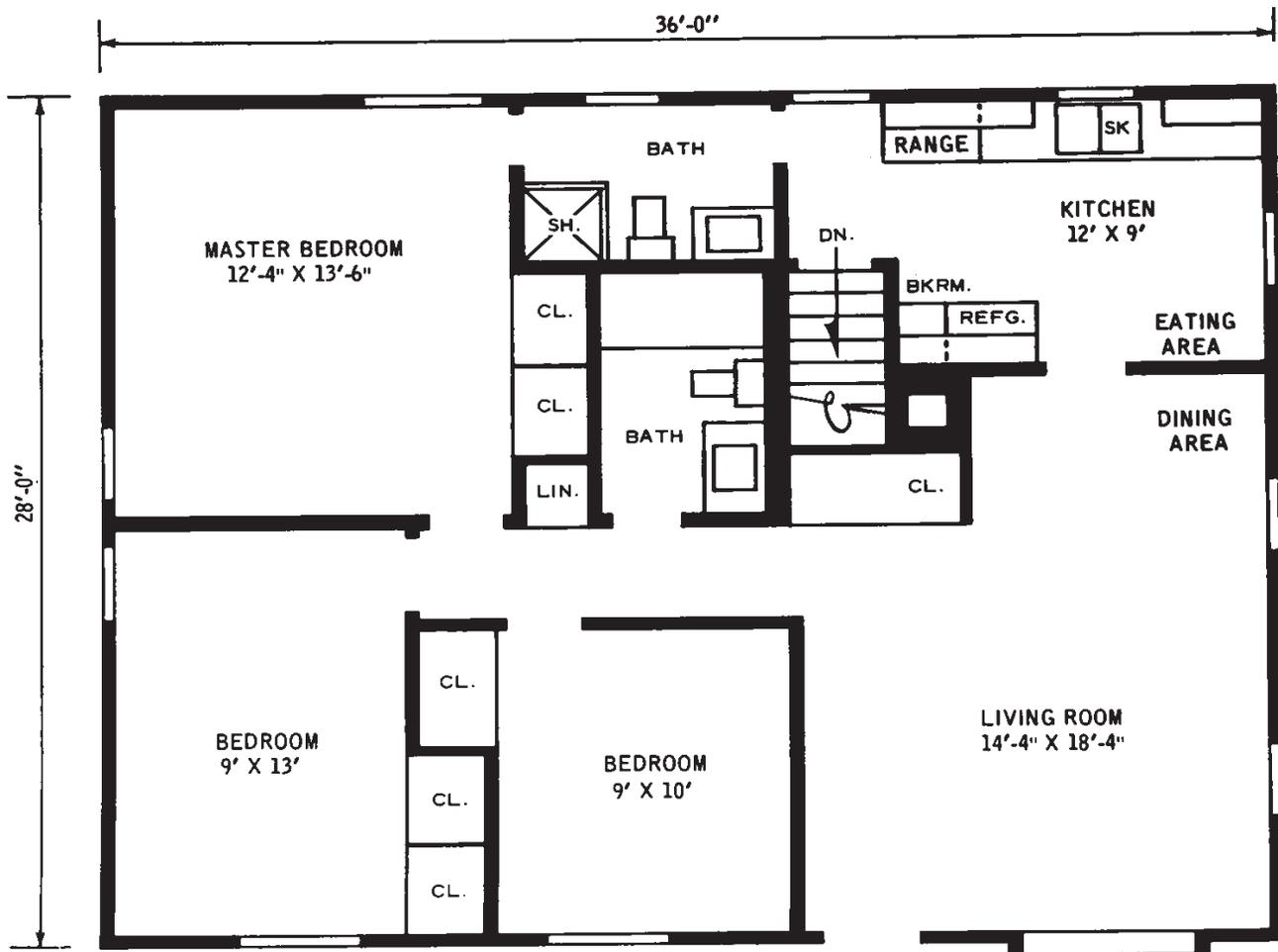
Figure 1. Floor Plan

Research Facilities

The research facilities (5)* consist of: (a) a loading system; (b) a rigid-frame structure for holding the loading cylinders and also serving as the laboratory; and (c) instrumentation for evaluating the full-scale house.

The hydraulic loading system, illustrated in Figures 2 and 3, is capable of simulating any combination of gravity and wind load imposed by nature. Gravity loads can be held constant while wind loads are cycled on and off. The cylinders were used in tension, as shown in Figures 4, 5, 6, 7, and 8, which also show the rigid frames and purlins holding the cylinders.

The instrumentation consisted of 29 deflection records, bonded SR-4 strain gages, an oscillograph and amplifier, a linearsyn differential transformer, a strain indicator, Ames dials, and surveyor's transits. Deflections were continuously recorded at 19 points for horizontal movement, and at 10 points for vertical movement, during wind loading. Figures 9, 10, 11 and 12.

The bonded SR-4 strain gages were used to detect floor joist vibrations, which were amplified and recorded by the oscillograph. All other instrumentation was used for obtaining corrections and calibrations, or conducting supplementary side studies. For more details see the step-by-step erection and testing procedures.

*Numbers in parentheses refer to appended references.

Figure 2.
Hydraulic Test Stand
and Vibration Equipment.

The machine at left was used to simulate gravity and wind load. Six different wind-load pressures were required and provided by a system of solenoid and pressure regulating valves activated by an electrical timer. At right are the osciligraph and amplifiers used for recording joist vibrations.
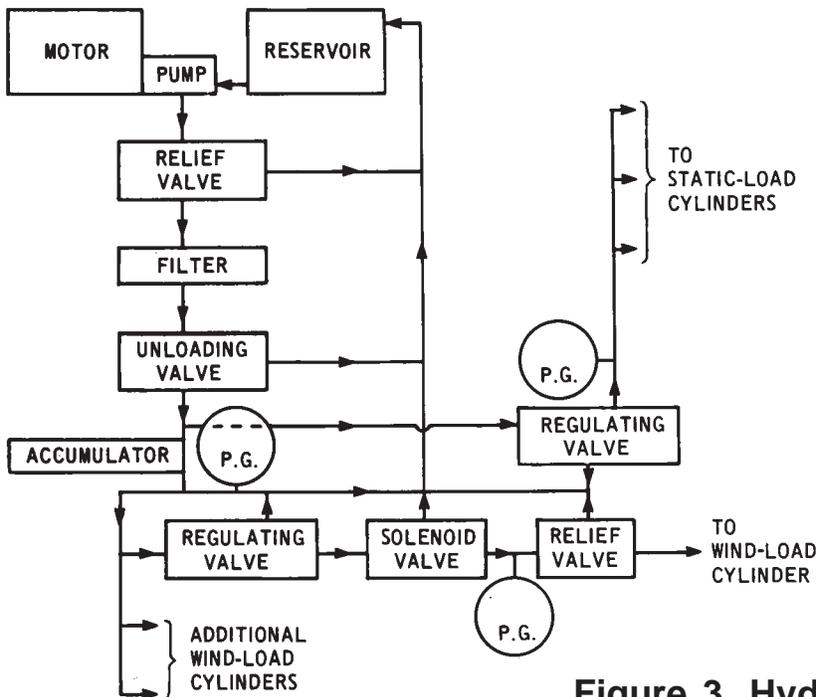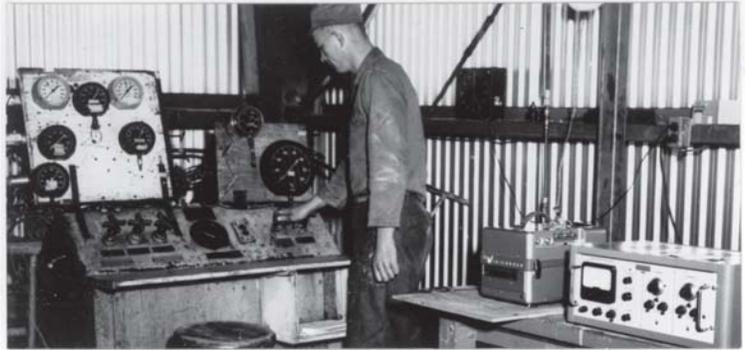
Figure 3. Hydraulic Loading System.

Figure 4.

Side view of test house, inside rigid-frame laboratory, showing wind-load cylinders and connections for loading end walls.
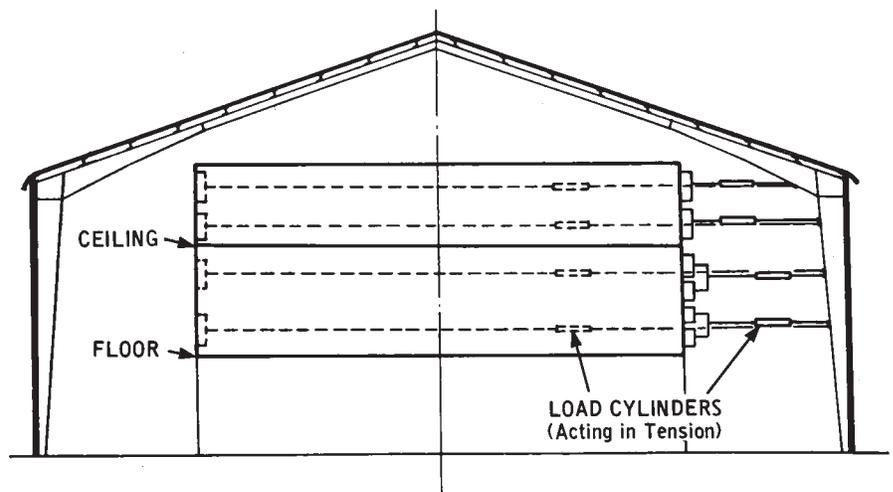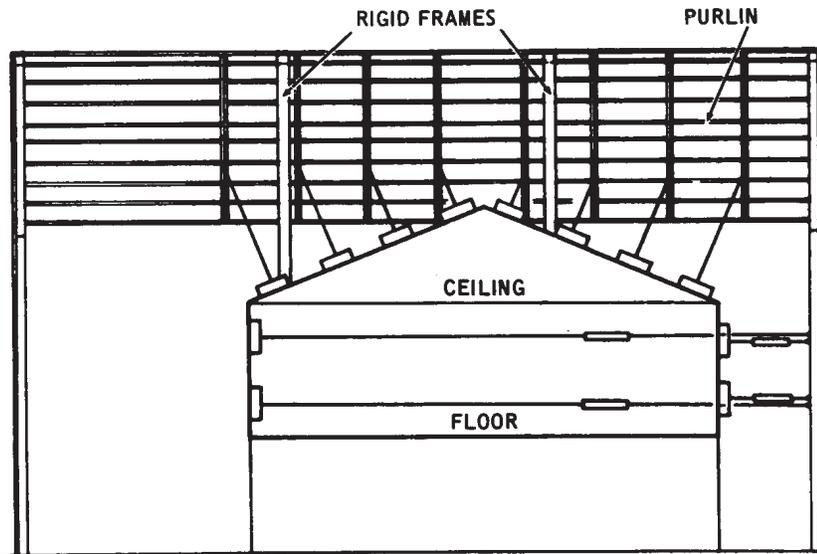
Figure 5.
Cross section of test house, inside the rigid-frame laboratory, showing wind-load cylinders and connections for side walls and roof loading.
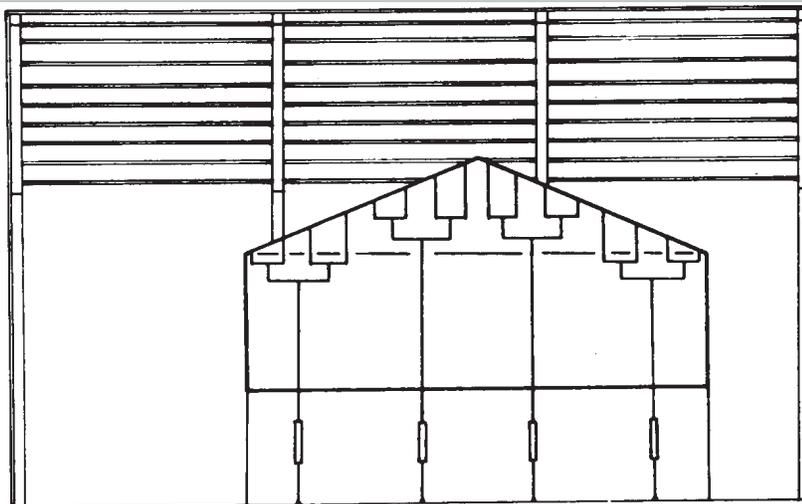
Figure 6.
Cross section of test house with gravity-load cylinders and connections for roof loading.
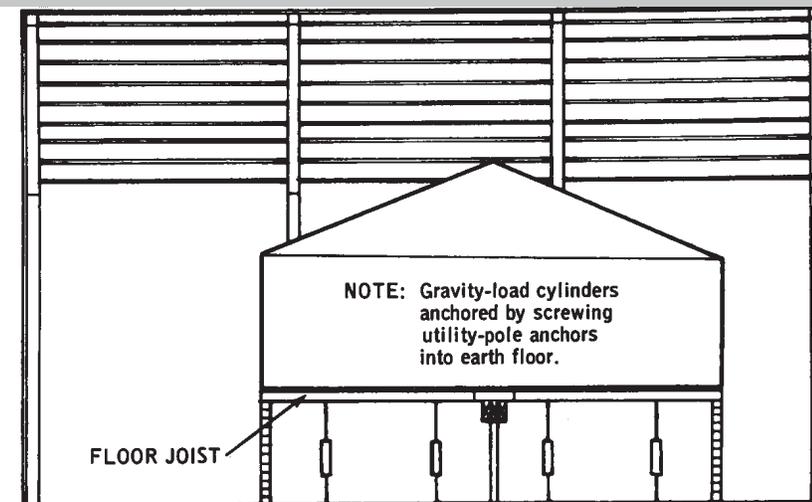
Figure 7.
Cross section of the house, showing gravity-load cylinders and connections for loading floor joists.

Figure 9.
Leeward end, showing numbers and locations of deflection recorders.
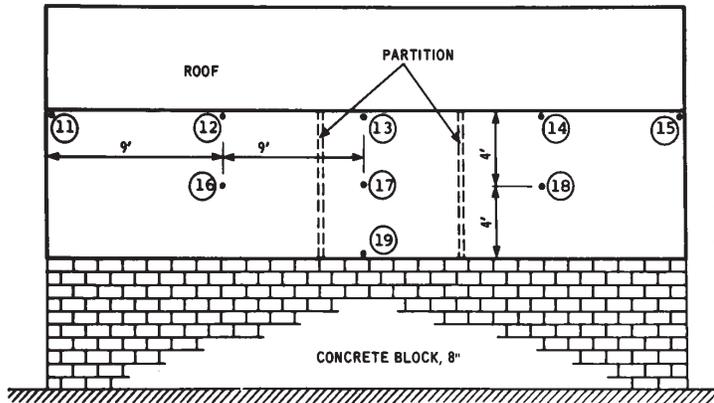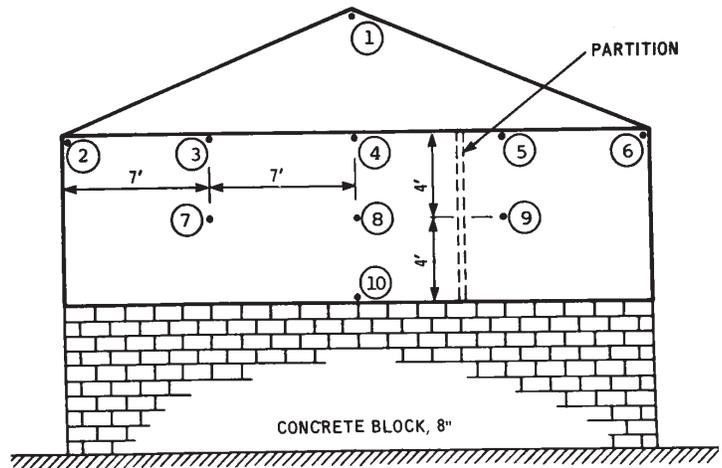
Figure 10.
On leeward side, numbers and locations of deflection recorders.

Figure 8.
The structurally complete house, showing (a) outward wind loading (suction) being applied to windward roof; (b) outward wind loading being applied to part of leeward end; and (c) the windward side which is being loaded inwardly by tension cylinders inside the test house.
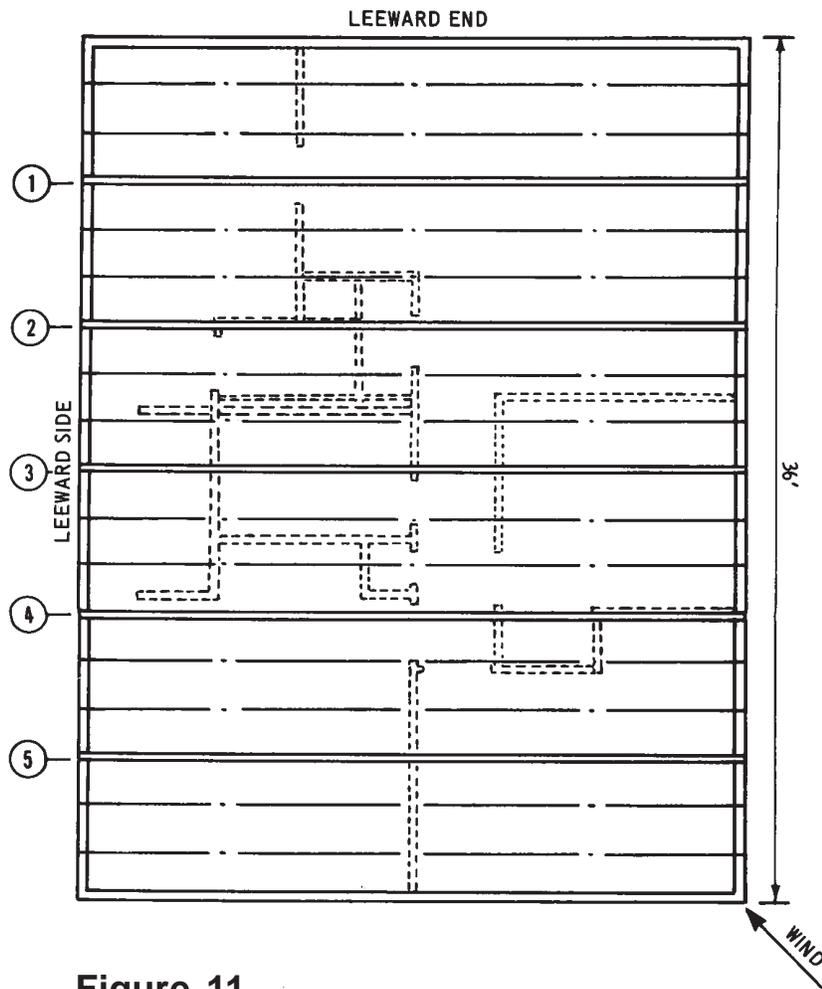
Figure 11.
Plan view, showing roof trusses, by number, for which
chord and crown deflections were recorded.
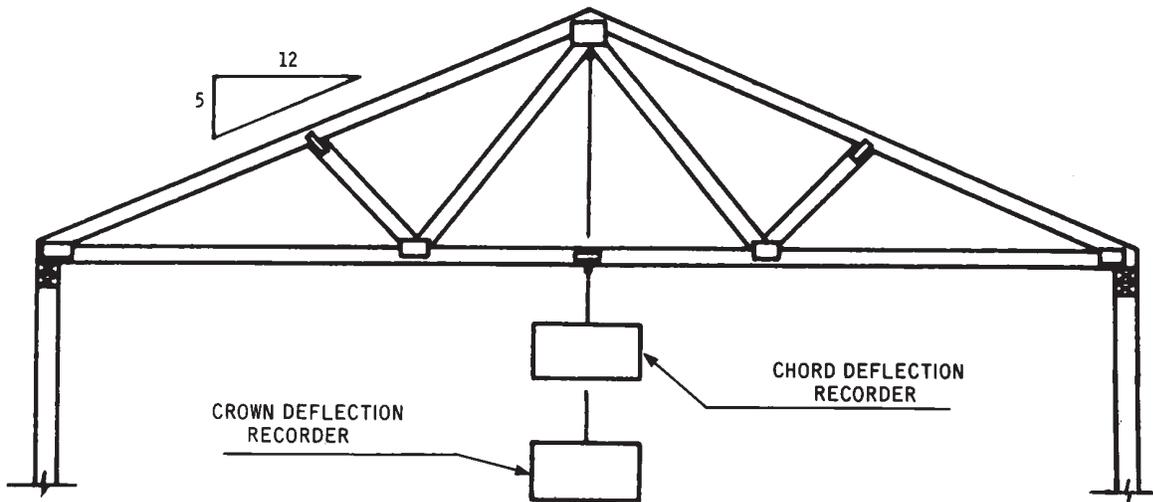
Figure 12. TECO plate truss, spaced 2 feet o.c. in test house.

EXPERIMENTAL PROCEDURE

Selection of Materials

All framing lumber was No. 2 southern pine, from a local mill, visually inspected and grade marked SPIB. Because much of the study was directed toward floor performance, and knowing that considerable variation usually exists within any lumber grade, it was decided that further selection of joists should be made on the basis of actual modulus of elasticity, E, and each joist within a range of about 1.5 to 1.9 x 10⁶.

The modulus of elasticity for each joist was determined by loading it to induce approximately 300 psi and then 1200 psi, while continuously recording the deflection. The difference in deflection between that at 300 psi and that at 1200 psi, together with the load required to produce this difference, provided the necessary information for calculating the modulus of elasticity.

Selected joists were randomly located on the foundation, as shown in Figure 13, and allowed to stabilize in moisture content before conducting the final selection test. Moisture contents ranged from 10.1% to 12.4% except joist No. 28, which was 15.8%. The size of each joist was measured to determine moment of inertia, I, at the time of final selection.
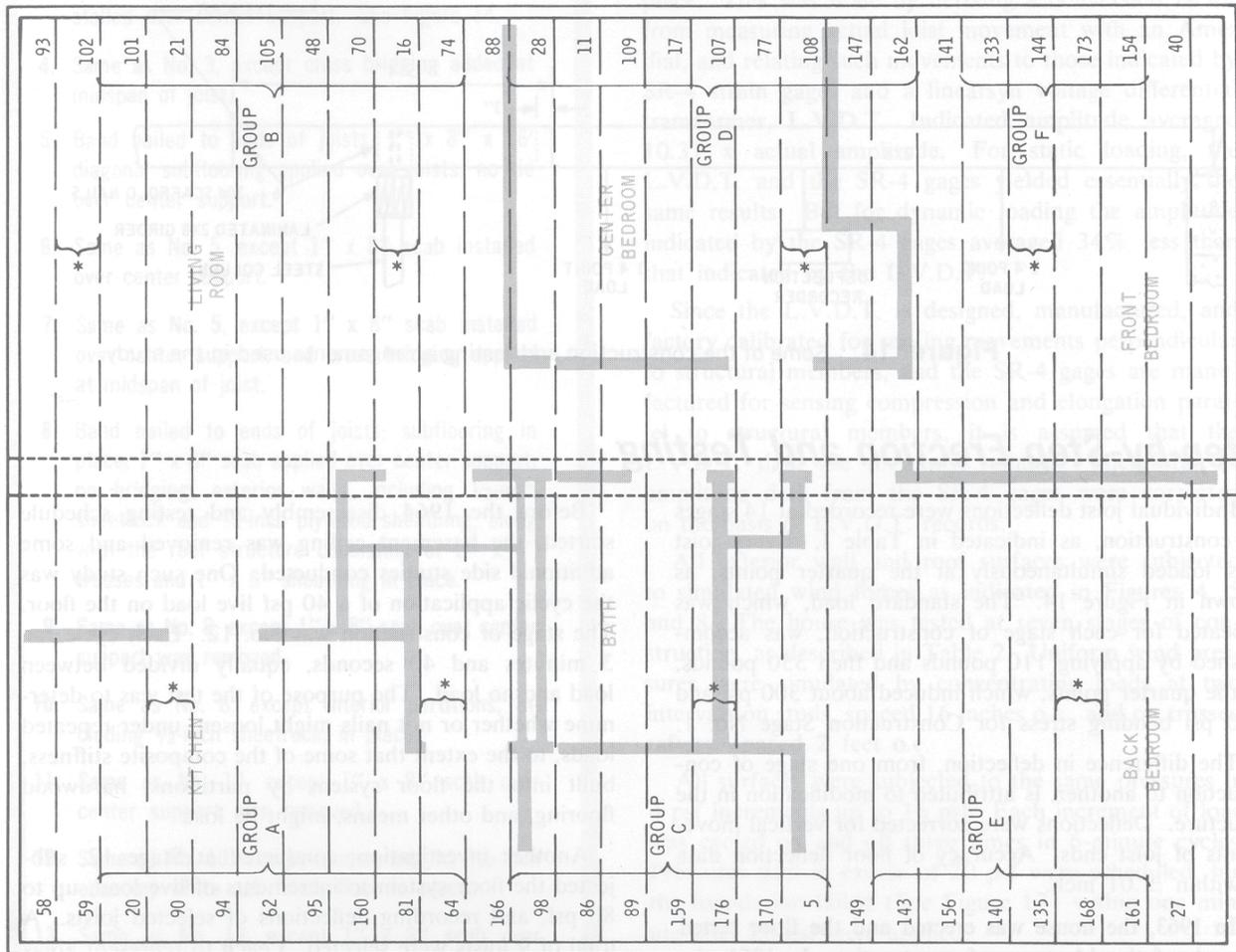
Figure 13.

Floor plan showing joist numbers,
locations and groups.
*Joists loaded to 344 pounds each
at center, and suddenly released
for vibration recording.
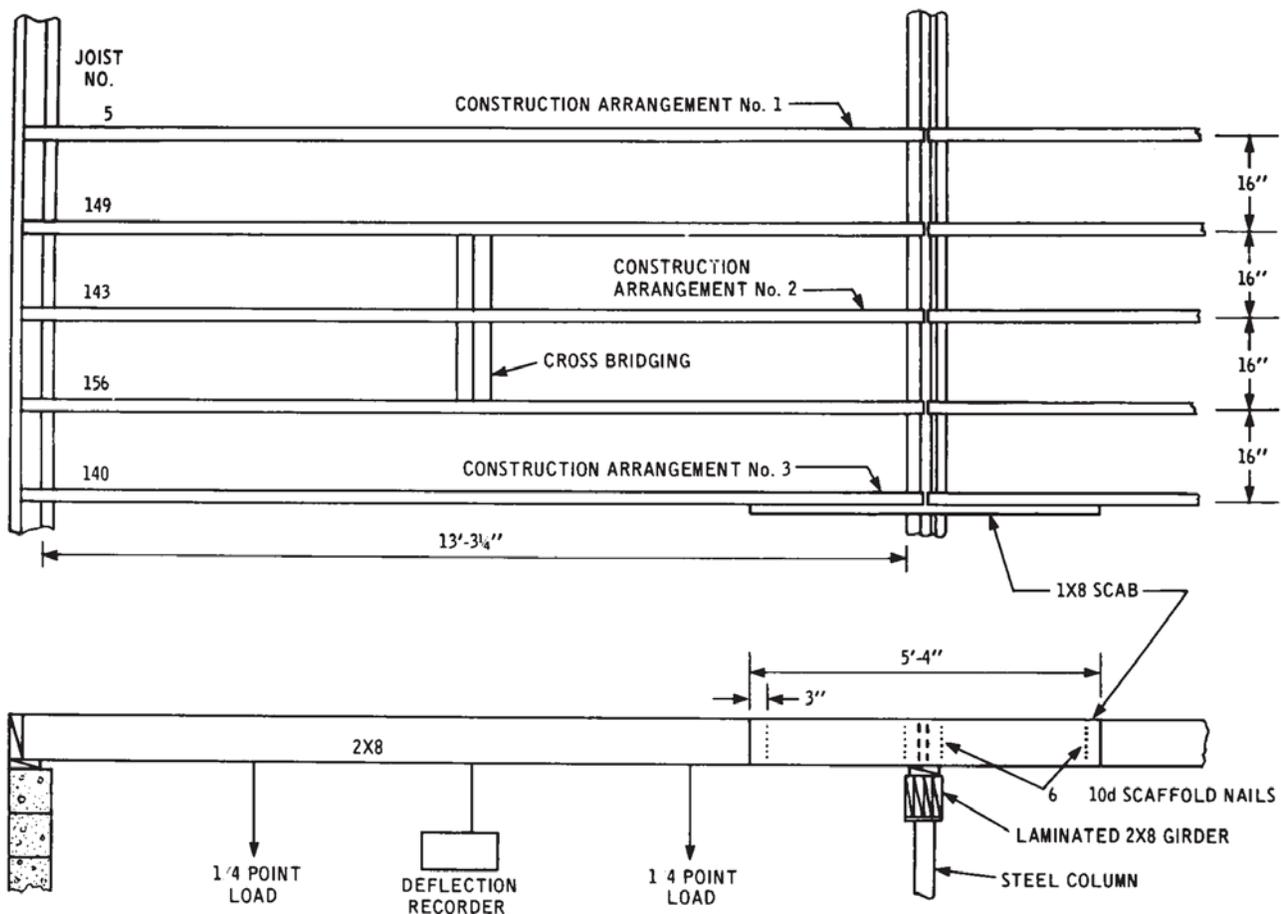
Figure 14. Some of the construction and testing arrangements used in the study.

Step-by-Step Erection and Testing

Individual joist deflections were recorded at 14 stages of construction, as indicated in Table 1. Every joist was loaded simultaneously at the quarter points, as shown in Figure 14. The standard load, which was repeated for each stage of construction, was accomplished by applying 110 pounds and then 330 pounds, at the quarter points, which induced about 300 psi and 900 psi bending stress for Construction Stage No. 1.

The difference in deflection, from one stage of construction to another, is attributed to modification in the structure. Deflections were corrected for vertical movements of joist ends. Accuracy of floor deflection data is within ±0.01 inch.

In 1963, the house was erected and the floor tested at each of the 14 stages of construction. In 1964, the house was disassembled and the floor tested at the same stages of construction, except those requiring cross bridging. The time lapse, between the 1963 and 1964 tests, ranged from 9 to 15 months. This procedure provided opportunity for studying the effects of short-term aging and/or repeatability of test results on a full-scale specimen.

Before the 1964 disassembly and testing schedule started, the basement ceiling was removed and some additional side studies conducted. One such study was the cyclic application of a 40 psf live load on the floor. The stage of construction was No. 12. Each cycle ran 3 minutes and 40 seconds, equally divided between load and no load. The purpose of the test was to determine whether or not nails might loosen, under repeated loads, to the extent that some of the composite stiffness, built into the floor system by partitions, hardwood flooring, and other means, might be lost.

Another investigation, conducted at Stage 12, subjected the floor system to increments of live load, up to 80 psf, and recording deflections of selected joists. A total of 9 joists were selected, 3 each to represent areas without partitions, those with partitions parallel to the joists, and areas with partitions perpendicular to joists. The process was repeated for Construction Stages 6, 5, 3 and 1, except deflections were recorded at fewer load levels.

Floor vibration tests were conducted on 43 joists the same stages of construction at which deflections were

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TABLE 1
Stages of Construction at Which Floor Tests Were Conducted

Stage No.	Description
1.	Band fastened to ends of joists with three 16d nails, no tie over center support. See Figure 14.
2.	Same as No. 1, except cross bridging added at midspan of joist. See Figure 14.
3.	Band nailed to ends of joists, 1" x 8" scab installed over center support. See Figure 14.
4.	Same as No. 3, except cross bridging added at midspan of joist.
5.	Band nailed to ends of joists, 1" x 8" x 16' diagonal subflooring applied over joists, no tie over center support.
6.	Same as No. 5, except 1" x 8" scab installed over center support.
7.	Same as No. 5, except 1" x 8" scab installed over center support, and cross bridging applied at midspan of joist.
8.	Band nailed to ends of joists; subflooring in place; 1" x 8" scab applied over center support; no bridging; exterior walls, including ½-inch sheetrock and $\frac{3}{8}$-inch plywood sheathing, along with the roof structure consisting of 2" x 4" trusses and 1" x 8" sheathing in place.
9.	Same as No. 8, except 1" x 8" scab over center support was removed.
10.	Same as No. 8, except interior partitions, including ½-inch sheetrock, in place.
11.	Same as No. 10, except 1" x 8" scab over center support was removed.
12.	Same as No. 10, except random-length, 2½-inch economy white oak finish floor in place.
13.	Same as No. 12, except 1" x 8" scab over center support was removed.
14.	Same as No. 12, except ½-inch sheetrock ceiling was applied to bottom of joists. See Figure 15.

recorded. Vibration was induced by suddenly releasing a 688-pound force, equally applied to two joists as indicated in Figure 13. Vibration was recorded for two joists each time the load was released, and a maximum of six joist records were taken for each load-releasing location.

Vibration was sensed by SR-4 strain gages, bonded to the bottom of joists at the center, and recorded by an oscillograph. All joists were equipped with strain gages, but for various reasons, only 43 yielded data. The difference in vibration, from one stage of construction to another, is attributed to modification in the structure.

In order to convert indicated amplitude from the oscillograph records to actual amplitude in inches, it was necessary to calibrate the vibration system in place. This was done by deriving a conversion factor from measuring actual joist movement with an Ames dial, and relating such movements to those indicated by SR-4 strain gages and a linearsyn voltage differential transformer, L.V.D.T. Indicated amplitude averaged 10.37 x actual amplitude. For static loading, the L.V.D.T. and the SR-4 gages yielded essentially the same results. But for dynamic loading the amplitude indicated by the SR-4 gages averaged 34% less than that indicated by the L.V.D.T.

Since the L.V.D.T. is designed, manufactured, and factory calibrated for sensing movements perpendicular to structural members, and the SR-4 gages are manufactured for sensing compression and elongation parallel to structural members, it is assumed that the L.V.D.T. data are the most reliable. Therefore, all amplitude data from the SR-4 gages were corrected on the basis of L.V.D.T. records.

All exterior wall and roof surfaces were subjected to simulated wind forces as indicated in Figures 4, 5 and 8. The house was tested at seven stages of construction, as described in Table 2. Uniform wind pressures were simulated by concentrating loads at two intervals on studs, spaced 16 inches o.c., and on trussed rafters, spaced 2 feet o.c.

All surfaces were subjected to the same pressures in 4 psf increments up to 16 psf. Each increment of load was cycled on and off three times in 6-minute cycles. Pressures well in excess of 20 psf were scheduled, but the foundation failed (See Figure 17) within one minute after 20 psf were applied.

The house was returned to its original position on the foundation, anchored with guy rods at the corners of the windward side, and the step-by-step testing and dismantling were continued as scheduled, except pressures were limited to 16 psf. Pressures were limited to 12 psf in Stages 6 and 7 of Table 2.
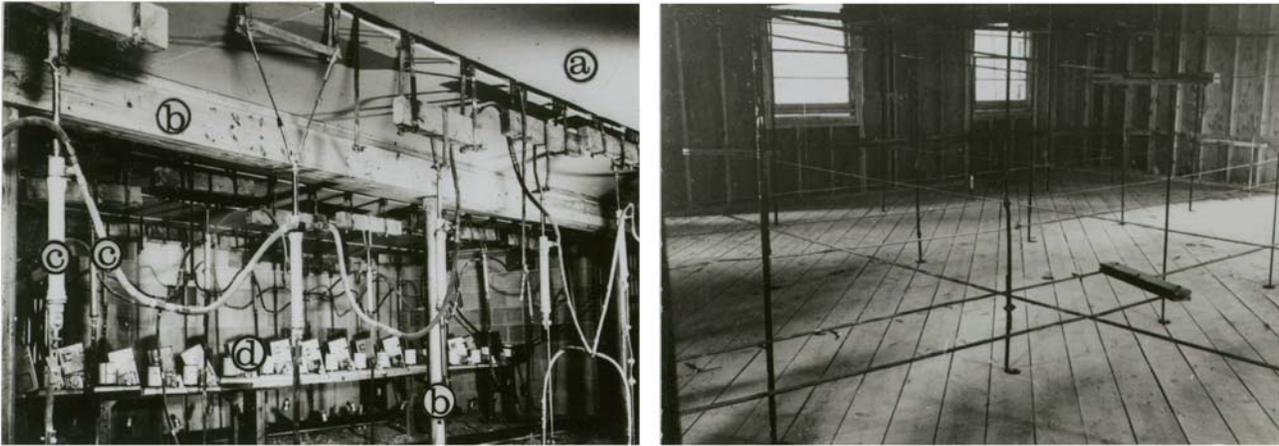
Figure 15. Basement Ceiling and Subfloor.

Photo at left shows: (a) ½-inch sheetrock ceiling with slot through which rigging passes to connect loading cylinders to joists; (b) center beam and steel columns; (c) hydraulic loading cylinders and flexible hose connections; and (d) deflection recorders. At right, a view of the interior after partitions and sheetrock finish were removed.

Simulated gravity loads on the roof were applied as shown in Figure 6. The magnitude of loading always equaled the wind loading for each stage of construction. For example, immediately after applying three cycles of 12 psf for each stage of construction, a gravity load of 12 psf was applied for five minutes.

Horizontal movements were continuously recorded at 19 points on the leeward end and side walls, as in Figures 9 and 10. Because all horizontal deflection recorders were mounted on the steel frame, to which the horizontal loading cylinders were attached, it was necessary to establish a correction factor for each recorder at each load level. Correction factors were established by using transits to measure the horizontal movements of the steel frame wherever recorders were mounted. The degree of

accuracy for the horizontal measurements is considered +/-0.05 inch, because some transit readings could only be read to the nearest millimeter, or 0.04 inch. The deflection recorder has an experimental error of +/-0.01 inch.

While this degree of accuracy would not be acceptable for experiments with small test specimens under controlled atmospheric conditions, it is considered accurate enough for the full-scale house tests. Greater accuracy is always desirable, but the difficulty and cost of attaining it in this case did not seem to be justified.

Vertical movements also were recorded at the crown and at the center of the bottom chord of every third truss, as shown in Figures 11 and 12.

Figure 16.

View of ceiling during Dismantling Stage No. 7, showing a 4-foot strip of ½-inch sheetrock adjacent to leeward end and side. As it was obvious that practically all resistance to outward movement, at the top plate, would be removed with the ceiling, the 4-foot strip of sheetrock was left in place, to see how effective it would be. The end wall pulled away from the sheetrock at 12 psf.
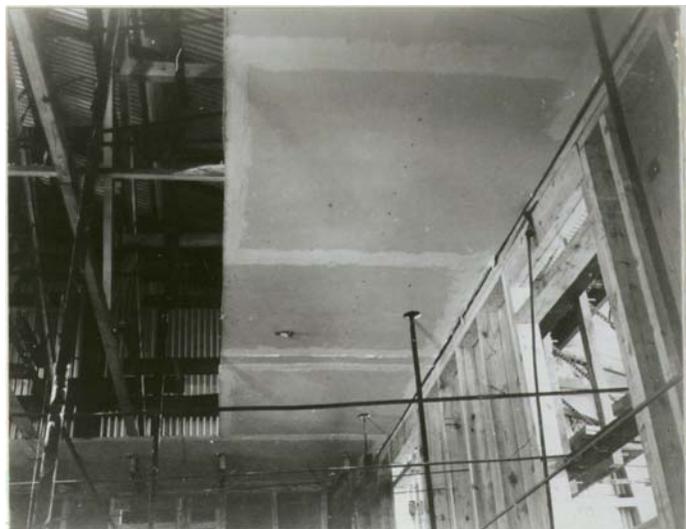
TABLE 2
Stages of Dismantling at Which House Racking Tests Were Conducted

| Stage No.	Description
1.	House structurally complete with $^3/_8$-inch exterior plywood sheathing; 1" x 8" roof sheathing; ½-inch sheetrock on walls, partitions and ceilings.
2.	Same as No. 1, except sheetrock joints weretaped and plastered.
3.	Same as No. 1 and 2, except sheetrock was removed from partitions.
4.	Same as No. 1 and 2, except partitions were removed.
5.	Same as No. 1 and 2, except partitions and sheetrock on walls were removed.
6.	Same as No. 1 and 2, except partitions, wall sheetrock, and roof sheathing removed.
7.	Same as No. 6, plus removal of all sheetrock ceiling, except a 4-foot strip adjacent to the leeward end and side wall. See Figure 16.
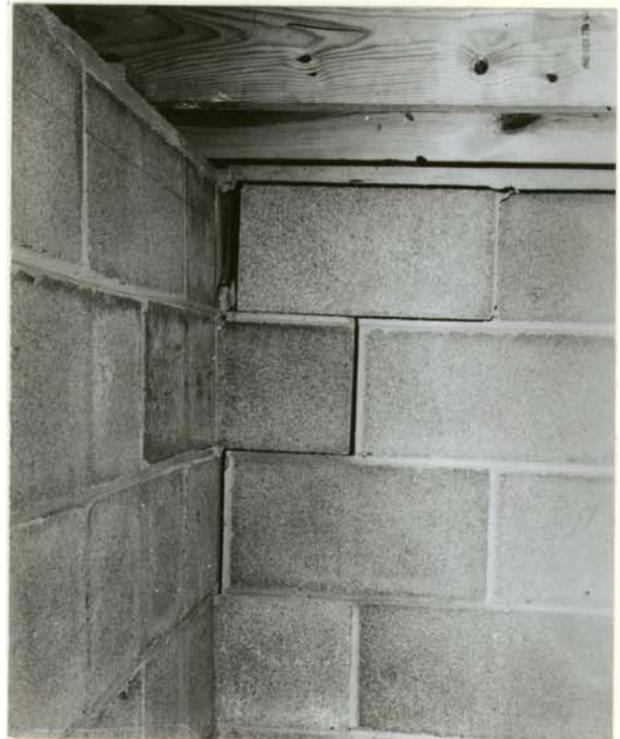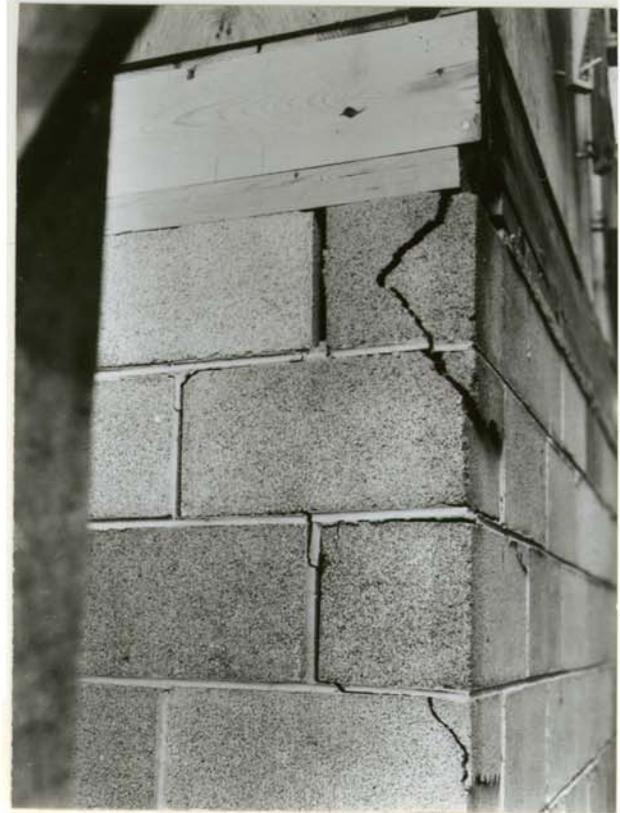
Figure 17. Foundation Failure.

All four corners and both side walls cracked within one minute after 20 psf were applied to the four walls and two roof surfaces. Photos, above, show foundation failure at the outside and inside corner of leeward side and end.

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RESULTS AND DISCUSSION

Floor Deflections

An analysis of variance of the deflection data indicated that, as joists 27, 40, 58 and 93 were influenced significantly by the end walls, they were not representative of the loading and support conditions of the balance of the joists, and were eliminated.

The remaining 48 joists were treated as a single group until partitions were installed, at Stage 10. Then they were separated into six groups, A through F, as shown in Figure 13. All joists in each group were considered to be affected, in substantially the same manner, by the partition arrangement within each group, and the data were tabulated and analyzed accordingly.

For analytical purposes, the stiffness variation between individual joists was eliminated in the following manner. By examining the formula: $D = 11Pl^3 / 384EI$, it will be seen that deflection, D, must vary inversely with the EI product, in order to maintain a constant relationship. The average EI product, for the group of 48 joists, was 93.4. Individual joist deflections were adjusted by the percentage their EI products varied from the average.

With the EI product eliminated as a variable, it was possible to compare floor stiffness, from one stage of construction to another, on a more accurate basis. Table 3 shows a summary of the results for the group of 48 joists and the first 9 construction stages for the 1963 and 1964 tests.

Previous research, by the National Association of Home Builders (3) and the Housing and Home Finance Agency (1), had provided considerable information on the stiffness attributable to bridging, subflooring, and continuity across the center support (2). Therefore, the trends for those items, indicated in Table 3, are as predicted. Unexpected results were the 1963 indications of increased floor deflections by the erection of the exterior walls and roof structure.

TABLE 3
Reduction of Floor Deflections Attributable to Various Construction Stages
(Group of 48 Joists Corrected for Variation of EI Product)

Construction Stage No.	Abbreviated Description	Percent Reduction 1963	1964
2	Bridging, by test	4.1	
3	Scabbing, by test	44.9	38.6
5	Subflooring, by test	12.2	21.1
4	Bridging, Scabbing, by test	46.9	
	Bridging, Scabbing, by adding No. 2 and 3	49.0	
	Overlapping Credit	3.1	
6	Scabbing and Subflooring, by test	53.1	43.9
	Scabbing and Subflooring, by adding No. 3 and 5	56.1	59.7
	Overlapping Credit	3.0	15.8
7	Bridging, Scabbing and Subflooring, by test	55.1	
	Bridging, Scabbing and Subflooring, by adding 2, 3 and 5	61.2	
	Overlapping Credit	6.1	
8	Scabbing, Subflooring, Walls and Roof Structures, by test	38.8	53.1
6	Scabbing and Subflooring, by test	53.1	53.1
	Wall and Roof Structure Credit	-14.3	0
9	Subflooring, Walls and Roof Structure, by test	16.3	24.6
5	Subflooring, by test	12.2	21.1
	Wall and Roof Structure Credit	4.1	3.5

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Figure 18. Comparative Deflections at 14 Stages of Construction.

Average deflections for the composite group of 48 joists at each stage of construction are shown. Four other joists, influenced significantly by end walls, were eliminated as non-representative of the loading and support conditions of the balance of the joists.

CONSTRUCTION STAGE NUMBERS (See Table 1)

*With 1x8 scab at center support.
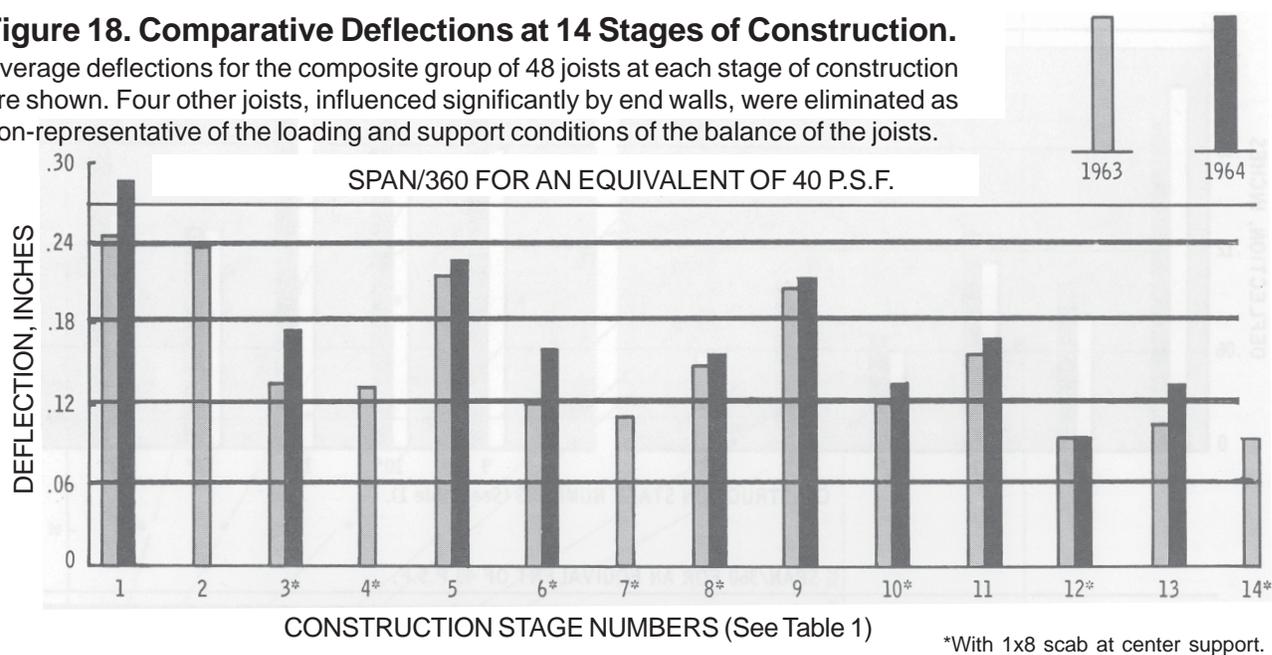
Since the 1964 tests showed that removing the exterior walls and roof structure made no difference in floor deflections, and that calculated reductions of floor deflections, due to fixed-end action for Construction Stage No. 8, was 0.017 inch, the 1963 test results for No. 8 are considered incorrect, and the effect of walls and roof structure on floor deflections is considered insignificant.

Average deflection for the composite group of 48 joists, at each stage of construction, is shown in Figure 18. A better comparison of average deflections is provided by Figure 19, which considers the five groups after partitions were installed. Construction Stage No. 9 is included in Figure 19 to emphasize the significant reduction of deflection in groups under partitions, while deflections usually increased slightly for those groups without partitions.

The average increase of deflections in the 1964 tests, over the 1963 tests, is assumed to be due to some relaxation in holding capacity of the smooth shank nails. An attempt was made to verify this assumption by conducting Test No. 12 twice in 1964, first with the scabs that were installed in 1963, then with the scabs installed immediately before the 1964 tests. The latter test resulted in slightly smaller deflections, and considerably more uncertainty as to the cause.

The 1963 data indicated that only three distinctly different conditions were represented in the flooring system of the complete house. These conditions were in areas with (a) no partition, (b) partitions parallel to joists, and (c) partitions perpendicular to joists. Joists 48, 70 and 105; 81, 88 and 108; and 17, 62 and 109 were selected to represent the three areas.

In addition to evaluating the influence of partitions on floor deflections, it was desirable to investigate performance at load levels that would produce the allowable deflection in the weakest area of the floor. The influence of partitions and floor performance, under varying loads, are shown in Figure 20. The relatively straight lines of Figure 20 show that the floor system was performing within elastic limits in all three areas, even at 80 psf.

Such performance was not surprising for Construction Stage 13, which did not have 1x8 scabs providing continuity across the center support. But stress concentrations in the 1x8 scabs were expected to exceed elastic limits, since 80 psf would induce a theoretical bending stress of 4822 psi, if the effects of such components as floors and partitions are ignored.

The ratio of actual deflection, at any stage of construction, to the calculated deflection of Construction Stage 1 will provide a factor for correcting the deflection formula. For example, the average deflection of Group A at Stage 13 was 0.10 inch. The correction factor to apply to the deflection formula is 0.10/0.27, or 0.37, and the formula becomes $D = 5Wl^3(0.37)/384EI$. The correction factors for all groups at 10 stages of construction, listed in Table 4, are based on 1964 tests. By using these correction factors, with known ranges of E values, designers can predict floor deflections much more accurately than by applying the standard formula to joists alone.
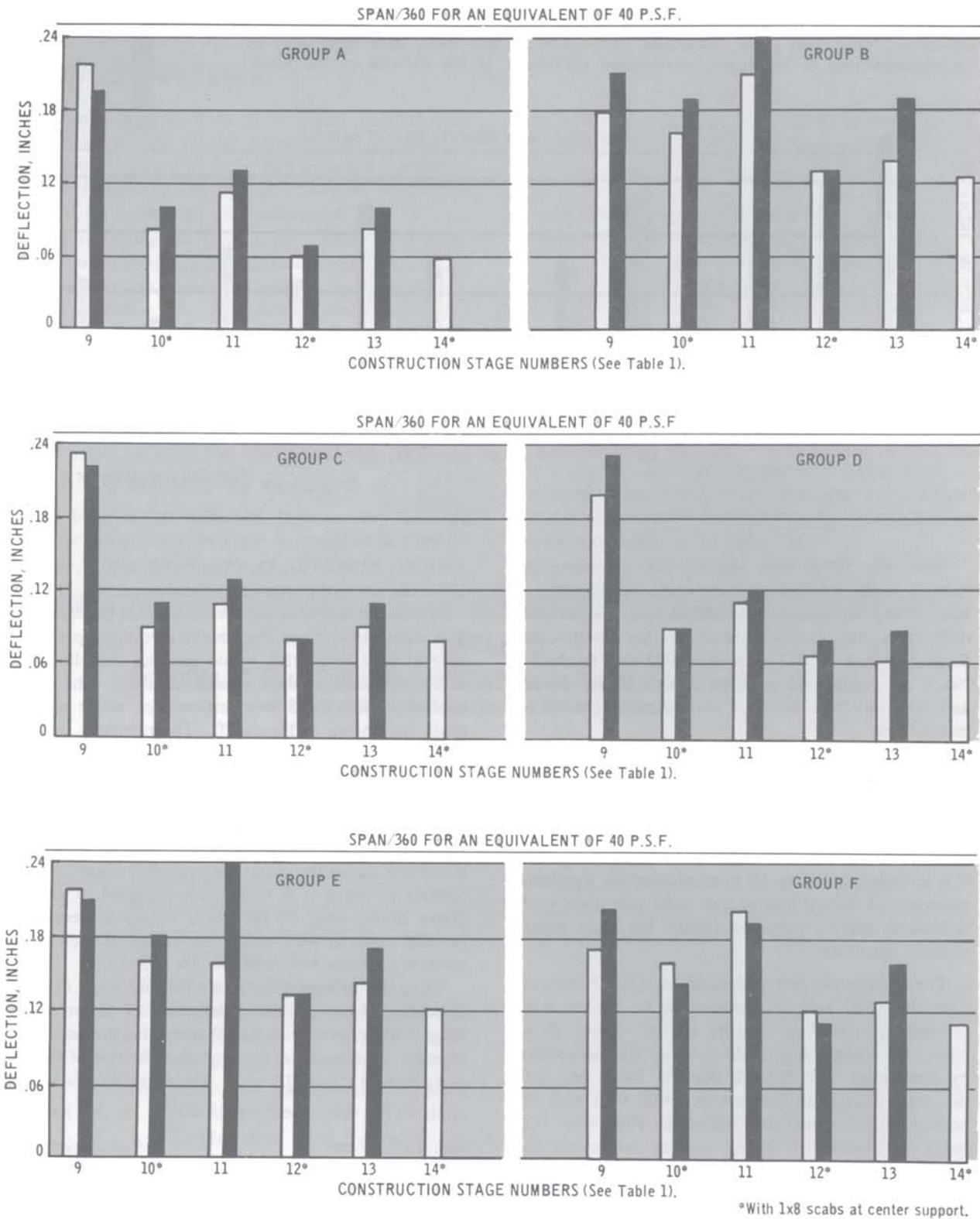
Figure 19. Comparative Deflections by Groups.

Average deflections for six groups, in the last six stages of construction, are shown by the open bars for 1963, the solid ones for 1964.

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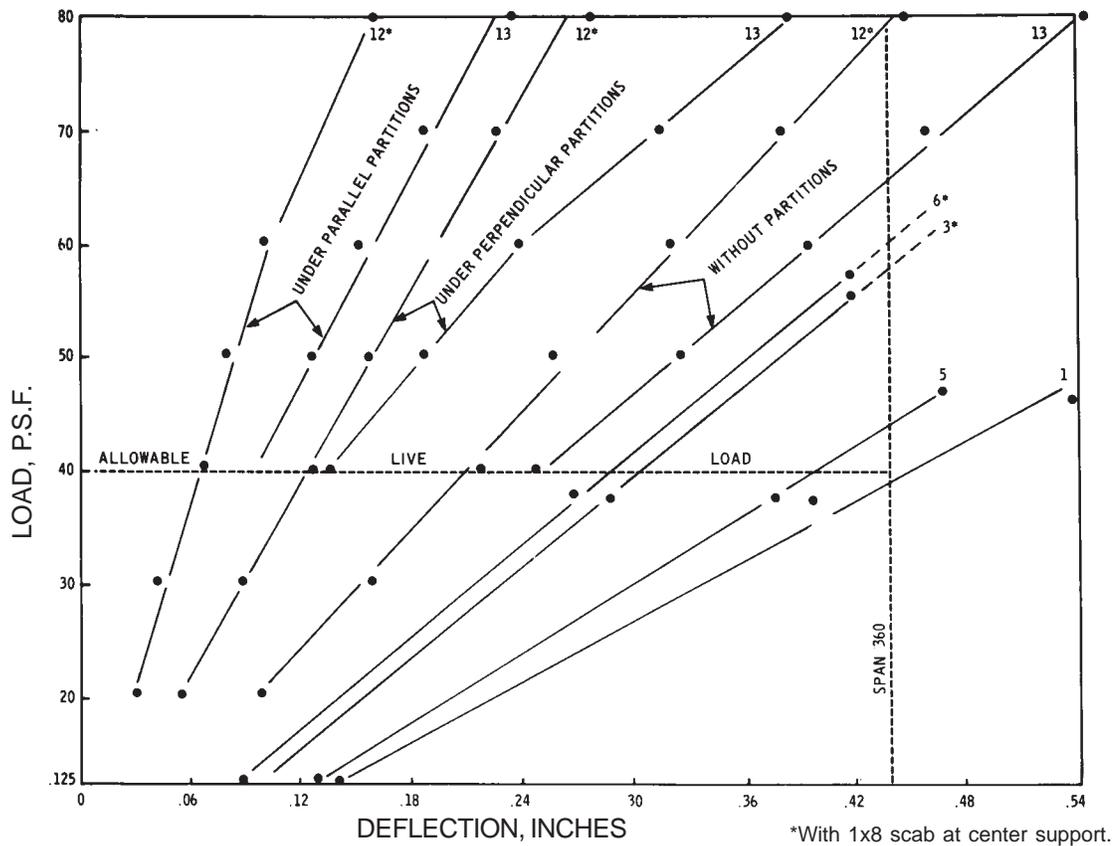
Figure 20. Floor Joist Deflections at Selected Stages of Construction.

The cyclic application of 40 psf on the floor, in 1964 at Stage 12, produced no creep, set, or change in deflection at the end of 529 cycles. Since the 1964 deflections were slightly more than in 1963, and cyclic loading had no effect, aging may be more important to structural performance than repetitive loads within the elastic limits.

Referring again to Figure 20, it can be seen that partitions parallel to and over joists are the most effective in reducing deflections. This is because partitions, when connected to the floor by a bottom plate, tend to act as deep beams, and as cantilever beams if fastened to a wall. Partitions also act as suspension supports from the ceiling, if fastened to bottom chord of roof trusses.

Partitions perpendicular to joists, even near the center of the house, were suprisingly effective in reducing floor deflections. Perhaps much of the stiffening effect

TABLE 4 Correction Factors for Calculating Deflections

Construction Stage No.	A	B	C	D	E	F
1	1.04	1.07	1.07	1.04	1.04	1.04
3*	.67	.63	.63	.59	.67	.67
5	.78	.79	.93	.85	.81	.74
6*	.59	.59	.59	.52	.59	.67
8*	.59	.59	.59	.63	.59	.56
9	.78	.78	.81	.85	.78	.74
10*	.37	.70	.41	.33	.67	.52
11	.48	.89	.48	.44	.89	.70
12*	.26	.48	.30	.30	.48	.41
13	.37	.70	.41	.33	.63	.59

*With 1x8 scab at center support.

Sample Calculations

$$\text{Correction Factor} = \frac{\text{actual D at standard load}}{\text{allowable D at standard load}}$$

$$\text{Allowable D at 40 psf} = \text{span}/360 = \frac{159.25''}{360} = .44''$$

$$\text{Allowable D at standard load of 24.8 psf} = \frac{24.8 \times .44}{40} = .27''$$

Example: From Group A, Stage 13: Average D = .10". Therefore, the Correction Factor = $\frac{.10''}{.27''}$ = .37, and the predicted finish floor deflection, D, of a room with partitions over and perpendicular to 2 x 8 joists = $\frac{5Wl^3(.37)}{384EI}$.

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can also be attributed to suspended cantilever-beam action of partitions and vertical support provided by the roof structure. No doubt, perpendicular partitions improve load-sharing qualities of floor joists, and also act as deep, inverted T-stems which greatly improve plate-action of floors.

The customary method of predicting deflections of floor systems, with wood joists, is to neglect the stiffening contributions of everything except the joists, and to calculate their deflections by the formula $D = 5Wl^3 / 384EI$. Assuming an allowance deflection of span/360 with a live load of 40 psf, the calculated deflection for Construction Stage 1 is 0.27 inch.

Floor Vibrations

The three aspects of vibration considered in this study are frequency, amplitude, and duration. The average change in vibration from one stage of construction to another is shown in Figures 21-24. Vibration patterns for three joists, representing floor areas with partitions parallel to joists, perpendicular to joists, and without partitions, are shown in Figure 25. Average frequencies remained constant at about 21 cycles per second, for Stages 1-4, but the application of 1 x 8 subfloor in Stage 5 decreased the frequency to 15 cps. The average frequency for Stages 6-14 ranged from 15 to 18 cps. Partitions and hardwood flooring, which significantly reduced static deflection, amplitude, and duration of vibration, increased frequency slightly.

Vibration amplitude does not seem to be affected by bridging, but scabbing reduced it slightly. Hardwood flooring and ½-inch sheetrock ceiling were also quite effective in reducing amplitude; but partitions were, by far, the most effective of all modifications.

Duration does not seem to be affected by bridging or scabbing, but Figure 25 shows how very effective are partitions in practically stopping floor vibrations. Finish flooring and ½-inch sheetrock ceiling also reduced duration, significantly, in non-partitioned areas.


Figure 21.
Comparative Floor Vibrations at 14 Stages of Construction.

*With 1x8 scabs at center support.
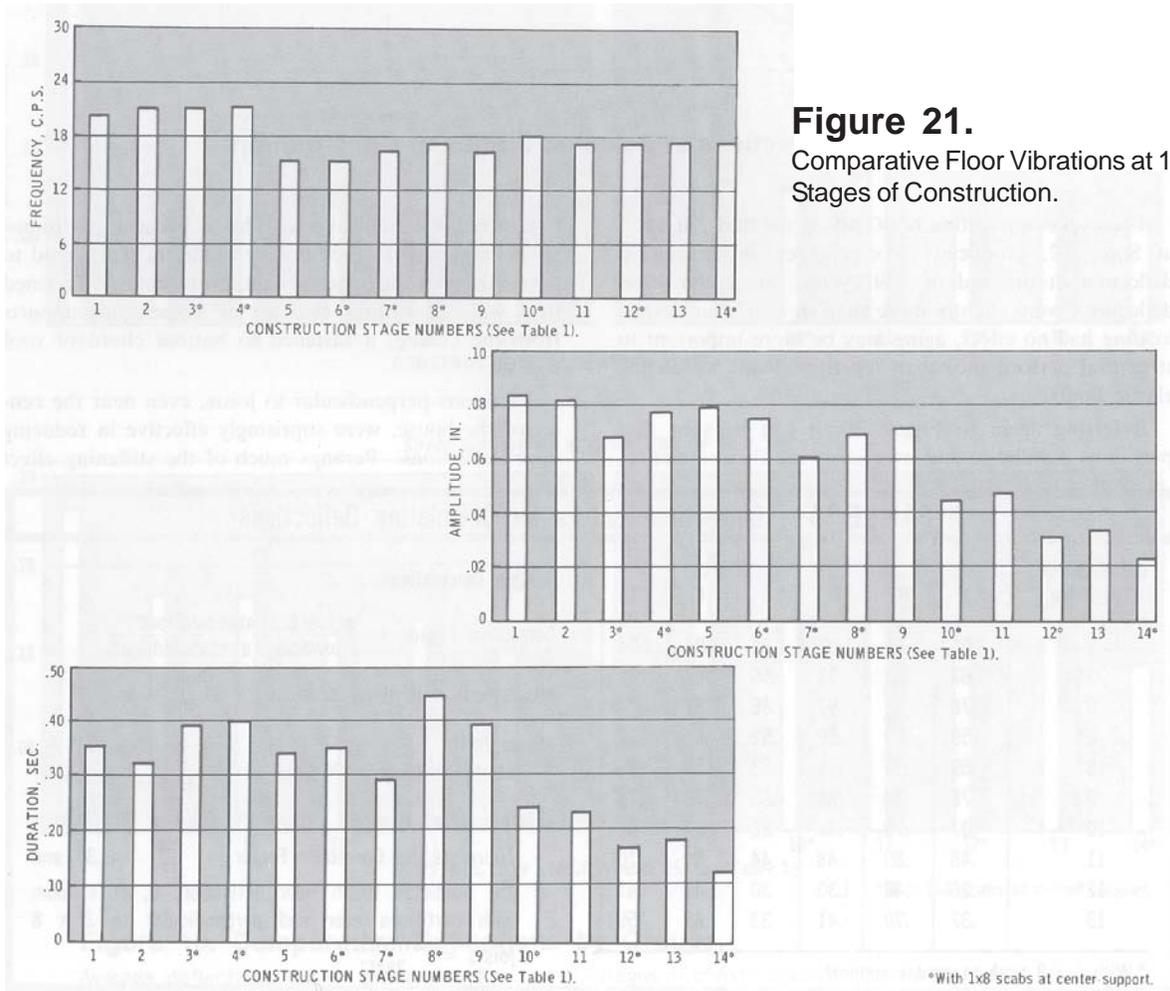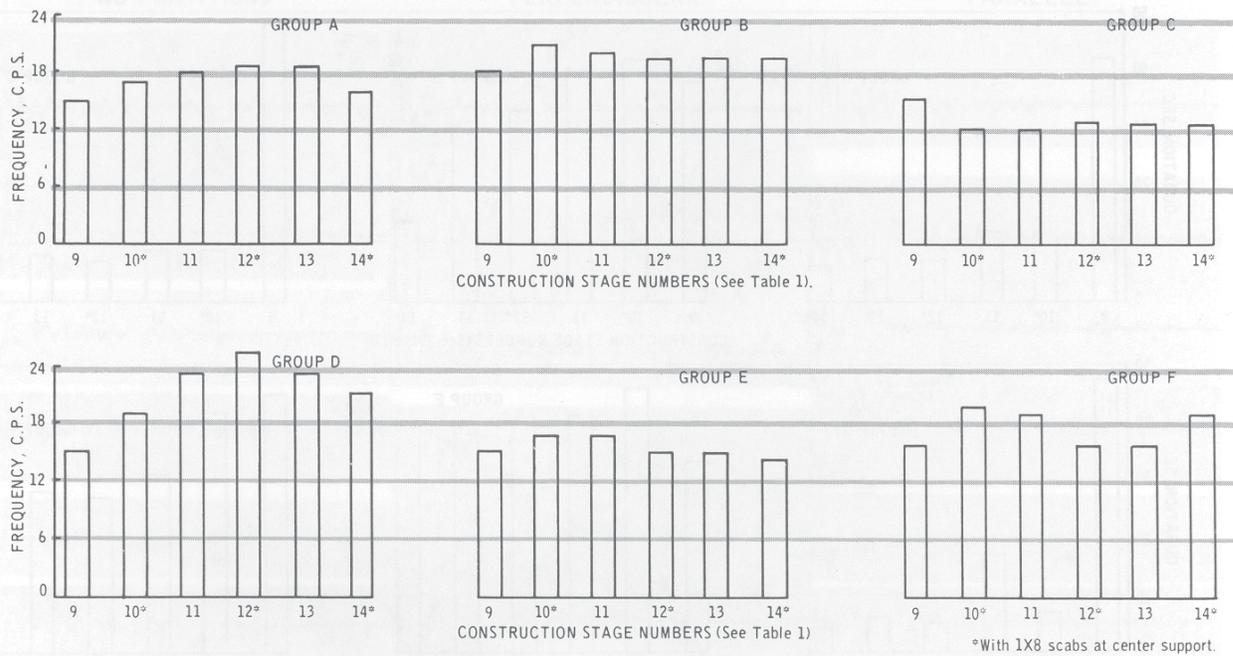
**Figure 22. Comparative Vibration Frequencies by Groups.**
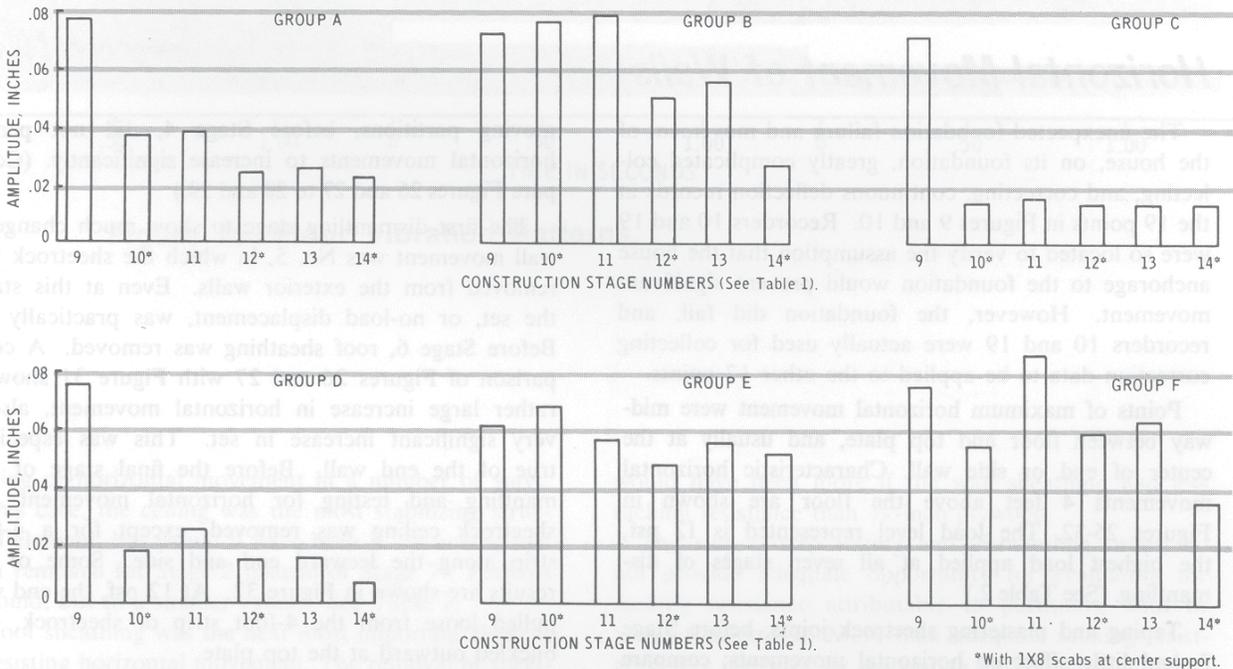
**Figure 23. Comparative Vibration Amplitude by Groups.**
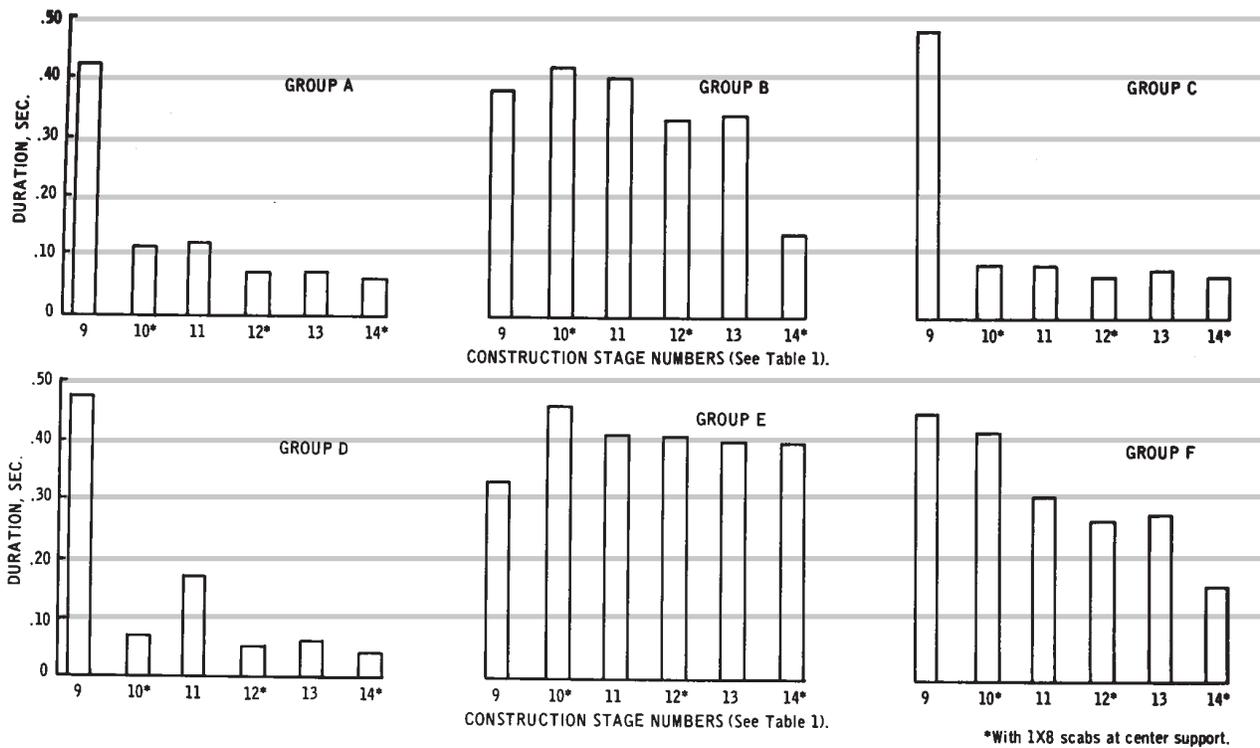
Figure 24. Comparative Duration by Groups.

Horizontal Movement of Walls

The unexpected foundation failure and movement of the house, on its foundation, greatly complicated collecting, and correcting, continuous deflection records at the 19 points in Figures 9 and 10. Recorders 10 and 19 were so located to verify the assumption that the house anchorage to the foundation would prevent significant movement. However, the foundation did fail, and recorders 10 and 19 were actually used for collecting correction data to be applied to the other 17 points.

Points of maximum horizontal movement were midway between floor and top plate, and usually at the center of end or side wall. Characteristic horizontal movements 4 feet above the floor are shown in Figures 26-32. The load level represented is 12 psf, the highest load applied at all seven stages of dismantling. (See Table 2.)

Taping and plastering sheetrock joints, before Stage 2, had little effect on horizontal movements; compare Figures 26 and 27. Removing sheetrock from partitions, before Stage 3, made little difference. Even removing

partitions, before Stage 4, did not permit horizontal movements to increase significantly. (Compare Figures 26 and 27 to 28 and 29.)

The first dismantling stage to show much change in wall movement was No. *5,* in which the sheetrock was removed from the exterior walls. Even at this stage, the set, or no-load displacement, was practically nil. Before Stage 6, roof sheathing was removed. A comparison of Figures 26 and 27 with Figure 31 shows a rather large increase in horizontal movement, also a very significant increase in set. This was especially true of the end wall. Before the final stage of dismantling and testing for horizontal movement, the sheetrock ceiling was removed, except for a 4-foot strip along the leeward end and side. Some of the results are shown in Figure 32. At 12 psf, the end wall pulled loose from the 4-foot strip of sheetrock, and buckled outward at the top plate.

The results, of this part of the study, strongly suggest that a typical wood-frame house may resist

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## FLOOR VIBRATIONS WITH JOISTS AND PARTITIONS
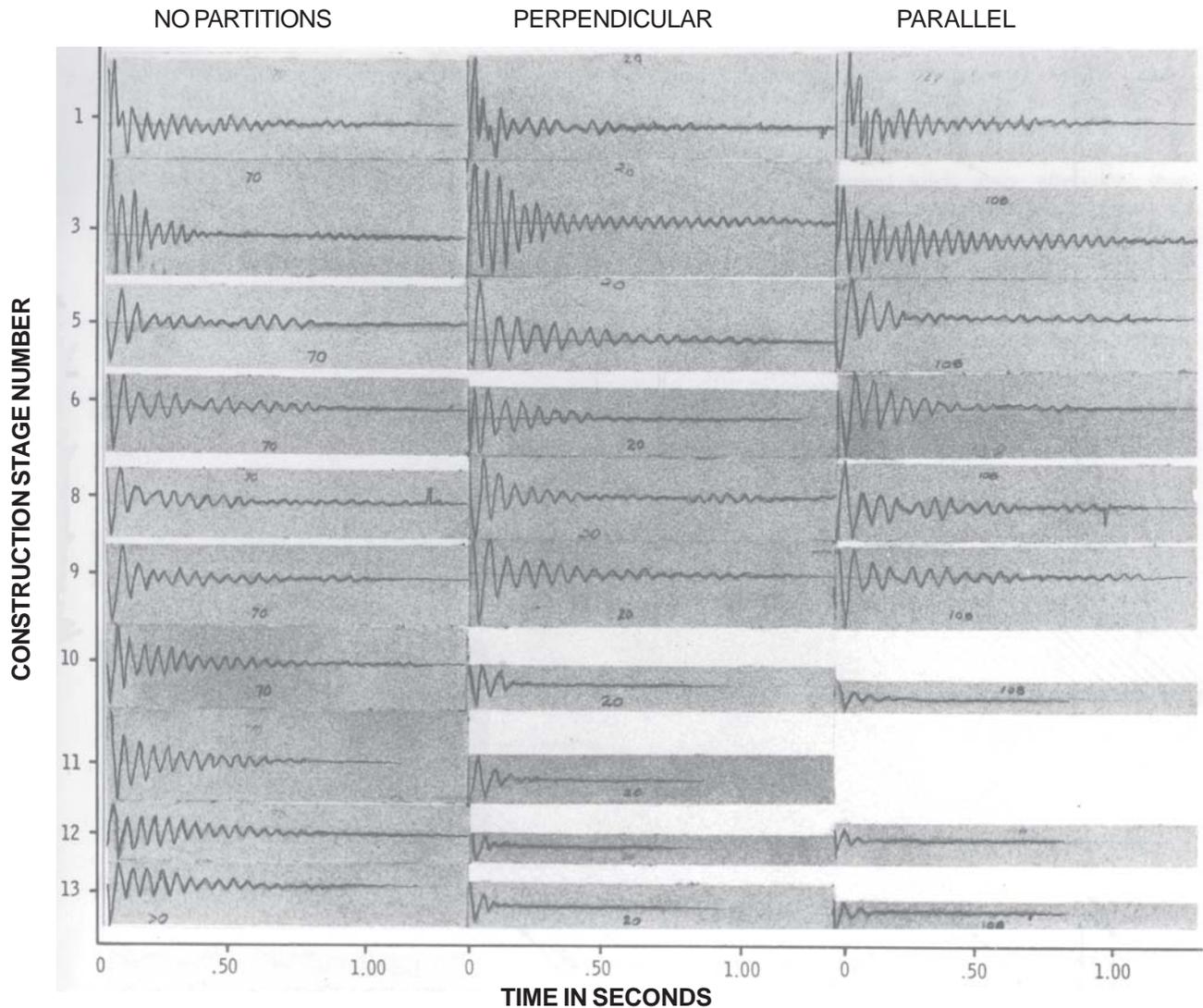
Figure 25. Floor Vibration Patterns.

racking or horizontal movement in a number of ways. In this case, the ceiling was the most stabilizing structural element, but would it have been if the ceiling had been removed for Stage 2 instead of Stage 7? Perhaps it would, but to a smaller extent. See Table 2.

Roof sheathing was the next most important element in resisting horizontal movement. The removal of sheetrock from the exterior walls permitted some increase in horizontal movement; but, no doubt, the movement would have been more if the wall sheathing had less racking resistance than $3/_8$-inch plywood.

The step-by-step testing and dismantling order did not provide adequate opportunity for evaluating the racking resistance attributable to partitions, with or without sheetrock. More than adequate racking resistance was provided by the ceiling and $3/_8$-inch plywood wall sheathing. Because of this, the removal of partitions caused little change in horizontal movement.

21
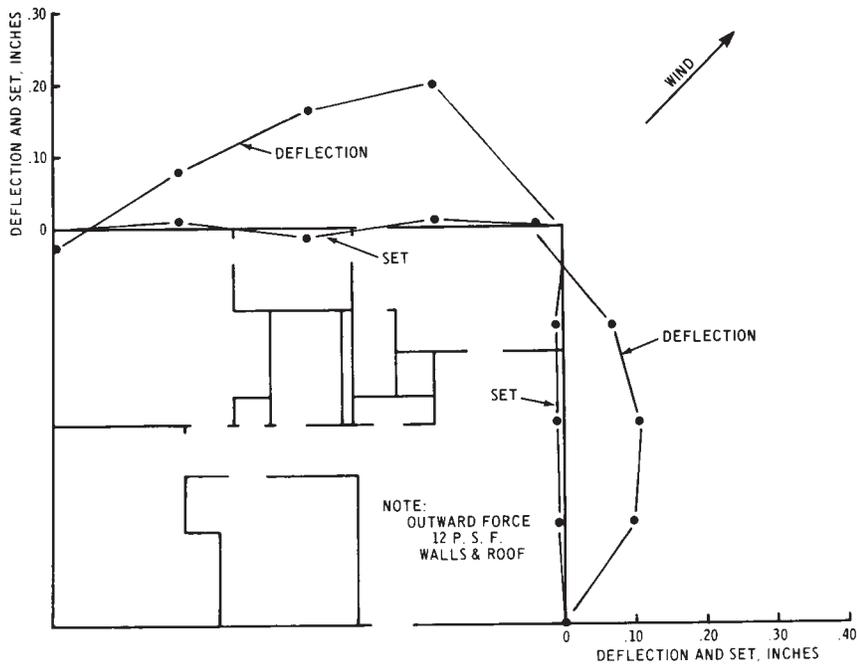
Figure 26. Stage No. 1.

WALL MOVEMENT
**4 feet above floor**

(See Table II)
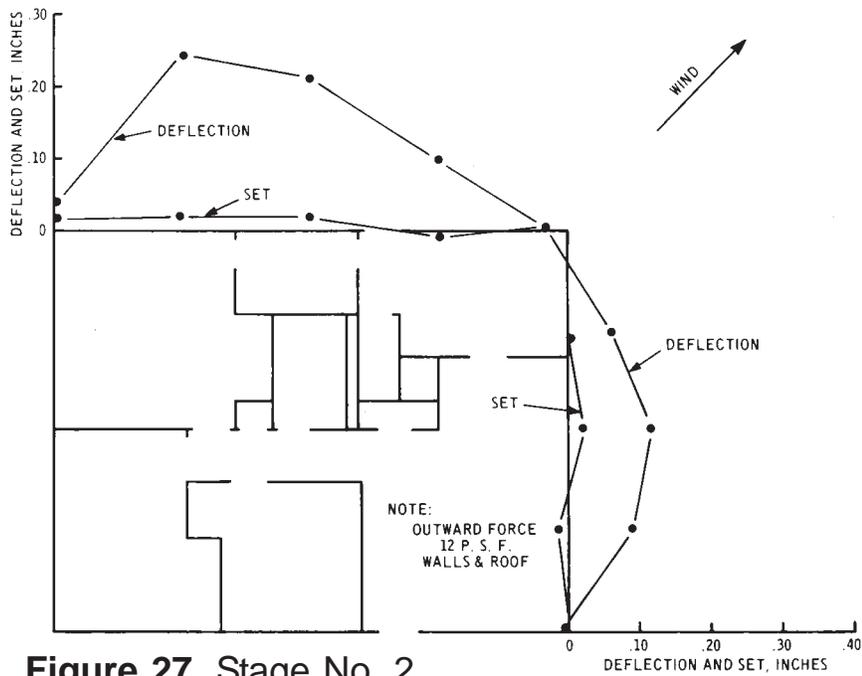
Figure 27. Stage No. 2.

22

Vertical Movement of Crown and Chord

Vertical movement of crown and chord was recorded for five trusses, as indicated in Figure 12. Vertical movements in both directions, at 12 psf, are plotted in Figures 33 and 34 for all seven stages of dismantling, except the 12 psf gravity load was inadvertently omitted after the wind-load failure in Stage 7.

Partitions were not removed until after test 3 was conducted. Deflections, up and down, increased substantially after partitions were removed. Resistance to vertical movement, attributable to partitions, also is indicated in Figure 33, Stages 1, 2 and 3 for Truss No. 1. This was not over a partition, and it moved more than the others, before all partitions were removed.

The roof structure appeared to be more resistant to gravity load than to wind load, as indicated in Figure 34. A possible reason is that the metal-plate-connected truss resists downward loads more effectively than upward loads. Another reason is that the same live loads were repeated for each stage. No adjustments were made for the decrease in dead load from one stage to another. Originally, adjustments in live load to compensate for changing dead load seemed unnecessary, since all loading was intended to be well within the elastic limit.
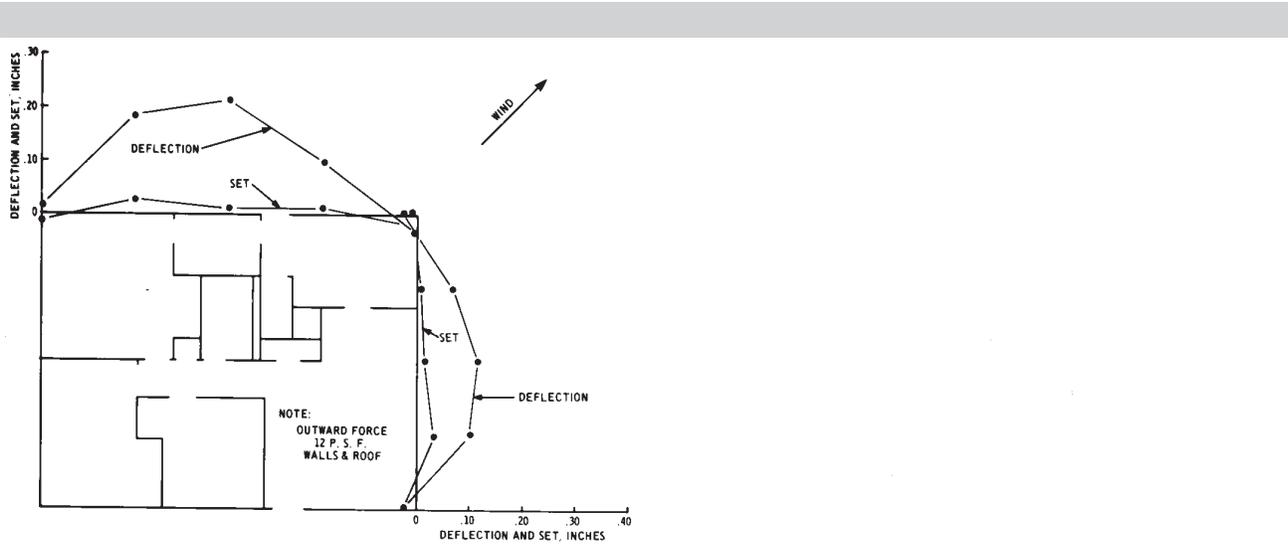

**Figure 28.** Stage No. 3.

WALL MOVEMENT
4 feet above floor
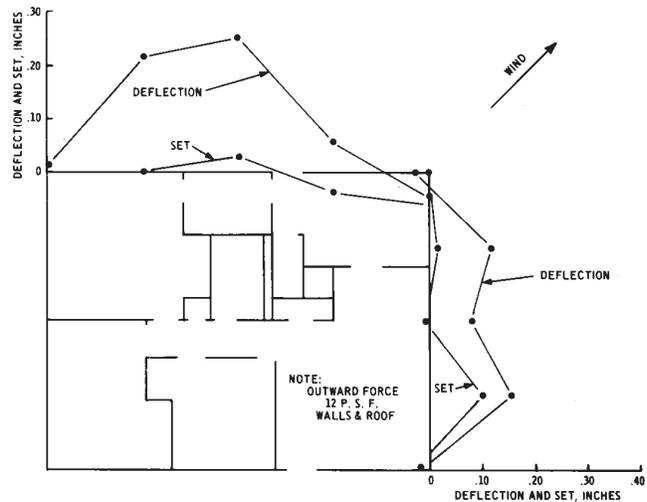
(See Table II)

Figure 29. Stage No. 4.

23
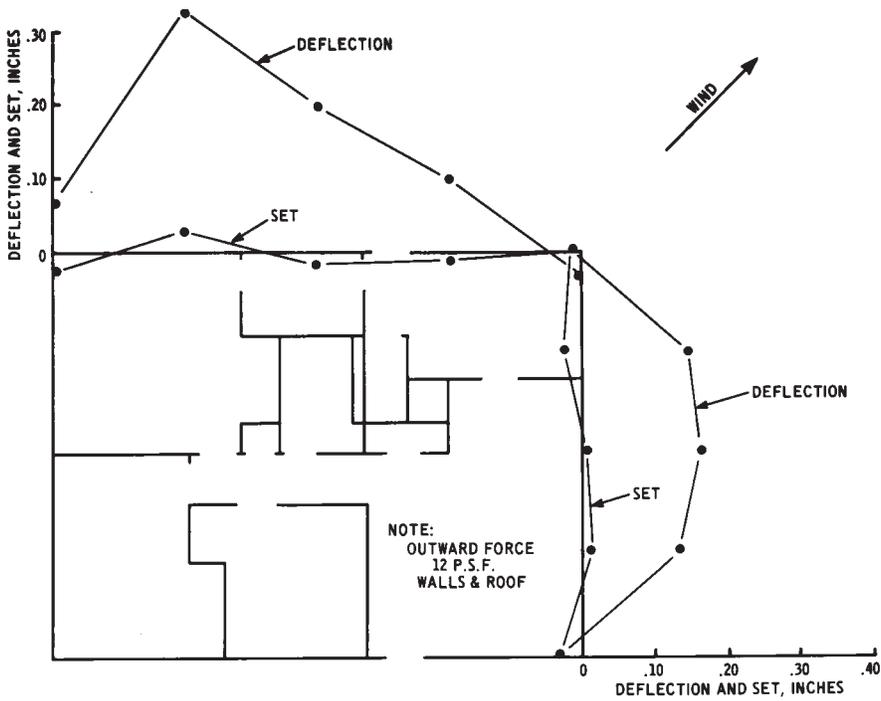
Figure 30. Stage No. 5.

WALL MOVEMENT
4 feet above floor
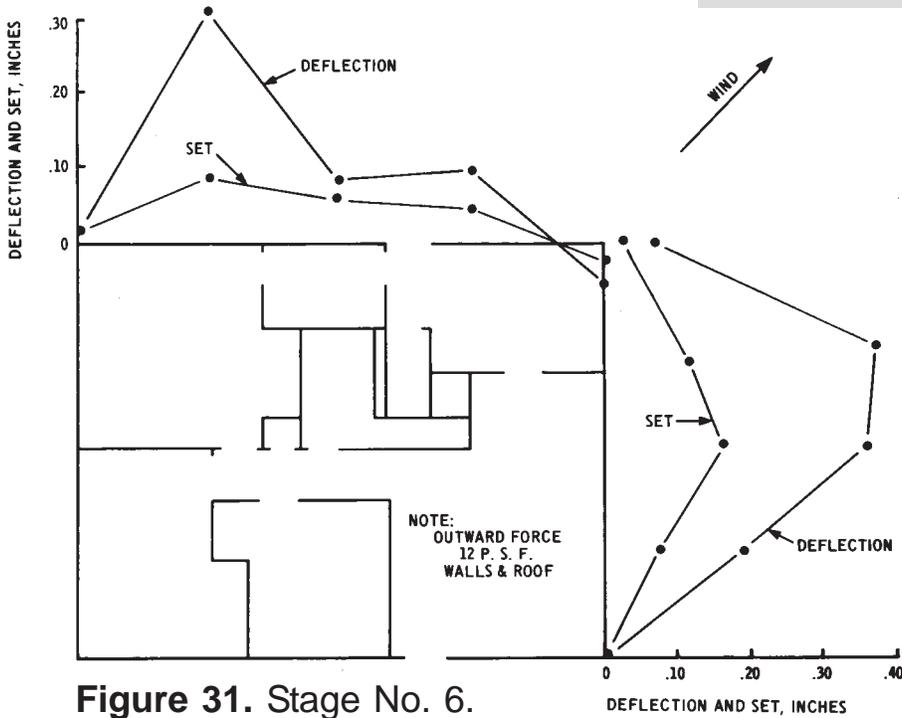
(See Table II)

Figure 31. Stage No. 6.

WALL MOVEMENT
4 feet above floor

(See Table II)

DEFLECTION AND SET INCHES

3.24″

DEFLECTION

1.90″   1.58″

.81″   SET   1.02″

41″

.30
.20
.10
0

WIND

SET   DEFLECTION

NOTE:
Outward force
12 P.S.F.
walls & roof

0   .10   .20   .30   .40   .50   .60   .70   .80
DEFLECTION AND SET, INCHES
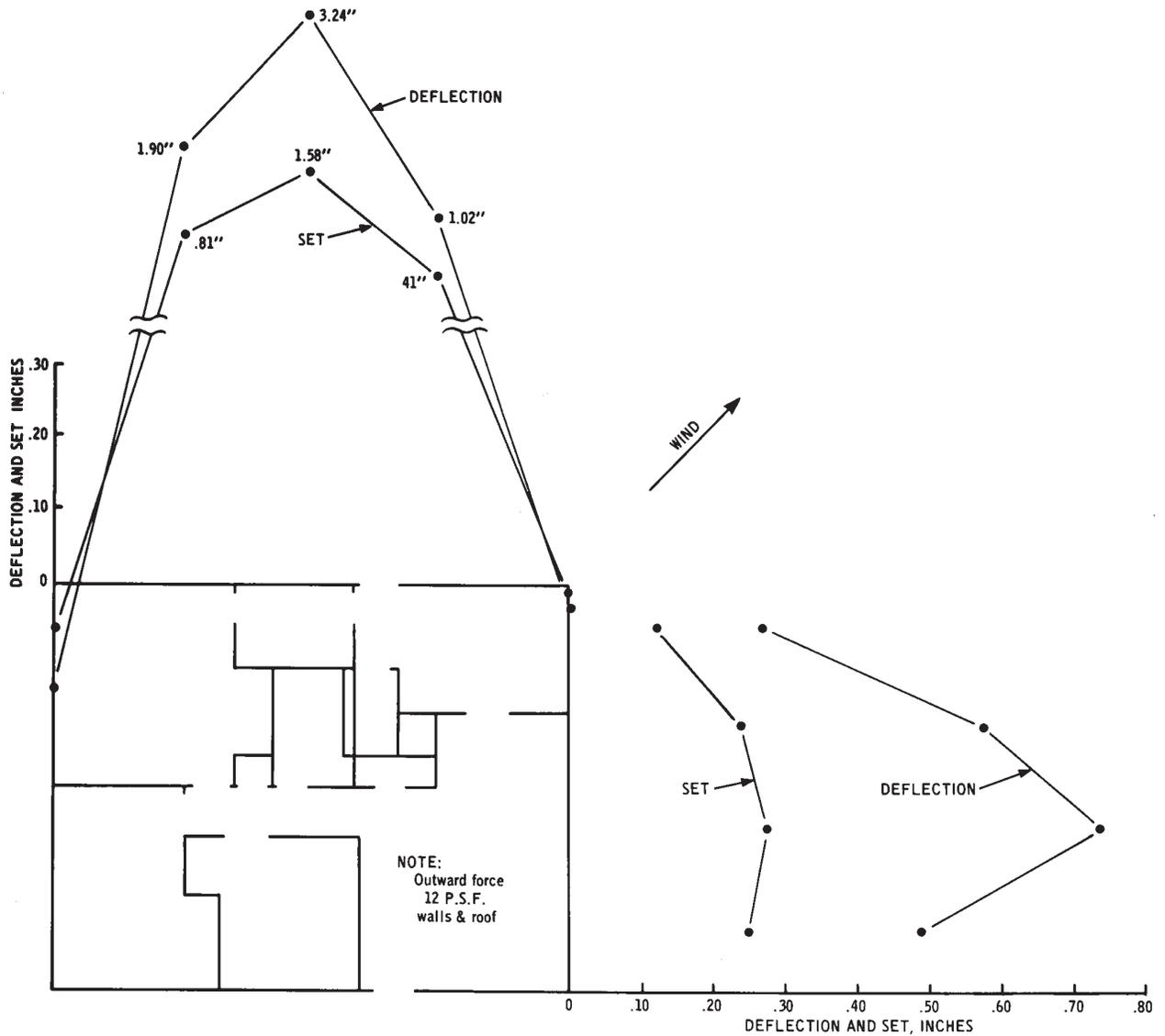
Figure 32. Stage No. 7.
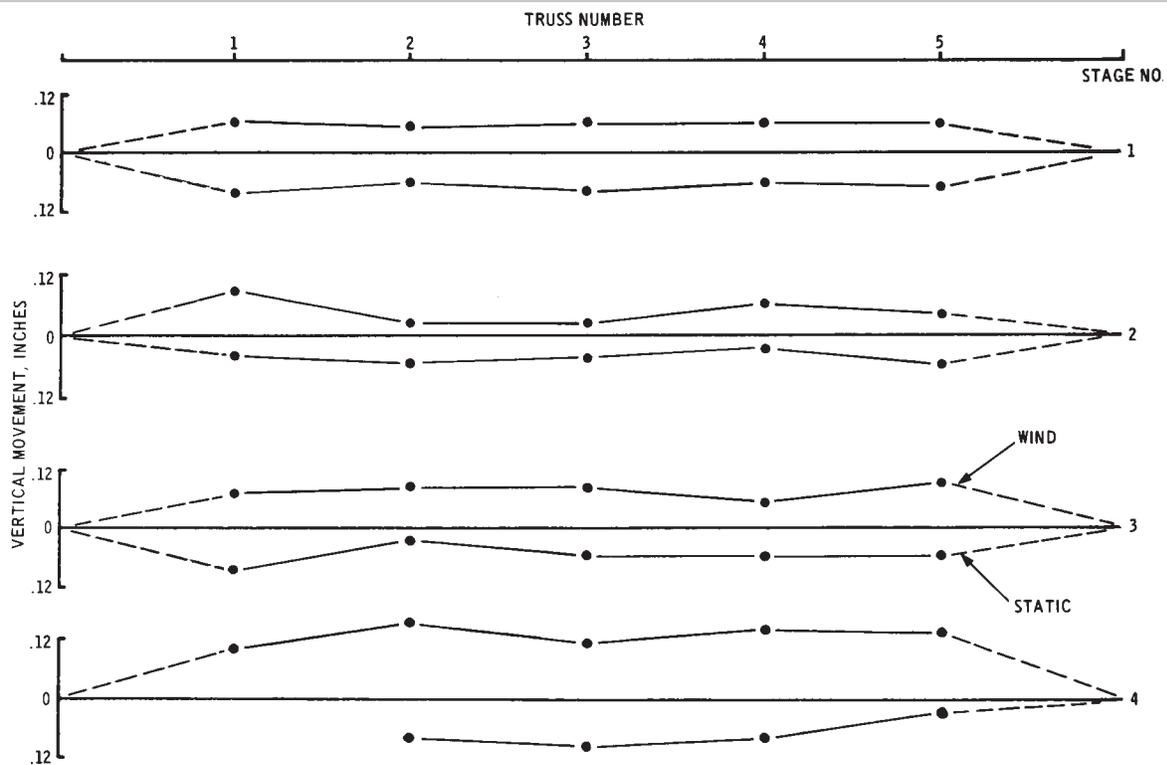
Figure 33.   Vertical movement at the crown for dismantling stages 1-4, loaded to 12 psf. (See Table 2 and Figure 11.)
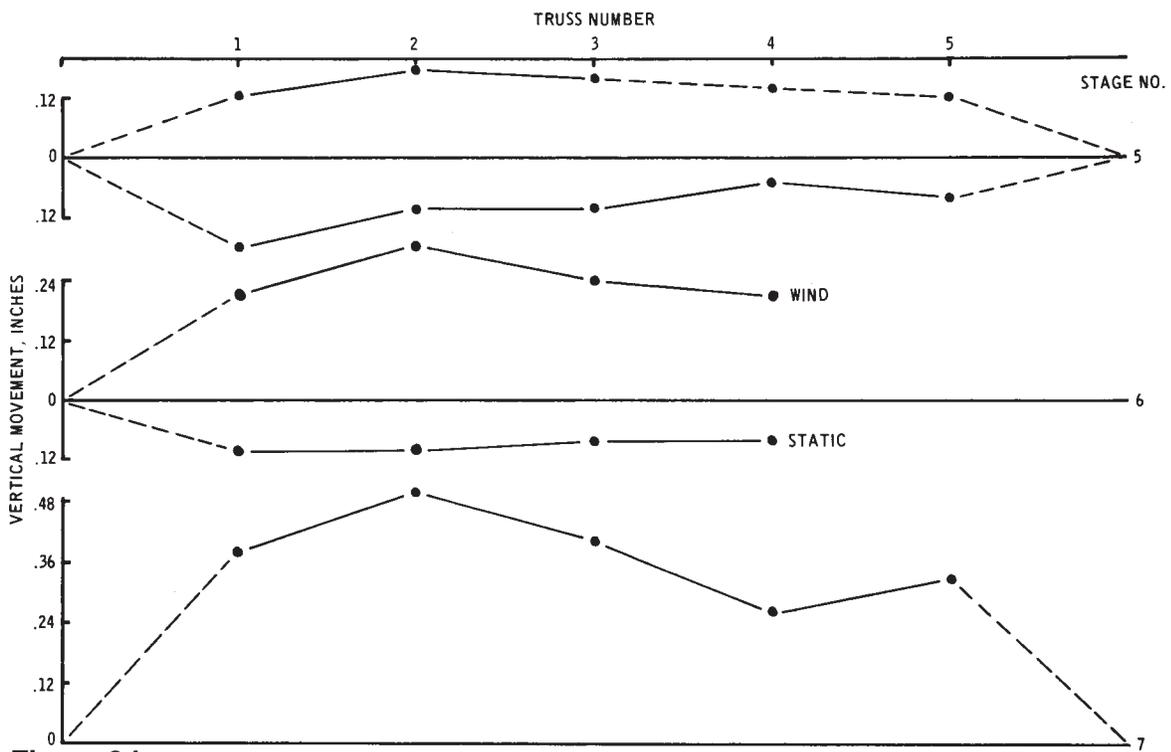

Figure 34.   Vertical movement at the crown for dismantling stages 5-7, loaded to 12 psf. (See Table 2 and Figure 11.)

CONCLUSIONS

1. The nature and complexity of this study did not permit exhaustive pursuits of many unknown factors that influence structural performance of complete floor systems. But, the project did provide an excellent opportunity for studying structural performance under controlled loading at many stages of construction.

2. The results of this and related studies, combined with conventional structural design procedures, will enable engineers and architects to design similar flooring systems more realistically.

3. In complete, conventionally constructed houses, actual deflections of residential floor systems, under 40 psf live load, appear to be substantially less than span/360.

4. Floor deflection and vibration are much less in partitioned areas than in non-partitioned areas. In Stage 13, a typically completed flooring system resulted in:

    (a) Average deflections 63% less than span/360 in partitioned areas, 36% less in non-partitioned areas. See Table 4 for suggested correction factors.

    (b) Average vibration amplitude, 70% less in partitioned areas.

    (c) Average duration of vibration. 79% less in partitioned areas.

5. Random-length, narrow-width, hardwood flooring significantly decreased floor deflection and vibration. In this case:

    (a) Flooring, with scabs, decreased average deflections 25%, without scabs, 26%.

    (b) Flooring, with and without scabs, decreased average vibration amplitude 31% and 26%, respectively.

    (c) Flooring decreased average vibration duration 24%, with scabs, and 19%, without.

6. Scabbing across the center support can substantially reduce floor deflections in non-partitioned areas, with an insignificant increase in lumber. For example, scabbing reduced the average floor deflection 20% for Stage 12, with only 9.6% more lumber.

7. On the basis of the foundation failure, at 20 psf, and of other tests of full-scale buildings, the wind loads, magnitude, and distribution, on low-profile buildings, are considerably different from those used in this study.

8. The ½-inch sheetrock ceiling, in combination with $^3/_8$-inch plywood wall sheathing, appeared to provide more racking resistance than any other combination of components and structural elements.

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