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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

Full Scale Test on a Two–Story House Subjected to Lateral Load

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SI Conversion Units

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

Length
 1 in = 0.0254 meter
 1 ft = 0.3048 meter

Force
 1 kip = 4448 newton

Stress
1 psf = 47.88 newton/meter^2

Temperature
 Temperature in °F = 9/5 (temperature in °C) + 32 °F

Contents

FULL SCALE TEST ON A TWO-STORY HOUSE SUBJECTED TO LATERAL LOAD *

Felix Y. Yokel, George C. Hsi, and Norman F. Somes

Tests were carried out on a single-family, detached house to determine its deflection characteristics under lateral loads. The house was a two-story building of conventional wood-frame construction. Two series of tests were conducted. The first of these was to determine the stiffness of the house when subjected to a simulation of wind loading. The second was to determine the dynamic response of the house to a single impulse load.

The report presents the results of these tests from which the following primary conclusions were derived:

(1) The measured second-story drift of the building was considerably less than that derived using present design criteria for medium- and high-rise buildings as applied to most areas of the United States.

(2) Only a small portion of the distortion of the exterior walls was transmitted to the interior gypsum board finish material.

(3) The upper-ceiling diaphragm experienced significant in-plane deformation. On the other hand, the floor/ceiling diaphragm at the lower ceiling level tended to act as a rigid diaphragm and to translate as a rigid body when the building was subjected to lateral load.

(4) The natural frequency of the structure was approximately 9 Hz and damping averaged approximately 6 percent of critical damping varying from 4 to 9 percent.

Key words: Building damping; drift; dynamics; earthquake; frequency; housing; lateral resistance; racking; stiffness; structural deflections; vibration; wind load; wood-frame construction.

1. Introduction

There is currently in the United States a strong trend toward the production of housing by industrialized methods. These methods frequently involve the innovative use of materials, structural concepts, or manufacturing procedures. It is reasonable that the occupant of housing, produced by these methods, should anticipate at least that level of structural performance which society has come to expect from conventional housing.

Conventional housing in the United States has evolved over several hundred years and, although this evolution has been based upon achieving a satisfactory level of performance, the final result has frequently gone unquantified. Thus, for example, the occupant of a conventional house would probably consider it to be adequately stiff but not know how stiff it is or how stiff he implicitly requires it to be. Surprisingly, there is very little published information on the response of conventional housing to static and dynamic loads and the information available [1,2][1] does not necessarily apply to housing built in the United States. How then are the criteria to be established by which to evaluate innovative products?

In the case of structural response to lateral load, there are design criteria for medium- and high-rise buildings limiting their drift (lateral displacement at any story level) under certain wind and seismic loads. These design criteria are not normally used to design low-rise buildings. Provisions presently used to assure minimum stiffness of low-rise buildings against lateral load [3] stipulate minimum stiffness of shear walls. Because of the complex interaction between structural elements and the contribution of partitions and cladding to lateral stiffness, these provisions do not provide a basis for predicting the response of conventional low-rise buildings to lateral load.

The purpose of the investigation reported herein was to measure the lateral drift of a conventional wood-frame building under simulated wind load to determine whether the drift limitations required in the design of medium- and high-rise structures are applicable to low-rise housing units.

It was realized that the drift displacement of buildings under static lateral load is not necessarily the

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[1]Numbers in brackets refer to literature references.

only independent variable affecting the adequacy of their real-life performance in a high wind. However, in absence of a full understanding of all the variables in this problem, information on the properties of conventional housing known to be acceptable to occupants provides the only available guidance for the evaluation of innovative, untried systems.

A secondary objective of the investigation was to determine the dynamic response characteristics of the structure in order to permit a more accurate calculation of the effects of dynamic lateral loads such as earthquake loads.

2. Scope of Investigation

2.1. Selection of House

Discussions were held with one of the largest producers of conventional housing in the United States. This builder agreed to make available a recently completed house located in the Washington, D.C. suburban subdivision of Bowie, Md. In terms of construction details, the house was considered to be typical of much of the conventional two-story housing in this country. The site provided adequate space in which to set up equipment for the application of horizontal loads to the exterior of the house. Figure 2.1 shows a general view of the subdivision.

FIGURE 2.1 *General view of the Bowie, Md. subdivision.*

2.2. Choice of Loading

It was decided to carry out two basic experiments. The first of these was to determine the stiffness of the house when subjected to a simulated wind load. The second was to determine the dynamic response of the house when subjected to an impulsive load. Because of the difficulty in applying a simulated wind load in a distributed manner over the building elevation, a series of concentrated forces were applied horizontally at two levels against the rear elevation of the building. These levels corresponded approximately to the levels of the centerlines of the upper-story floor joists and the underside of the lower chords of the roof trusses, respectively. Forces were applied first at one level and then at the other. The separate effects of these forces were combined to compute a total effect using the principle of superposition. Justification for applying this principle is provided by the approximately linear response of the house to the loading. Four rams were used to apply the forces at each level and these were spaced so as to achieve a reasonably uniform distribution of load along the rear wall.

2.3. Measurements

In the first experiment, the measurements included loads, vertical deflection, horizontal drift of floors and walls, and racking distortions of walls. In the second experiment, the basic measurement was that of the deflection amplitude/time relationship for the vibration of the building.

3. Description of Test Structure

3.1. Building Tested

A front view of the building is shown in figure 3.1. It is a two-story wood-frame structure with a partial brick veneer front at the lower story. The front entrance is from a portico having a 4-in-thick concrete floor slab resting on compacted fill. The fill is retained by an 8-in-thick hollow concrete block masonry wall. The portico slab abuts the front wall of the house with its top surface 2 ft 10 in above the first-floor level.

Figures 3.2 and 3.3 show floor plans and elevations, respectively. The lower story contains a family room, bedroom, bathroom, and a garage. The upper story has an L-shaped living and dining room, a kitchen, three bedrooms, and two bathrooms.

The lower[2] floor consists of a 4-in-thick concrete slab

[2]For brevity, the term "lower" will be used to describe items within the lower story and the term "upper" will be correspondingly used for items within the upper story.

FIGURE 3.1 *Front view of the building.*

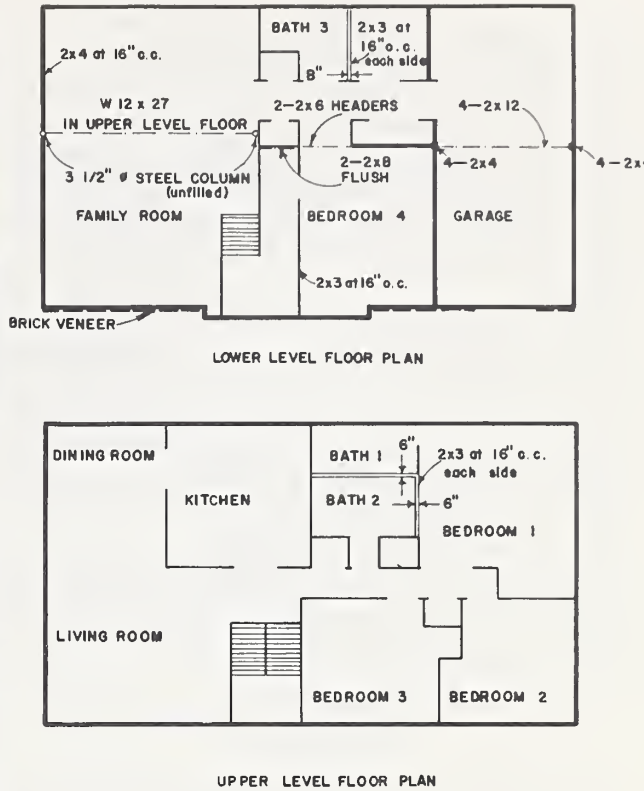

FIGURE 3.2 *Floor plans of the building.*

on grade. Walls are of wood-stud construction covered on all interior surfaces of the building with 3/8-in.-thick gypsum board (conforming to ASTM C36) [4] and on all exterior surfaces with a 1/2-in-thick gypsum sheathing (conforming to ASTM C79) [5]. Stud sizes[3] and spacings are shown in figure 3.2. The brick veneer is a single wythe of 4 in nominal thickness. The veneer

[3]All sizes of wood members in the figure as well as in the text hereafter are given as nominal sizes in inches, in accordance with SPR 16-53 [6].

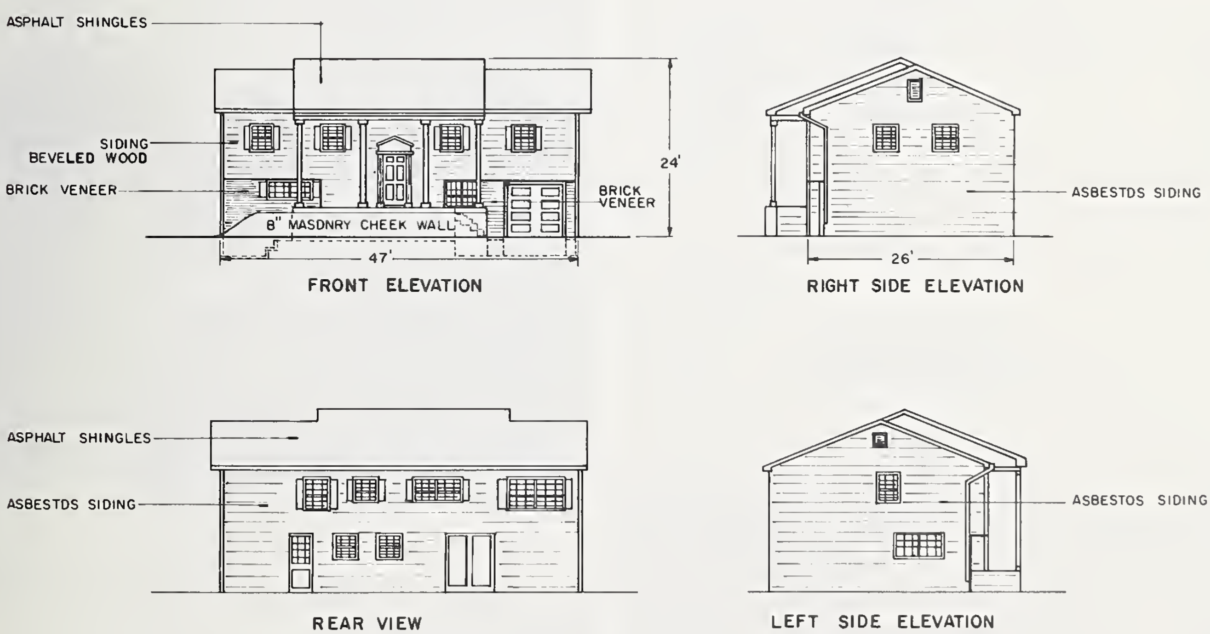

FIGURE 3.3 *Elevations of the building.*

is tied to the stud wall by galvanized corrugated metal ties, provided in every 7th course and spaced 32 in on center. Exterior-wall studs are braced at all building corners with 1×4 let-in bracing installed at a 45° angle to the horizontal in accordance with the provisions in the FHA Minimum Property Standards [7]. Exterior siding is asbestos shingle or 3/8-in-thick beveled wood siding with a 6-in exposure, as shown by the elevations in figure 3.3.

The structural framing of the upper floor consists of 2×8 wood joists spaced 12 in on center, supported by bearing walls and intermediate supports as shown in figure 3.2. The lower- and upper-story ceilings are 1/2-in-thick gypsum board (conforming to ASTM C36). The upper-floor subflooring is 5/8-in-thick plywood covered in all areas by resilient vinyl floor tile.

The upper ceiling and the roof are supported by trussed roof rafters made of 2×4 wood members and spaced at 24 in on center. Roofing consists of 1/2-in-thick plywood covered by asphalt shingles.

3.2. Special Structural Features Affecting Response to Lateral Load

Lateral resistance to movement of the building in the direction in which load was applied is increased by the backfilled portico abutting the front wall. However, the four portico columns shown in figure 3.1 are dowelled to the 4-in-thick portico slab by single 1/2-in-diameter bolts, and probably do not contribute materially to the rigidity of the building. The 7-ft floor-to-ceiling height, which is relatively low for this type of building, also tends to increase lateral resistance to movement. The brick veneer front, which could influence resistance to movement in the long direction of the building, does not substantially affect rigidity in the direction in which load was applied, namely, normal to the plane of the veneer.

4. Test Arrangement

4.1. Loading System

The loading arrangement is shown in figure 4.1. Two 10-ton forklifts were used to hold the loading assembly in its desired position and to resist the reaction forces. Each forklift carried a 5-kip concrete block to counterbalance the overturning moment caused by the applied horizontal load and to increase frictional resistance to sliding on the ground. A loading assembly was bolted to each concrete block. The assembly consisted of two vertical 5-ft-long $W8 \times 31$ beams[4] and one horizontal 14-ft-long $W8 \times 31$ beam which supported two rams spaced 12 ft on center. Figure 4.2 shows the concrete blocks during the attachment of the vertical beams. In figure 4.3, a horizontal beam is positioned in its correct location by the forklift. The horizontal beams were attached to the vertical beams by clips which permitted leveling and vertical adjustment of their position. Slotted bolt holes permitted some horizontal adjustment of the positions of these beams; however, in general, the correct horizontal positioning of the rams was achieved by correct positioning of the forklifts.

[4]Nominal size of wideflange steel beams in accordance with AISC [8].

FIGURE 4.1 *Loading arrangement.*

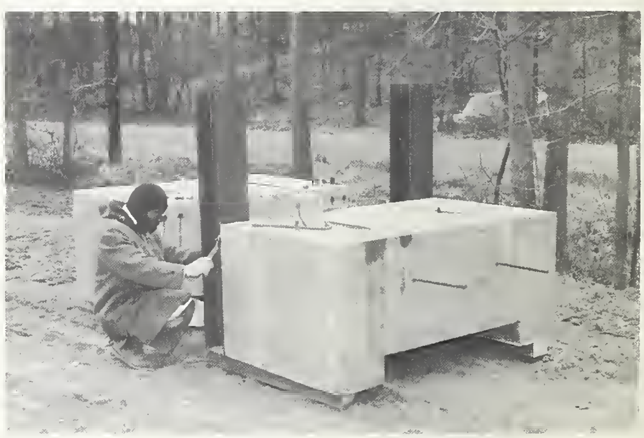

FIGURE 4.2 *Mounting of loading assembly.*

Figure 4.4 shows one of the rams carried by a horizontal beam.

The loading system and the horizontal position of the loads are shown schematically in figure 4.5. Each of the four single-acting hydraulic rams had a load capacity of

FIGURE 4.3 *Positioning of horizontal loading beam.*

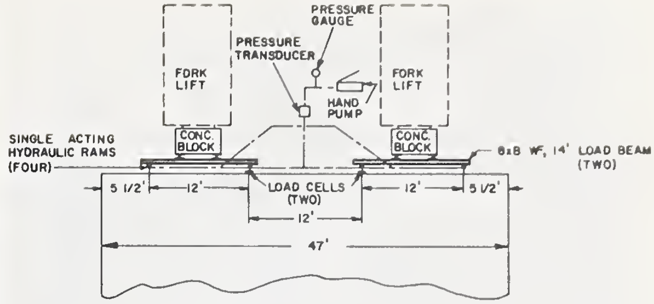

FIGURE 4.5 *Loading system.*

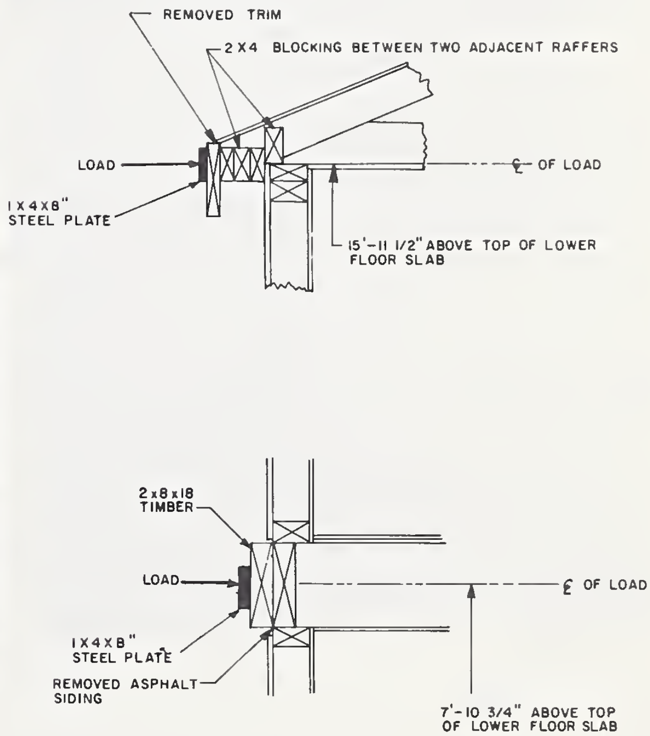

FIGURE 4.6 *Load transfer to the building.*

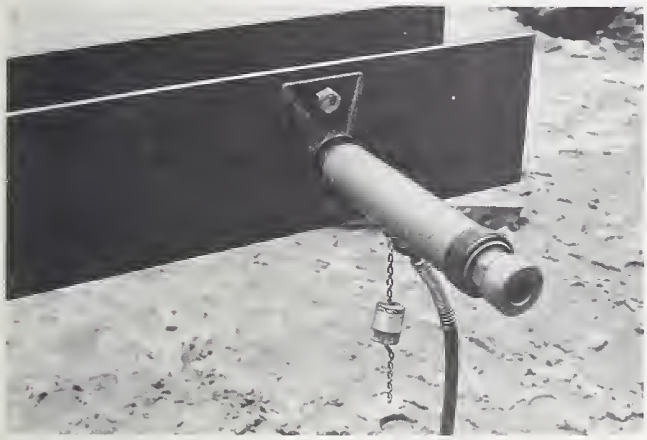

FIGURE 4.4 *Loading ram.*

10 tons, a 2-in-diameter piston and a 6-in stroke. Oil pressure was applied by a single hand pump to all four rams through a manifold and hoses arranged in parallel. Load was monitored by two separate and redundant systems: a pressure transducer connected to the hydraulic system; and two load cells, each with an operating range of 5 kip, monitoring two of the ram loads as shown in the figure. Compressive loads were applied to the rear wall of the building. Loads were monitored electronically. Data in this report are referenced to readings of one of the load cells as described in the appendix.

The manner of load transfer to the building as well as the vertical positioning of the loads are illustrated in figure 4.6. Load was applied at the underside of the horizontal roof-truss members and at the level of the centerline of the second-story floor joists. At the upper level, load was applied through an $8 \times 4 \times 1$-in steel plate to a 2×8 wood member which in turn transferred the load to 2×4 members nailed between two successive roof trusses. This method of load transfer was chosen to prevent local load concentrations and accompanying permanent damage and also to minimize the removal of siding. At the lower level, load was applied through an $8 \times 4 \times 1$-in steel plate to a 2×8 wood member which in turn transferred the load through the rim joist to the floor joists.

In the experiment to determine the dynamic response of the building, a 12-in-long piece of 3/4-in-diameter steel pipe was inserted between the ram and

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FIGURE 4.7 *Reaction blocks at rear of forklift.*

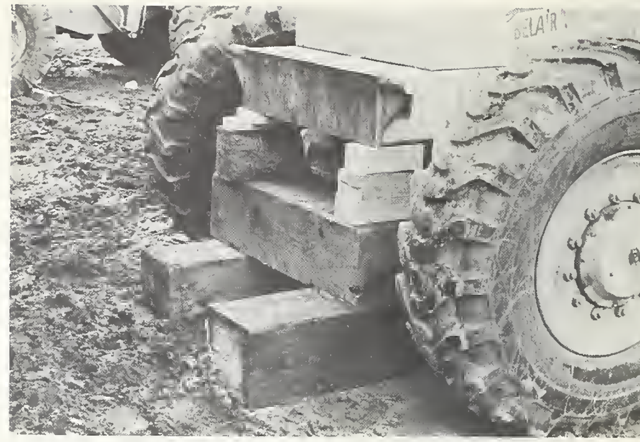

FIGURE 4.8 *Reaction block in front of forklift.*

the loading plate in one of the loading points at the lower level. After a predetermined load was applied, the pipe was removed by a sharp hammer blow.

Some difficulties developed during the testing because of muddy ground conditions which reduced the friction force on the forklift wheels. Wooden blocking had to be used in the front and the rear of the forklifts to increase lateral load resistance (see figs. 4.7 and 4.8). This arrangement did not affect the accuracy of load positioning.

ALL LVDT'S NEAR THE SIDE WALLS, EXCEPT THE LVDT'S AT THE CENTER VERTICAL PLANE, WERE SET 5.5" BELOW THE CEILING AND 9" AWAY FROM THE WALL.

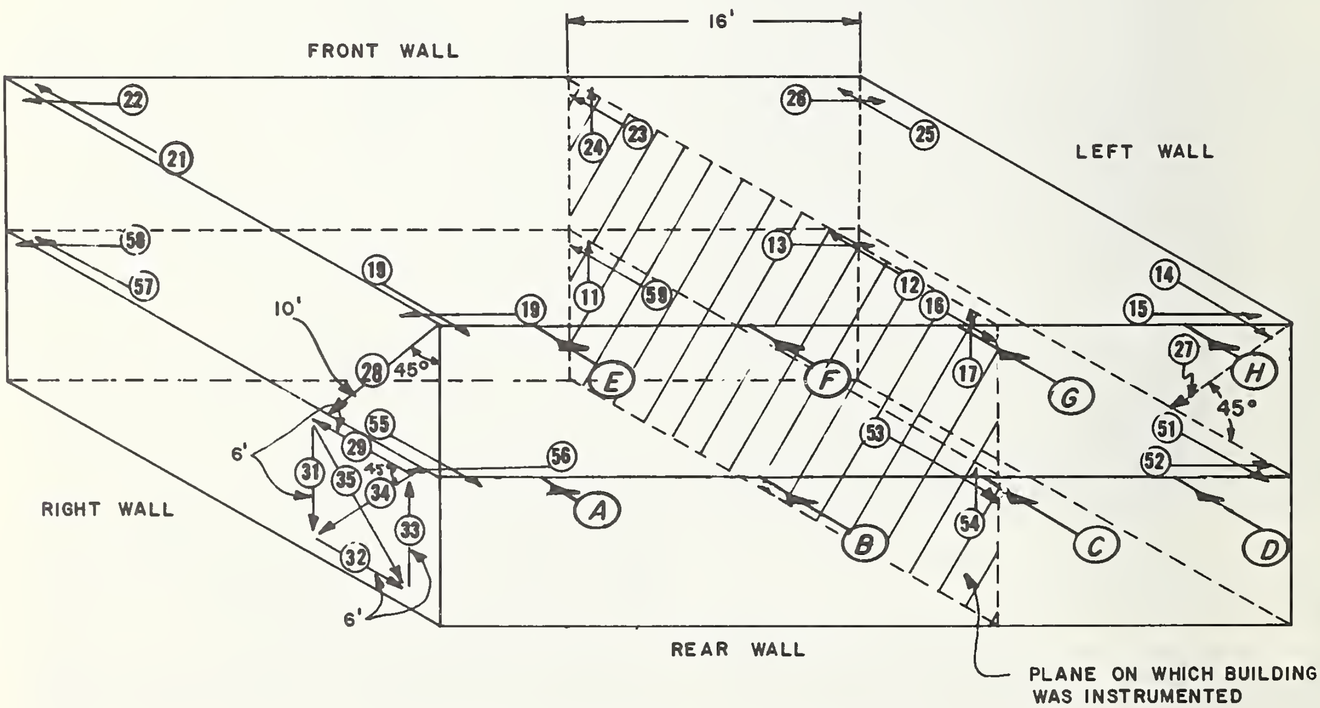

FIGURE 4.9 *Location of transducers and loading points.*

4.2. Displacement-Measurement System

Displacement transducers were used to monitor movement of the building and racking distortion of walls. Of the total of 32 displacement transducers used, the readings from 30 had a resolution of approximately 1×10^{-3} in. The two transducers used to monitor dynamic response were more sensitive. The resolution of the graphical records of the dynamic response is approximately 5×10^{-4} in. All transducers were mounted in the interior of the building where the temperature could be maintained at approximately 70 °F using the conventional heating control system provided in the house.

The location of the transducers is shown in figure 4.9 wherein the circled numbers identify each displacement transducer. The arrows show the displacement vectors measured. Points of load application are identified by letters. The letters and numbers shown in figure 4.9 are used throughout this report to designate the locations of loads and displacements. Instruments were installed near the corners of the building and in the plane, shown cross-hatched, which is parallel to the side walls and located 16 ft from the exterior face of the left side foundation wall. The location of the measurement points relative to the interior wall and ceiling surfaces is noted in the figure. It also can be seen that the rear part of the right side wall in the lower story was instrumented to measure racking distortion. Similar measurements were made on the rear part of the right and left side walls in the upper story by instrumenting a single diagonal.

Typically, transducers were mounted on stands consisting of 2-in-diameter steel pipes welded to a base of a steel plate as shown in figure 4.10 for a typical transducer installation in the upper story. Figure 4.11 shows a closeup view of two transducers. Contact with the measurement point was maintained by the spring pressure.

A typical setup for measuring racking distortion of walls is shown in figure 4.12. Each displacement transducer was attached to one end of a 3/4-in-diameter brass or aluminum tube. The plunger of the transducer impinged on an aluminum plate which was glued to the wall surface and its movement recorded the change of length of wall over which the tube and transducer was extended.

In order to maintain stable temperature and protect the equipment against inclement weather, it was necessary to measure deformations inside the building. This precluded the use of transducer supports which would reference upper-story measurements to the ground floor. Since upper-story instruments were supported on the second-story floor, total displacements had to be

FIGURE 4.10 *Transducer stand.*

FIGURE 4.11 *Displacement transducers.*

FIGURE 4.12 *Instrumentation of wall diagonal.*

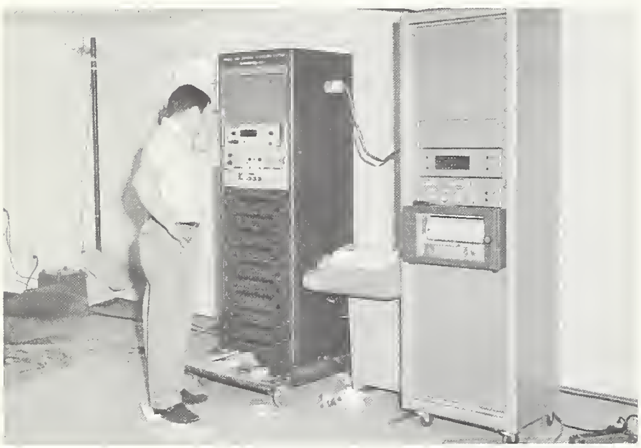

FIGURE 4.13 *Data logging system.*

derived by allowing for the displacement of the upper-story floor. It was not feasible to measure, and correct for, transducer-support rotation which was judged too small to be measurable with the available instrumentation.

4.3. Data Acquisition

Data from 32 displacement transducers, two load cells and one pressure transducer were electronically scanned, converted into digital form, and transmitted to a teletype unit. The teletype unit produced a printout which could be examined in the field and, in addition, punched the data on paper tape. The data were later transferred from the paper tape to magnetic tape for electronic computer processing.

The data acquisition system had a 100-channel capacity and was capable of logging approximately one reading per second. Data were scanned after each increment of loading and after unloading. The test schedules did not permit readings of deflection recovery to be made several hours after unloading.

Data on dynamic response from either of the two more-sensitive displacement transducers were recorded by a strip-chart recorder. The deflection-time history was recorded on a horizontal scale of 50 mm/second and a vertical scale of 20 mm per 0.01-in displacement. The data logging system shown in figure 4.13, from left to right, consisted of a digital scanning system, teletype, and a strip-chart recorder.

4.4. Visual Inspection

Visual observations of the interior and exterior surfaces of the building were made before and after each test.

5. Test Program

The static tests are summarized in table 5.1. Four

TABLE 5.1. *Summary of static tests*

(See figure 4.9 for location of loads)

Test No.	Date	Loading points	Loading sequence kip	Conditions	Comments
1	2/5/71 pm	A, B, C, D	0– 5.63–0.14 0.14– 8.00–0 0– 7.93–0	Cloudy 35 °F	Loading was limited by frictional resistance of forklifts.
2	2/6/71 am	A, B, C, D	0–10.00	Sunny 40 °F	Horizontal resistance was increased by blocking of forklifts.
3	2/7/71 am	E, F, G, H	0– 2.00–0 0– 4.00–0 0– 6.00–0 0– 7.23–0	Rainy 36 °F	Do.
4	2/7/71 pm	A, B, C, D	0–10.00–0	Rainy 36 °F	Do.

TABLE 5.2. *Summary of dynamic tests*

(See figure 4.9 for location of loads and transducers)

All tests performed on 2/8/72

Test No.	Load kip	Location of load	Location of transducer	Notes
5.1	2.0	C	53	
5.2	2.0	C	53	
5.3	2.0	C	53	Not a clean hit.
5.4	2.0	C	53	
5.5	1.5	C	53	
5.6	1.0	C	53	
5.7	1.0	C	53	
5.8	2.0	B	53	
5.9	2.0	B	53	

tests were performed. Test 1 consisted of three cycles of load applied at the lower level. In this test, the load was limited due to sliding of the forklifts. In Test 2, a single cycle of load was applied at the lower level after increasing the horizontal resistance of the forklifts by reaction blocks. In this cycle, the load exceeded the maximum applied in Test 1. In Test 3, four cycles of load were applied at the upper level. In Test 4, a single cycle of load was applied at the lower level to determine residual drift after slackness in the building had been taken up by previous testing.

The dynamic tests are summarized in table 5.2. The response in each test was recorded by a single transducer. In order to determine the response for various relative locations of loads and transducers, the test had to be repeated many times. Upper story transducers could not be used to measure vibrations because of excitation of the transducer support.

6. Discussion of Results

6.1. Overall Building Response in Tests 1 through 4

6.1.1. Residual Drift Displacements

Figure 6.1 shows a plot of total horizontal load against drift, measured at transducer 53, which was located at the lower-ceiling level near the point of largest displacement. The plot is for Test 1, in which three cycles of load were applied. In the unloaded position after the first loading cycle, the residual drift displacement was 0.002 in. This was approximately 12 percent of the drift due to the maximum load applied in this cycle. Subsequent increments of residual deflection were smaller, indicating that residual deflection was reduced by reduction of slackness in the system and possibly by response characteristics similar to strain hardening.

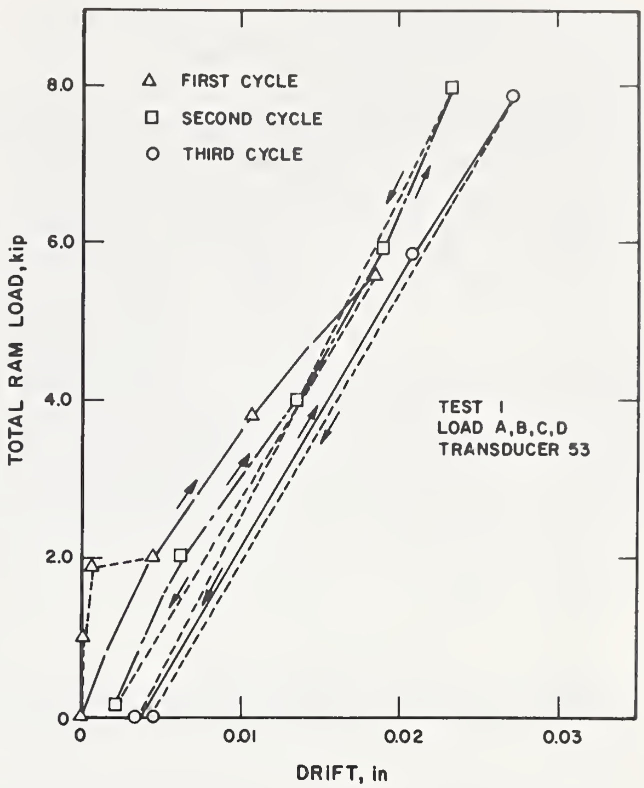

FIGURE 6.1 *Response to lateral load in Test 1.*

The total residual displacement in this test was 0.004 in, which is approximately 15 percent of the maximum displacement observed in this test (0.027 in).

Figure 6.2 shows a similar plot for Test 4, where the total ram load was increased to 10 kip. In this case, the residual displacement was 0.003 in, or approximately 8 percent of the 0.039-in total displacement in the test.

Figure 6.3 is a plot of Test 3 for transducer 16, which was located at the upper ceiling level near the point of the largest displacement. In this test, four cycles of load were applied at the upper-ceiling level. The load applied in this test was rather high (a 2.82 kip total ram load would be equivalent to the portion of a total wind load of 15 psf tributary to these points of load application. The total ram load actually applied was 7.23 kip.). The total residual displacement from all four cycles was 0.018 in, which is about 27 percent of the total maximum 0.068-in displacement measured. However, if the last loading cycle is considered separately, it caused an additional residual displacement of 0.007 in, which is approximately 13 percent of the 0.057-in maximum additional displacement in this loading cycle. The first loading cycle in this test, where the 0.004-in residual displacement was almost 40 percent of the total 0.011-in displacement, indicates that additional residual dis-

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placements will decrease after preloading of the structure.

In the first load cycle in Test 1 and the second load cycle in Test 3, the deflection at maximum load exceeded the deflection at the same load level in the subsequent load cycle. This response was probably caused by differences in the rate of loading. Miscellaneous adjustments in these initial load cycles substantially increased the time required for load application and data readout.

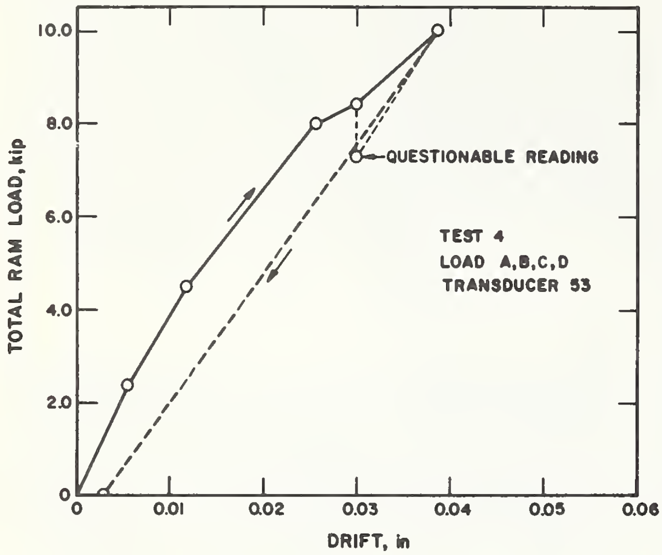

FIGURE 6.2 *Response to lateral load in Test 4.*

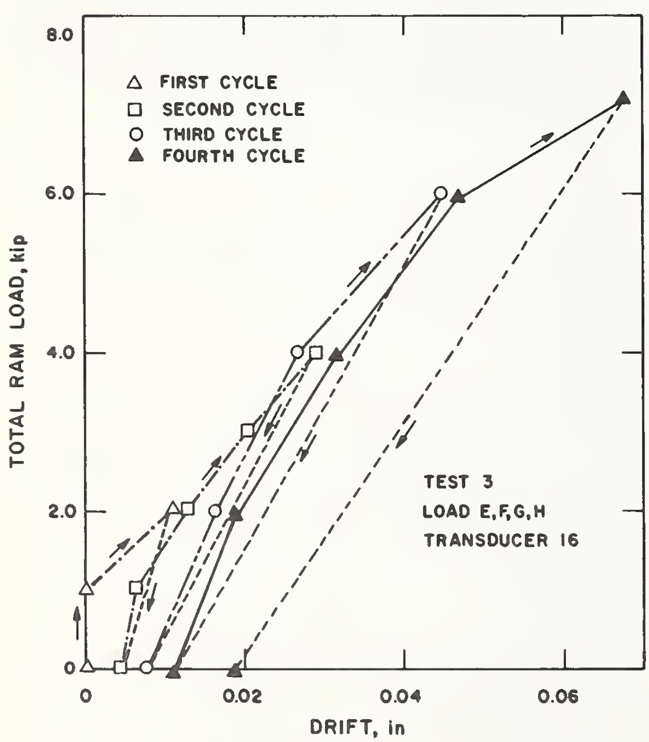

FIGURE 6.3 *Response to lateral load in Test 3.*

The test sequence did not allow time to measure displacement recovery several hours after unloading, which probably would have resulted in recovery of some of the residual displacements previously discussed. It is also reasonable to assume that at the smaller loads actually acting in service conditions, residual displacements would represent an even smaller percentage of total displacements. Thus, in general, it can be concluded from the previous discussion that after preloading, up to the level of the preload, the structural response to lateral load was substantially elastic.

6.1.2. Reproducibility of Data

Reproducibility of data is illustrated in figures 6.4 and 6.5. Figure 6.4 shows a plot of displacement at point 53 against lower-level loading for cycles 2 and 3 in Tests 1, 2, and 4. Data from all these four tests are reasonably consistent. Similarly, figure 6.5 shows displacements at transducer 16 for cycles 2 and 3 of Test 3, which are in good agreement. Similar trends were observed for other transducers measuring displacement in the direction of the applied load.

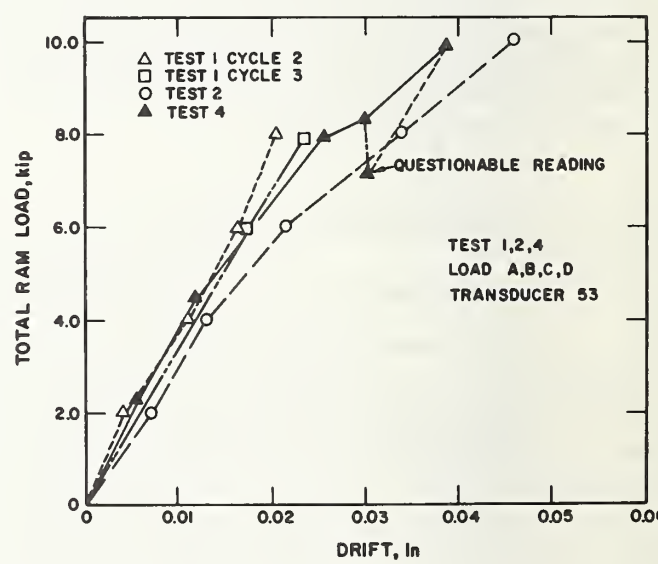

FIGURE 6.4 *Reproducibility of structural response to lower-level loading.*

Thus, it can be concluded that after the application of one or two load cycles, structural response to lateral load was predictable and reproducible.

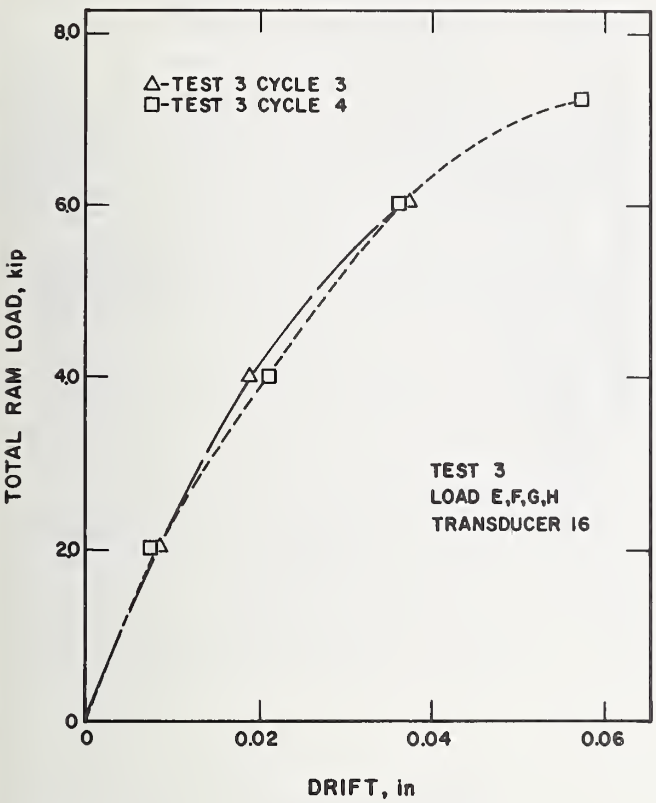

FIGURE 6.5 *Reproducibility of structural response to upper-level loading.*

6.2. Drift Under Wind Load

Since, after pre-loading, structural response to lateral load was approximately linear and measured load-displacement characteristics in various tests were reasonably consistent, results of upper- and lower-level loading can be combined by superposition to approximately predict the effect of simultaneously applying lower- and upper-level load. In this way, the effect of a load similar to that resulting from wind pressure, but statically applied, can be approximately predicted.

The wind load simulated by superimposing lower- and upper-level ram loads was computed in accordance with ANSI Standard A58.1-1955 [9]. Accordingly, no resultant load was assumed to act on the roof (see table A5 in A58.1-1955) and an evenly distributed load was assumed to act on the projected wall area in the direction of the ram load. Thus, it was assumed that the lower ram loads would simulate the wind load on a wall area equal to 376 ft^2, extending from midheight of the lower story to midheight of the upper story, 8 ft high and 47 ft long. The upper ram loads were assumed to simulate the wind load acting on the wall area equal to 188 ft^2, extending from midheight of the upper story to the roof. It was further assumed that the area between the midheight of the lower story and grade level would be resisted at the foundation level and thus would not contribute to drift. Using this approach, a design wind load of 15 psf is simulated by the total ram loads of 2.82 kip at the upper level and 5.64 kip at the lower level, acting simultaneously.

Figures 6.6 through 6.9 show drift versus wind load for all the points where drift in the direction of the applied load was measured. The figures were derived by superimposing displacements caused by lower-level loading measured in Test 2 and displacement caused by upper-level loading equal to the average of the measurements in the second and third cycles in Test 3.

6.3. Resistance to Lateral Load

6.3.1. Lateral Displacements

Figure 6.10 shows the displacement at the upper-ceiling level relative to the surface of the upper floor. This drift was measured in the last loading cycle of Test 3, for which lateral load was applied at the upper-ceiling level. Drift was derived for a total ram load of 2.82 kip which simulates approximately the contribution of the wind load to the upper-ceiling level when a total wind load of 15 psf acts normal to the long walls of the building.

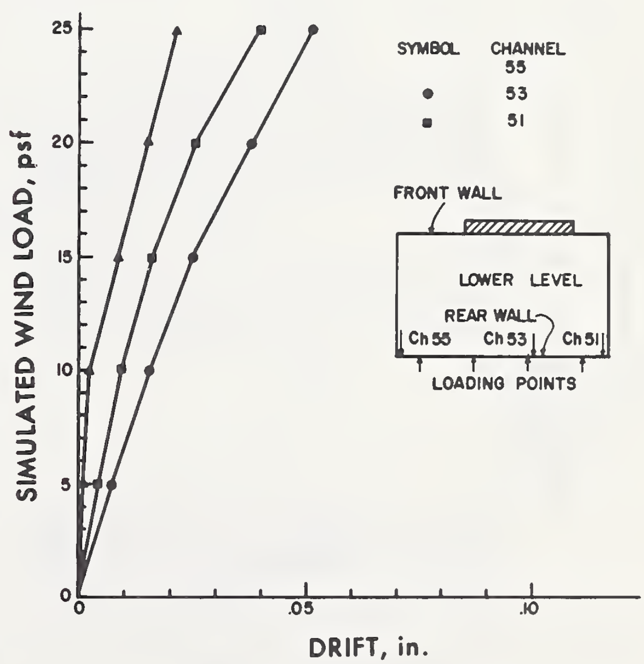

FIGURE 6.6 *Drift at upper-floor level.*

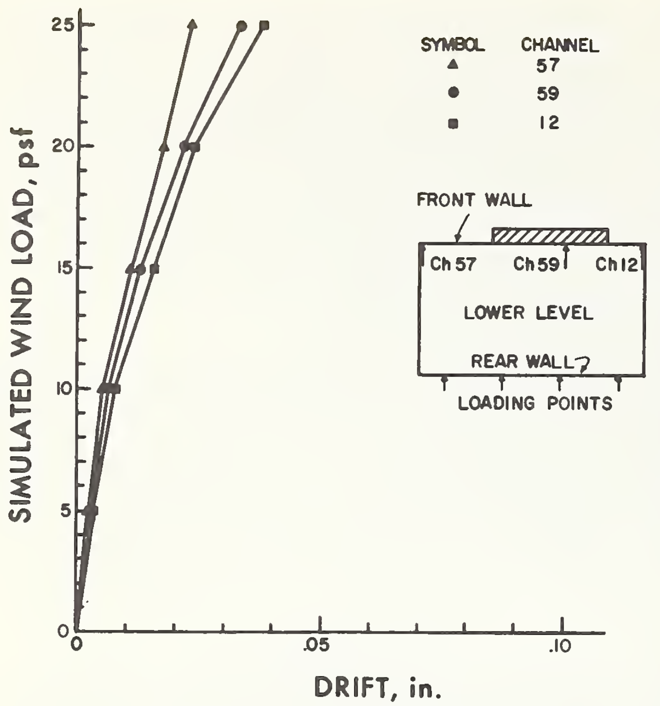

FIGURE 6.7 *Drift at upper-floor level.*

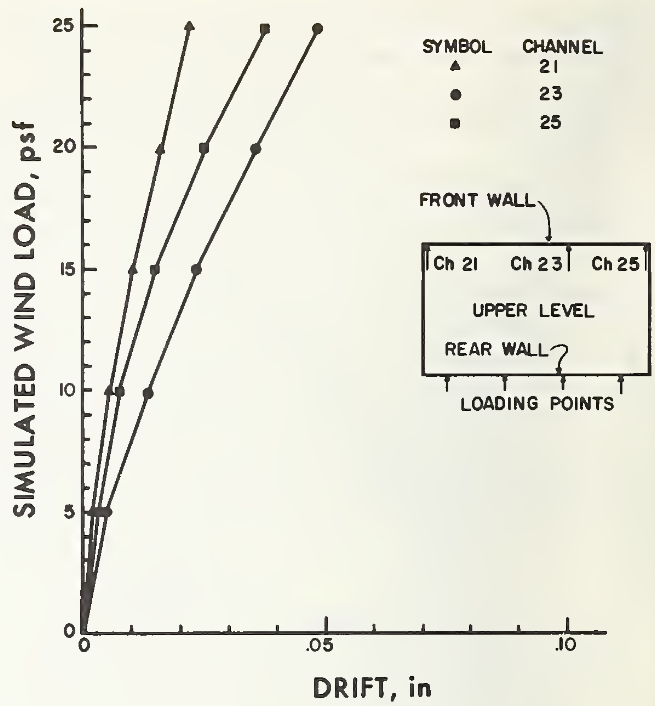

FIGURE 6.9 *Drift at upper-ceiling level.*

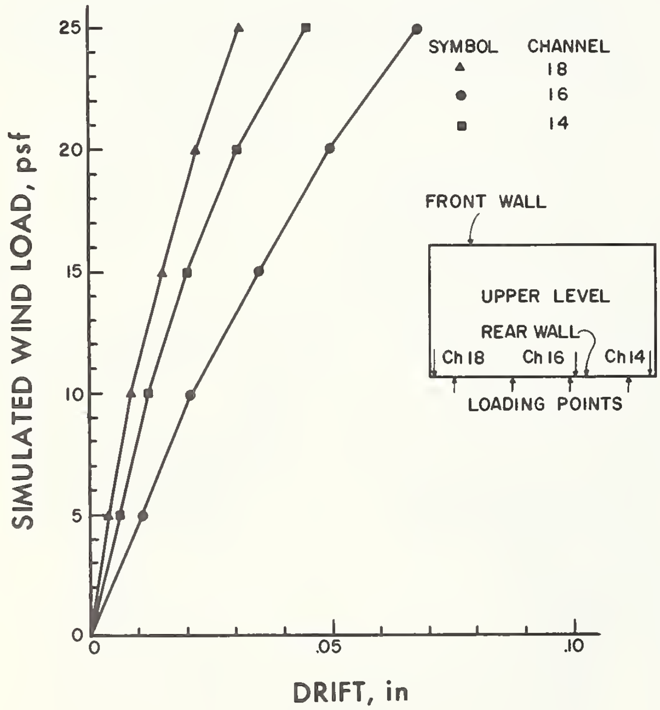

FIGURE 6.8 *Drift at upper-ceiling level.*

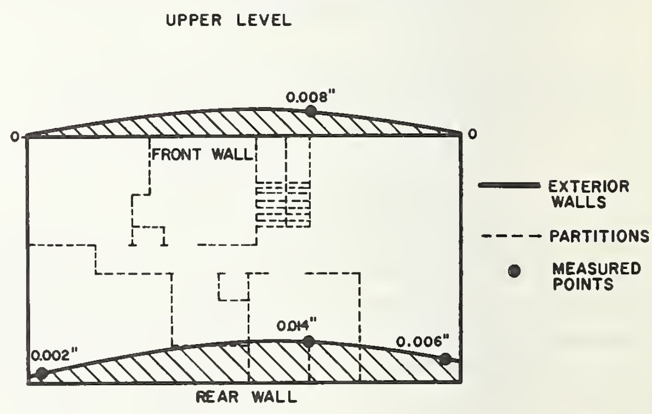

FIGURE 6.10 *Displacement of upper ceiling relative to upper floor under upper-level loading, simulating* 15 *psf wind load.*

The figure shows significant in-plane deformation of the upper-ceiling diaphragm. At the upper rear corners, the exterior side walls moved in the direction of the applied load; however, no translation was observed at the two front corners. The framing of these walls provides let-in bracing from each rear upper corner, at a 45° angle to the vertical, down to the upper-floor level.

Since there is incomplete rigidity at the connections, this brace could conceivably resist the horizontal thrust without participation of the 2 × 4 member at the top of the wall studs. This mechanism could account for the mode of deformation of these walls.

Figure 6.11 shows the total drift of the upper- and lower-story ceilings due to a lateral load applied at the upper-ceiling level (Test 3, last loading cycle). The total translation of the upper ceiling was derived by adding the measured lower- ceiling translation to the measured upper-ceiling translation. This is the best approximation that can be obtained from the data since measurements at the upper-ceiling level were not directly referenced to the ground level. No correction was made for possible rotation of the frames supporting the transducers, which was too small to be measured with the available instrumentation. It can be seen from figure 6.11 that while substantial in-plane deformation of the upper-ceiling diaphragm can be observed, drift at the lower-ceiling level approximates a rigid body translation. This leads to the conclusion that at the upper level, interior partitions experienced a much greater racking deformation than the side walls. This mechanism probably caused the interior partitions to transfer a substantial part of the horizontal load, exerted at the upper-ceiling level, to the upper- floor level.

Figure 6.12 shows drift at the upper- and lower-ceiling levels under a simulated wind load of 15 psf normal to the long walls. The translations shown in the figure were computed by superposition, adding translations caused by applying ram loads at the upper-ceiling level (last loading cycle, Test 3) to those caused by ram loads applied at the lower-ceiling level (Test 2). Wind pressures corresponding to the ram load were computed as in section 6.2. The building as a whole translated and rotated slightly. The rotation is probably attributable to the unsymmetrical distribution of interior partitions and is an order of magnitude smaller than the overall drift deformations. Even though the drift near the center of the building at the lower-ceiling level was greater than that at the side walls on the same level, it cannot be concluded that this difference is attributable to overall in-plane deformation of the floor-ceiling assembly, since the translation near the front wall on the same level corresponds approximately to a rigid body displacement.

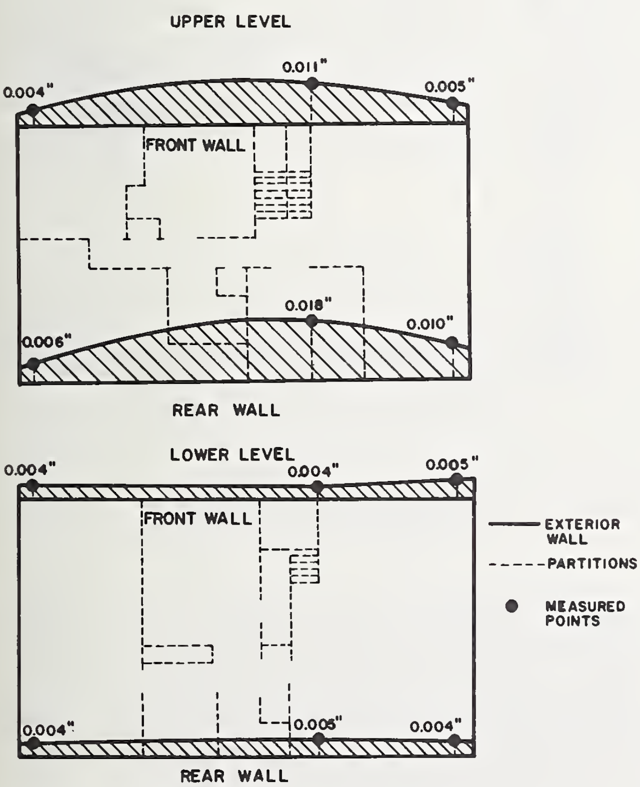

FIGURE 6.11 *Total drift under upper-level loading simulating* 15 *psf wind load.*

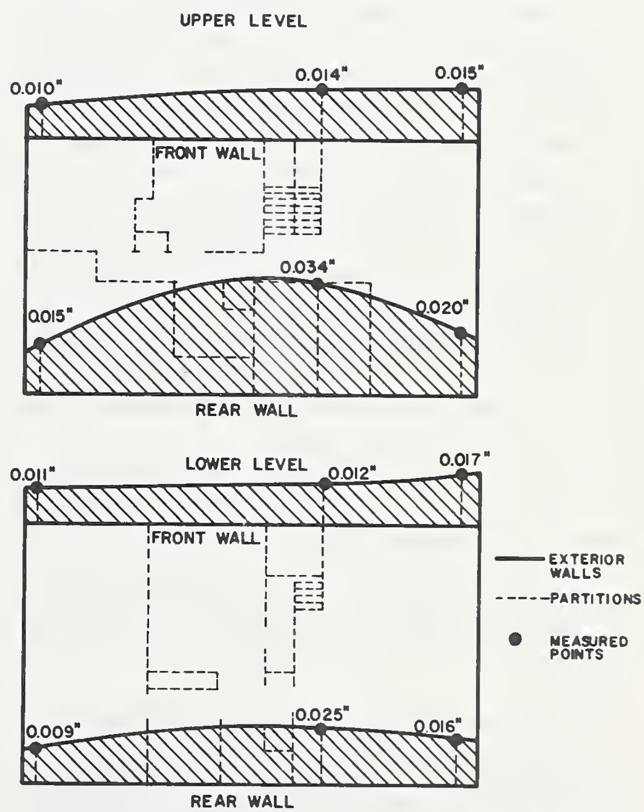

FIGURE 6.12 *Drift under combined upper- and lower-level loading simulating* 15 *psf wind load.*

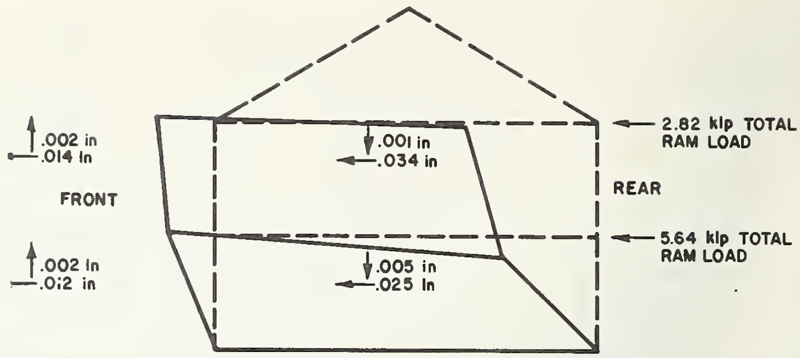

FIGURE 6.13 *Lateral and vertical displacements near the center of the building (refer to fig. 4.9 for location of measurements).*

6.3.2. Vertical Displacements

Figure 6.13 shows lateral and vertical displacements near the center of the building (refer to fig. 4.9 for the position of displacement measurements), caused by a simulated 15 psf wind load. In general, the vertical displacements were one order of magnitude smaller than the horizontal displacements. As a result, no significant conclusions can be drawn from the vertical measurements.

6.3.3. Wall Distortion

Figure 6.14 shows a plot of displacements at the lower-ceiling level (points 55 and 57) corresponding to the extreme right of the building, both front and rear. The figure also shows a plot of the change in length of two diagonals across part of the right side wall instrumented at 45° angles to the horizontal (points 34 and 35). The gage points for the diagonal transducers were attached to the interior gypsum board and, therefore, the changes in length of these diagonals are a measure of the racking distortion of the interior gypsum board. It can be seen that the change in length of the diagonals was approximately 10 percent of the drift measured at corresponding load levels. If the gypsum board had participated fully in the racking distortion of the wall, the length change of the instrumented diagonals would correspond to approximately 60 percent of the drift measured at the upper wall corner. Thus, subject to the qualifications stated below (sec. 6.3.5), the important conclusion can be drawn that only a small portion of the racking force was transmitted to the gypsum board. It is, therefore, reasonable to assume that the let-in bracing provided the major portion of the resistance to the lateral force.

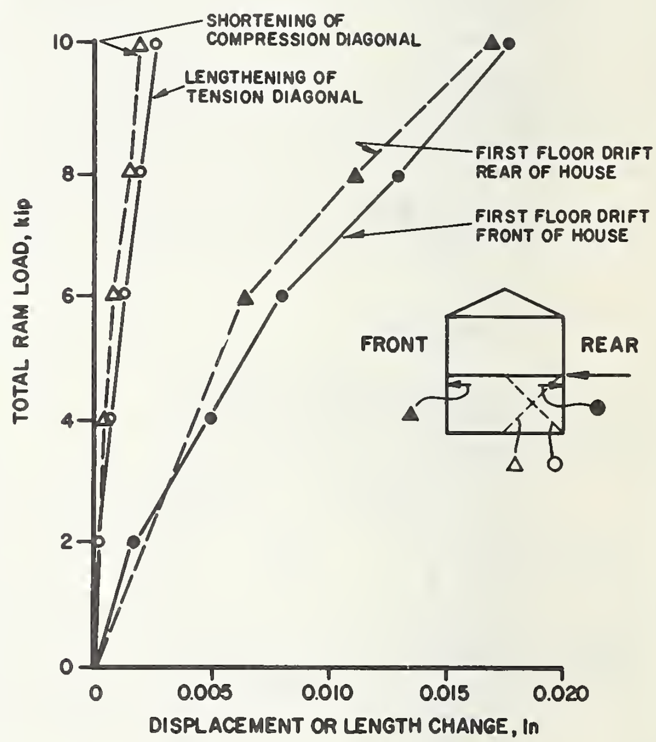

FIGURE 6.14 *Wall distortion.*

6.3.4. Lateral Displacement Normal to the Applied Load

Lateral displacements normal to the applied load were measured by transducers 56, 52, 13, and 58 at the lower level and by transducers 19, 15, 26, and 22 at the upper level. In general, these displacements were one order of magnitude smaller than the drift displacements in the direction of loading and no significant conclusion can be drawn from these measurements. The following table shows the displacements corresponding to a simulated 15 psf wind load computed by superposition using Test 2 and the third cycle of Test 3. Drift displacement in the direction of the applied loads at the same locations are given for comparison.

Story	Transducer	Displacement normal to load in	Drift displacement in
Lower	56	0.002 inward	0.009
	52	0.001 inward	0.016
	13	0.000	0.017
	58	0.001 inward	0.011
Upper	19	0.002 inward	0.015
	15	0.002 inward	0.020
	26	0.003 inward	0.017
	22	0.007	0.010

6.3.5. Possible Effects of Slippage in Joints

The interpretation of structural response to lateral load presented in section 6.3 is based on the premise that joints were capable of transmitting displacements to structural elements without significant slippage. Thus, it was assumed in 6.3.1 and 6.3.3 that the displacements measured at the inside face of the rear wall of the building were imparted to the side walls. While this assumption seems reasonable, there is no evidence by actual measurements that the displacements of the rear walls were fully transmitted to the floor or ceiling diaphragms, and that the translation of these diaphragms near the side walls was actually transmitted to the side walls without slippage at the joints. The conclusions with respect to side wall distortion presented in 6.3.1 and 6.3.3 must therefore be qualified, since they are based on a premise that cannot be proven.

6.4. Dynamic Response

The plots on the left side of figure 6.15 show the results of various tests. Figure 6.15(a) shows the superimposed results of four tests, 5.1, 5.2, 5.3, and 5.4, in which a 2,000-lb force was removed at point C and response was measured by gage No. 53 (see fig. 4.9) which is close to pointC. The width of the curve is partly due to higher-frequency electrical noise of the recording equipment, but also indicates the range of variation between the results of the four tests.

The range of variation between individual tests is relatively small, indicating that dynamic response was reproducible in successive tests. The response curves indicate that the method of removing the lateral force in the building apparently did not permit the structure to freely vibrate from the initial deflected position. The apparent deflection position at load release is shown in the figure as approximately 1/4 that of static displacement. The irregular response in the first cycle, subsequent to the load release, was reproducible in all the tests and is probably attributable to rebound of the spring-loaded gage. Similar plots are shown in figure 6.15(b) for tests 5.8 and 5.9, wherein a 2,000-lb force was removed at point B and response was measured at gage 53 which is located at a distance of 12 ft from point B, and in figure 6.15(c) for tests 5.6 and 5.7, wherein a 1,000-lb force was removed at point C and response was measured at gage 53 in the vicinity of point C.

Even though it is demonstrated that data are reproducible, the following must be taken into account in assessing the validity of conclusions drawn from the tests: resolution of displacement time-history records taken at the lower-ceiling level is marginal due to the low magnitude of displacement resulting from the method of excitation used (maximum peak-to-peak displacement of the free vibration was approximately 0.003 in). In view of this small displacement amplitude, it is possible that vibrations in the region of deflection measurement may not accurately reflect the vibration of the overall structure. In addition, transmission of structural motion to the transducers and seating in the structure may have adversely affected the resolution of these low magnitude vibration measurements.

Analysis of the superimposed records shown in the plots in figure 6.15(a), (b), and (c) shows a high frequency caused by electrical noise and a lower dominating frequency of approximately 9 Hz. Frequencies derived from these plots are reasonably consistent with each other. The frequency of 9 Hz appears reasonable for a structure of this type. The plots on the right side of figures 6.15(a), (b), and (c) show average deflection response and estimated envelopes of deflection decay from which the percentage of critical damping was computed by the following equations:

$$\text{percent critical damping} = \nu \times 100$$

$$2\pi\nu = \ln x_1/x_2$$

where:

ν = critical damping ratio

x_1/x_2 = two successive displacement peaks

ln = natural logarithm

Damping computed from the plots in figures 6.15(d), (e), and (f) averages 6 percent of critical damping with an approximate range from 4 to 9 percent. Damping ratios would probably increase for vibrations with larger displacement amplitude.

In summary, it can be concluded on the basis of the

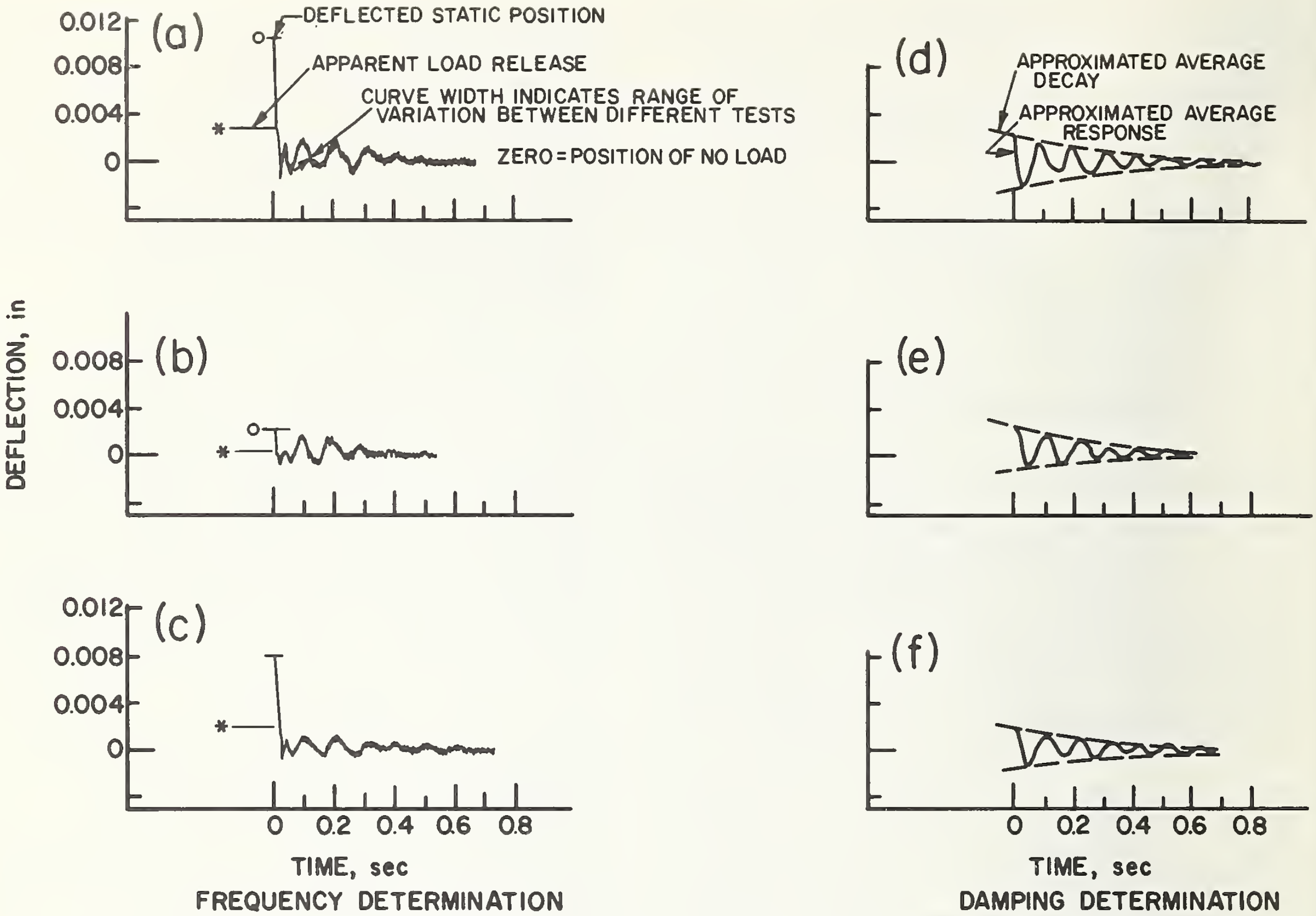

FIGURE 6.15 *Dynamic response characteristics.*

measurements and subject to the stated qualifications that the natural frequency is approximately 9 Hz and that damping averages 6 percent of critical damping, ranging from 4 to 9 percent.

6.5. Comparison of Building Response With Present U.S. Design Practice

Figure 6.16 shows a plot of drift at the lower-ceiling level against simulated wind pressure normal to the long wall. The solid line connecting the points designated by circles shows the drift measured in the fourth loading cycle and was derived by superposition of the results of Test 2 and the last loading cycle of Test 3. Drift is shown for the location of the largest displacement observed at this level (gage 53). Superposition was used, as discussed in section 6.2, assuming that a wind force of the magnitude shown on the vertical scale of the plot acted normal to the entire long-wall area, and that no resultant wind pressure acted on the projected roof area.

The dash-dotted vertical line represents the drift limit of h/500, where h is the height above grade level, which is normally used in the United States in the design of medium- and high-rise buildings for a wind of a 50-year mean recurrence interval.

To the right of the plot, wind loads computed for various areas in the United States and for different exposure conditions are shown. Columns A, B, and C were computed using the ANSI-A.58.1 Standard now proposed for adoption. Columns D were computed using ANSI Standard A.58.1-1955 which is presently in force and which does not distinguish between various exposure conditions. Note that, except for the Miami, Fla. region, the measured drift of this building, after slackness in the system was removed in three preloading cycles, is considerably less than that derived using present design criteria for medium- and high-rise buildings. No conclusion can be drawn for Miami, since the design wind loads required for this region exceed the loads actually applied in the test.

While the previously discussed plot provides information on drift that is anticipated when the building is subjected to repeated cycles of windload in one direction, consideration should also be given to the magnitude of drift in the first load cycle and to the total magnitude of lateral displacement, including residual displacement, when several load cycles are applied in one direction.

At least part of the residual displacement would be recovered if the direction of the lateral load is reversed. The first reverse cycle of lateral load could cause a total displacement which would include the cumulative effect of recovery of part of the residual displacement in the initial direction of loading, and the initial load cycle in the reverse direction.

Some indication of the magnitude of this total displacement can be derived from figure 6.16. The points designated by squares show the magnitude of drift that the building is estimated to experience in the first load cycle. The points designated by triangles show the total displacement relative to the initial position of the building estimated for the third load cycle. The points were derived using the results of Tests 1 and 3.

It can be concluded from the plot of these data that even the maximum drift that could reasonably be expected in the first cycle of load reversal under windloads up to 20 psf would be considerably less than h/500.

7. Conclusions

The following conclusions can be drawn on the basis of an analysis of the test results:

(1) The measured second-story drift of the building was considerably less than that derived using present design criteria for medium- and high-rise buildings as applied to most areas of the United States.

(2) Only a small portion of the distortion of the exterior walls was transmitted to the interior gypsum board finish material. Thus, the let-in bracing probably made the major contribution to the resistance to racking loads. This conclusion is subject to the qualification stated in section 6.3.5.

(3) The upper-ceiling diaphragm experienced significant in-plane deformation. Correspondingly, the racking distortion of the upper-story interior partitions exceeded that of the exterior side walls.

(4) The floor-ceiling diaphragm at the lower-ceiling level tended to act as a rigid diaphragm and to translate as a rigid body when the building was subjected to lateral load.

(5) The measured structural response indicates that the natural frequency of the structure is approximately 9 Hz and the damping averages approximately 6 percent of critical damping varying from 4 to 9 percent. The validity of these conclusions is somewhat in

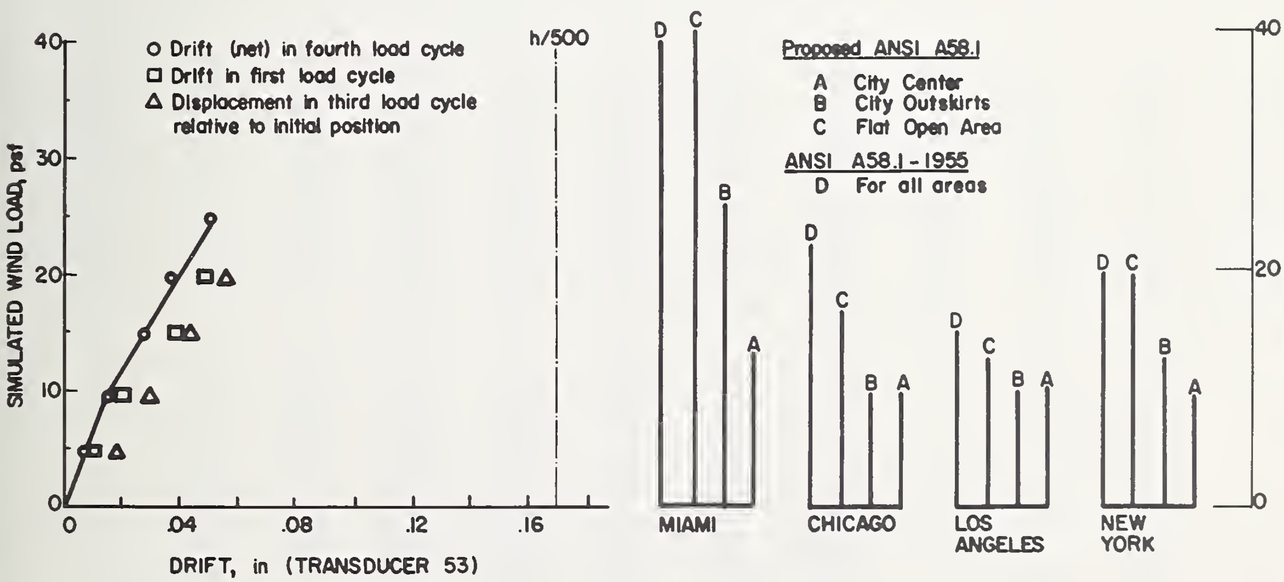

FIGURE 6.16 *Comparison of measured building response with design criteria for medium- and high-rise buildings.*

question because of the marginal resolution of the displacement time history records.

(6) Slackness in the structure caused relatively large residual displacements in the initial cycles of lateral loading. Response characteristics in subsequent cycles of loading were substantially elastic and reasonably consistent and reproducible, as were the measurements of dynamic response.

8. Acknowledgment

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9. References

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APPENDIX

1. Static Tests

The results of the four static tests are presented in tables A.1, A.2, A.3, and A.4, respectively. Channel numbers on top of each column correspond to the numbers on the transducers shown in figure 4.9. The following numbers represent measurements of loads:

Load cell opposite load B	91
Load cell opposite load C	41
Pressure transducer measuring oil pressure	43

Each table lists all three load readings. Load cell readings are multiplied by 4 to give total ram load (A+B+C+D) or (E+F+G+H). The displacement readings are given in inches $\times 10^4$. Negative numbers indicate displacements in the direction of the arrows in figure 4.9; positive numbers indicate displacements opposite to the arrow directions.

In tables A.1, A.2, and A.3, "loads" are based on readings of the load cell opposite B(91). In table A.4, readings of the load cell opposite C(41) are used to compute loads. The averages of the various readings of load cells B and C and the pressure transducer for the various tests are compared below using load cell B (channel 91) as reference:

	Cell B	Cell C	Transducer
Test 1	1	0.95	0.88
Test 2	1	.97	0.83
Test 3	1	.99	0.81
Test 4	1	1.09	0.81

Table A.1 Results of Test 1

Total Ram Load, kip	11 a/	12	13	14	15	16	17	18	19	21	22	23
.00	.00 b/	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.02	-5.00	-4.00	-6.00	-8.00	-1.00	-7.00	-1.00	1.00	-4.00	2.00	4.00	-3.00
1.90	-7.00	-17.00	-6.00	-13.00	-8.00	-9.00	-2.00	1.00	-4.00	3.00	6.00	-3.00
2.03	-10.00	-21.00	-4.00	-12.00	.00	-14.00	-3.00	5.00	.00	4.00	12.00	-9.00
3.83	-15.00	-67.00	-4.00	-18.00	-22.00	-20.00	-14.00	5.00	.00	5.00	17.00	-6.00
5.63	-18.00	-127.00	-4.00	-36.00	-57.00	-41.00	-26.00	4.00	.00	7.00	22.00	17.00
.14	-3.00	-28.00	-3.00	-6.00	-15.00	6.00	5.00	8.00	7.00	1.00	10.00	-29.00
2.03	-11.00	-46.00	-4.00	-22.00	-31.00	-8.00	-6.00	11.00	5.00	4.00	16.00	-24.00
4.03	-15.00	-82.00	-5.00	-34.00	-46.00	-25.00	-16.00	4.00	6.00	6.00	21.00	5.00
5.95	-19.00	-134.00	-5.00	-43.00	-74.00	-47.00	-37.00	5.00	6.00	5.00	28.00	9.00
8.00	-24.00	-205.00	-2.00	-80.00	-108.00	-32.00	-43.00	6.00	5.00	5.00	26.00	36.00
.00	-9.00	-59.00	-5.00	-15.00	-20.00	22.00	-7.00	9.00	10.00	3.00	12.00	-7.00
5.93	-22.00	-159.00	-7.00	-57.00	-88.00	-35.00	-30.00	-4.00	5.00	9.00	24.00	.00
7.93	-26.00	-205.00	-8.00	-80.00	-111.00	-43.00	-40.00	-14.00	8.00	13.00	30.00	15.00
.00	-10.00	-58.00	-6.00	-22.00	-22.00	22.00	-1.00	2.00	16.00	3.00	15.00	-20.00

Total Ram Load, kip	24	25	26	27	28	29	31	32	33	34	35	51
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.02	-4.00	-1.00	4.00	-1.00	.00	.00	1.00	.00	.00	.00	-1.00	7.00
1.90	-5.00	-1.00	7.00	-1.00	.00	.00	2.00	.00	-1.00	1.00	-2.00	17.00
2.03	-8.00	-2.00	8.00	-5.00	.00	-1.00	2.00	-1.00	-7.00	-3.00	-7.00	20.00
3.83	-4.00	-4.00	11.00	-6.00	.00	-1.00	2.00	-1.00	-7.00	-1.00	-8.00	57.00
5.63	-5.00	-8.00	19.00	-7.00	.00	-1.00	2.00	-1.00	-7.00	-1.00	-9.00	125.00
.14	-6.00	-2.00	8.00	-4.00	.00	-3.00	.00	-3.00	-7.00	-7.00	-7.00	16.00
2.03	-10.00	-4.00	11.00	-12.00	-1.00	-3.00	4.00	-4.00	-7.00	-5.00	-9.00	41.00
4.03	-9.00	-4.00	17.00	-11.00	-1.00	-3.00	4.00	-4.00	-8.00	-4.00	-9.00	75.00
5.95	-10.00	-7.00	21.00	-12.00	-1.00	-3.00	4.00	-4.00	-9.00	-4.00	-9.00	134.00
8.00	-10.00	-14.00	24.00	-16.00	.00	-3.00	5.00	-3.00	-9.00	-2.00	-10.00	204.00
.00	-12.00	-2.00	14.00	-10.00	.00	-4.00	.00	-3.00	-9.00	-6.00	-10.00	36.00
5.93	-5.00	-10.00	21.00	-14.00	.00	-4.00	7.00	-3.00	-9.00	4.00	-20.00	145.00
7.93	-4.00	-13.00	28.00	-16.00	-1.00	-5.00	6.00	-3.00	-10.00	5.00	-24.00	192.00
.00	-11.00	-4.00	11.00	-13.00	-1.00	-5.00	-1.00	-3.00	-10.00	-6.00	-14.00	35.00

Total Ram Load, kip	52	53	54	55	56	57	58	59	41 c/	43 c/
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.02	3.00	2.00	-18.00	-1.00	3.00	-3.00	-1.00	-6.00	.98	1.01
1.90	3.00	6.00	-1.00	-1.00	6.00	-11.00	-2.00	-19.00	1.79	1.68
2.03	1.00	45.00	-11.00	-4.00	10.00	-11.00	.00	-28.00	1.95	1.72
3.83	.00	109.00	4.00	-4.00	17.00	-24.00	-2.00	-98.00	3.61	3.03
5.63	-14.00	187.00	14.00	23.00	28.00	-31.00	-9.00	-110.00	5.50	4.82
.14	-7.00	22.00	-41.00	3.00	11.00	2.00	-1.00	-27.00	.01	.20
2.03	-2.00	63.00	-15.00	-1.00	15.00	-14.00	-2.00	-50.00	2.12	1.85
4.03	-3.00	135.00	9.00	-4.00	23.00	-25.00	-4.00	-89.00	4.15	3.45
5.95	-16.00	191.00	26.00	-2.00	36.00	-28.00	-7.00	-125.00	5.60	5.26
8.00	-34.00	232.00	20.00	27.00	53.00	-38.00	-13.00	-171.00	3.97	8.79
.00	-13.00	36.00	-44.00	26.00	18.00	-3.00	-1.00	-49.00	.00	-.02
5.93	-10.00	208.00	11.00	44.00	31.00	-87.00	.00	-144.00	5.41	4.96
7.93	-7.00	272.00	15.00	89.00	38.00	-117.00	-3.00	-185.00	6.23	7.26
.00	-6.00	44.00	-54.00	23.00	25.00	-12.00	3.00	-56.00	.01	-.01

a/ Transducer number (refer to figure 4.9 for transducer location)
b/ Displacement x 10^4, in.
c/ Total ram load, kip, computed from corresponding transducer reading.

It can be seen that, except for Test 4, there was reasonably good agreement between the two load cell readings. In Test 4, the average of load cell C readings was higher and the correlation between individual readings was erratic. In this test, the readings of load cell C were judged to be more reliable. The pressure transducer readings were significantly lower, particularly in Tests 3 and 4. No explanation could be found for this discrepancy, particularly in view of the fact that any oil leakage would cause the transducer readings to be higher. The effect of temperature on load cell and transducer accuracy was investigated and found to be negligible. Since the load cells were calibrated before and after the test and found to be accurate, their readings, rather than pressure transducer readings, were used in interpreting the measurements.

Table A.2 Results of Test 2

Total Ram Load, kip	11 a/	12	13	14	15	16	17	18	19	21	22	23
.00	.00 b/	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.00	-4.00	-16.00	5.00	-4.00	34.00	-19.00	13.00	18.00	17.00	2.00	8.00	15.00
4.00	-9.00	-55.00	4.00	-9.00	30.00	-31.00	-2.00	27.00	17.00	5.00	13.00	42.00
6.00	-15.00	-103.00	4.00	-20.00	27.00	-45.00	-8.00	27.00	20.00	7.00	18.00	60.00
8.00	-24.00	-184.00	.00	-47.00	-27.00	-92.00	-42.00	26.00	25.00	11.00	25.00	82.00
10.00	-25.00	-303.00	-1.00	-72.00	-47.00	-109.00	-A8.00	9.00	24.00	14.00	32.00	117.00

Total Ram Load, kip	24	25	26	27	28	29	31	32	33	34	35	51
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.00	5.00	2.00	5.00	.00	-1.00	.00	1.00	1.00	.00	2.00	-2.00	36.00
4.00	8.00	1.00	A.00	-1.00	-2.00	.00	1.00	.00	.00	4.00	-6.00	75.00
6.00	5.00	.00	13.00	-2.00	-2.00	.00	2.00	.00	1.00	6.00	-13.00	124.00
8.00	11.00	-5.00	21.00	-5.00	-4.00	.00	5.00	.00	.00	15.00	-20.00	211.00
10.00	7.00	-A.00	30.00	-9.00	-4.00	-1.00	5.00	.00	.00	20.00	-27.00	328.00

Total Ram Load, kip	52	53	54	55	56	57	5A	59	41	43
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00 c/	.00 c/
2.00	11.00	70.00	29.00	.00	15.00	-16.00	2.00	-15.00	1.91	1.58
4.00	16.00	129.00	44.00	1.00	20.00	-46.00	2.00	-49.00	3.81	3.06
6.00	16.00	216.00	57.00	64.00	22.00	-82.00	1.00	-95.00	5.85	4.79
8.00	27.00	341.00	85.00	111.00	30.00	-132.00	-3.00	-176.00	8.62	6.71
10.00	24.00	459.00	114.00	168.00	43.00	-177.00	-9.00	-286.00	9.84	8.92

a/ Transducer Number (refer to figure 4.9 for transducer location).
b/ Displacement x 10^4, in.
c/ Total ram load, kip, computed from corresponding transducer reading.

Table A.3 Results of Test 3

Total Ram Load, kip	11 a/	12	13	14	15	16	17	18	19	21	22	23
.00	.00 b/	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.00	1.00	-15.00	2.00	28.00	-3.00	42.00	1.00	13.00	-1.00	.00	15.00	-12.00
2.00	.00	-39.00	3.00	58.00	-7.00	111.00	-11.00	28.00	.00	-1.00	32.00	-46.00
.00	3.00	-4.00	1.00	15.00	14.00	43.00	-7.00	18.00	4.00	-1.00	3.00	-2.00
1.00	2.00	-18.00	4.00	42.00	19.00	64.00	-7.00	16.00	3.00	-2.00	16.00	-18.00
2.00	.00	-39.00	5.00	68.00	18.00	129.00	-21.00	23.00	-1.00	-3.00	39.00	-52.00
3.00	-1.00	-61.00	7.00	91.00	17.00	204.00	-36.00	42.00	-1.00	-2.00	44.00	-81.00
4.00	-5.00	-70.00	6.00	18.00	2.00	290.00	-55.00	46.00	-3.00	-2.00	64.00	-129.00
.00	-1.00	-9.00	5.00	32.00	31.00	76.00	-3.00	26.00	9.00	1.00	10.00	-15.00
2.00	-3.00	-45.00	5.00	70.00	9.00	163.00	-17.00	33.00	3.00	1.00	37.00	-71.00
4.00	-5.00	-90.00	7.00	125.00	-11.00	266.00	-35.00	48.00	-2.00	-1.00	63.00	-131.00
6.00	-6.00	-160.00	10.00	193.00	-30.00	450.00	-69.00	99.00	-8.00	-3.00	107.00	-224.00
.00	.00	-16.00	5.00	55.00	33.00	110.00	-8.00	44.00	11.00	2.00	15.00	-44.00
.00	-6.00	-6.00	12.00	45.00	46.00	106.00	.00	33.00	5.00	9.00	4.00	-56.00
2.00	-8.00	-36.00	11.00	81.00	30.00	188.00	-14.00	50.00	-2.00	9.00	35.00	-101.00
4.00	-10.00	-88.00	13.00	138.00	16.00	319.00	-32.00	65.00	-6.00	7.00	68.00	-174.00
6.00	-11.00	-151.00	17.00	198.00	-5.00	472.00	-56.00	106.00	-12.00	2.00	107.00	-252.00
7.23	-13.00	-234.00	23.00	287.00	-35.00	680.00	-101.00	159.00	-17.00	1.00	150.00	-362.00
.00	-3.00	-19.00	14.00	75.00	57.00	185.00	-18.00	73.00	8.00	7.00	19.00	-101.00

Total Ram Load, kip	24	25	26	27	28	29	31	32	33	34	35	51
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.00	-5.00	.00	8.00	4.00	2.00	-2.00	1.00	.00	.00	1.00	1.00	13.00
2.00	-3.00	-1.00	21.00	8.00	6.00	-1.00	2.00	.00	.00	3.00	.00	31.00
.00	-4.00	-1.00	.00	2.00	5.00	.00	.00	.00	.00	1.00	.00	3.00
1.00	-3.00	.00	7.00	-1.00	4.00	-1.00	1.00	.00	-1.00	1.00	-2.00	22.00
2.00	-1.00	-1.00	14.00	-1.00	4.00	-1.00	-1.00	-1.00	-1.00	1.00	-6.00	31.00
3.00	-4.00	.00	22.00	-1.00	4.00	-2.00	-2.00	-1.00	-1.00	1.00	-8.00	50.00
4.00	-3.00	.00	38.00	3.00	5.00	-2.00	-2.00	.00	-2.00	2.00	-10.00	75.00
.00	-2.00	.00	3.00	-11.00	1.00	-2.00	-4.00	.00	-2.00	-1.00	-8.00	7.00
2.00	-4.00	.00	21.00	-1.00	4.00	-2.00	-2.00	.00	-1.00	1.00	-7.00	39.00
4.00	.00	.00	41.00	8.00	12.00	-2.00	1.00	.00	-2.00	3.00	-8.00	73.00
6.00	-3.00	.00	71.00	19.00	24.00	-1.00	2.00	.00	-2.00	6.00	-11.00	122.00
.00	-7.00	.00	6.00	-8.00	7.00	-2.00	-2.00	-1.00	-2.00	.00	-5.00	10.00
.00	-10.00	-1.00	-26.00	-19.00	-3.00	-4.00	-5.00	.00	-7.00	-1.00	-10.00	6.00
2.00	-3.00	.00	-5.00	-12.00	-2.00	-4.00	-3.00	.00	-5.00	1.00	-11.00	28.00
4.00	-5.00	.00	16.00	.00	4.00	-5.00	-2.00	.00	-6.00	2.00	-13.00	74.00
6.00	2.00	.00	41.00	13.00	16.00	-6.00	-1.00	.00	-6.00	6.00	-17.00	128.00
7.23	2.00	.00	77.00	26.00	28.00	-5.00	1.00	1.00	-6.00	8.00	-20.00	182.00
.00	-3.00	.00	-9.00	-8.00	4.00	-4.00	-5.00	.00	-6.00	-2.00	-10.00	13.00

Total Ram Load, kip	52	53	54	55	56	57	58	59	41 c/	43 c/
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.00	-5.00	20.00	.00	.00	1.00	-10.00	.00	-6.00	.90	.29
2.00	-5.00	38.00	1.00	26.00	.00	-30.00	1.00	-18.00	2.07	.57
.00	-1.00	6.00	-2.00	4.00	1.00	-3.00	-1.00	-3.00	-.01	-.00
1.00	-6.00	16.00	-4.00	3.00	3.00	-13.00	.00	-11.00	.98	.31
2.00	-2.00	42.00	-6.00	20.00	2.00	-29.00	1.00	-24.00	2.11	.57
3.00	-4.00	56.00	-4.00	39.00	2.00	-45.00	2.00	-34.00	2.84	.84
4.00	-4.00	80.00	-8.00	51.00	2.00	-69.00	4.00	-58.00	3.81	1.09
.00	-6.00	-1.00	-14.00	2.00	4.00	-6.00	-1.00	-9.00	.01	.01
2.00	-4.00	40.00	-9.00	19.00	4.00	-33.00	.00	-30.00	2.06	.58
4.00	-14.00	76.00	-14.00	51.00	3.00	-70.00	4.00	-59.00	3.64	1.09
6.00	-9.00	131.00	-13.00	107.00	-1.00	-123.00	5.00	-106.00	5.82	1.65
.00	-7.00	14.00	-15.00	5.00	6.00	-9.00	.00	-18.00	.00	.00
.00	-8.00	12.00	-33.00	-14.00	18.00	4.00	1.00	-33.00	.01	.01
2.00	-9.00	46.00	-33.00	.00	19.00	-20.00	4.00	-53.00	1.83	.57
4.00	-10.00	62.00	-36.00	54.00	15.00	-63.00	8.00	-92.00	3.85	1.11
6.00	-10.00	142.00	-35.00	95.00	11.00	-114.00	10.00	-134.00	5.77	1.67
7.23	-19.00	165.00	-37.00	142.00	7.00	-153.00	9.00	-183.00	7.41	2.07
.00	-7.00	15.00	-37.00	3.00	14.00	-1.00	4.00	-50.00	.01	.00

a/ Transducer Number (refer to figure 4.9 for transducer location).
b/ Displacement x 10^4, in.
c/ Total ram load, kip, computed from corresponding transducer reading.

Table A.4 Results of Test 4

Total Ram Load, kip	11 a/	12	13	14	15	16	17	18	19	21	22	23
.00	.00 b/	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.42	-4.00	-33.00	1.00	-11.00	-15.00	-7.00	-1.00	1.00	-2.00	2.00	6.00	15.00
4.52	-9.00	-73.00	-2.00	-22.00	-36.00	-38.00	-9.00	.00	-4.00	4.00	10.00	36.00
8.21	-15.00	-163.00	-3.00	-51.00	-77.00	-93.00	-40.00	-14.00	-6.00	8.00	17.00	74.00
8.37	-20.00	-187.00	-9.00	-49.00	-75.00	-97.00	-41.00	-38.00	-11.00	10.00	16.00	63.00
7.27	-22.00	-199.00	-12.00	-36.00	-39.00	-99.00	-42.00	-40.00	-11.00	11.00	16.00	65.00
9.97	-21.00	-240.00	-6.00	-65.00	-75.00	-130.00	-50.00	-27.00	-3.00	13.00	21.00	90.00
.03	7.00	-3.00	.00	-11.00	20.00	-22.00	3.00	.00	3.00	-4.00	1.00	10.00

Total Ram Load, kip	24	25	26	27	28	29	31	32	33	34	35	51
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2.42	2.00	.00	7.00	-1.00	.00	1.00	3.00	1.00	.00	2.00	-1.00	37.00
4.52	5.00	.00	11.00	.00	-1.00	.00	6.00	1.00	-1.00	5.00	-4.00	83.00
8.21	3.00	.00	19.00	2.00	.00	1.00	11.00	1.00	-2.00	12.00	-12.00	177.00
8.37	12.00	.00	21.00	2.00	.00	1.00	14.00	.00	-4.00	26.00	-27.00	201.00
7.27	9.00	.00	21.00	-3.00	-2.00	.00	12.00	1.00	-6.00	24.00	-28.00	202.00
9.97	10.00	.00	29.00	-1.00	-3.00	-1.00	12.00	1.00	-8.00	27.00	-35.00	255.00
.03	.00	.00	-3.00	5.00	.00	2.00	2.00	2.00	-5.00	1.00	-1.00	15.00

Total Ram Load, kip	52	53	54	55	56	57	58	59	43	91
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00 c/	.00 c/
2.42	-3.00	62.00	17.00	17.00	2.00	-25.00	1.00	-29.00	1.66	2.00
4.52	-4.00	136.00	39.00	57.00	3.00	-64.00	1.00	-73.00	3.40	4.00
8.21	2.00	263.00	93.00	125.00	5.00	-126.00	-1.00	-159.00	6.12	6.10
8.37	5.00	306.00	94.00	198.00	4.00	-199.00	4.00	-177.00	6.26	11.13
7.27	5.00	308.00	85.00	199.00	5.00	-197.00	6.00	-186.00	5.83	7.47
9.97	13.00	388.00	118.00	225.00	5.00	-213.00	4.00	-239.00	7.11	10.77
.03	-5.00	32.00	-8.00	18.00	6.00	-6.00	8.00	-25.00	-.01	.00

a/ Transducer Number (refer to figure 4.9 for transducer location).
b/ Displacement x 10^4, in.
c/ Total ram load, kip, computed from corresponding transducer reading.

2. Dynamic Tests

Oscillograms for Tests 5.1, 5.2, 5.3, and 5.4 are shown in figure A.1. Figure A.2 shows Tests 5.5, 5.6, and 5.7. Tests 5.8 and 5.9 are shown in figure A.3.

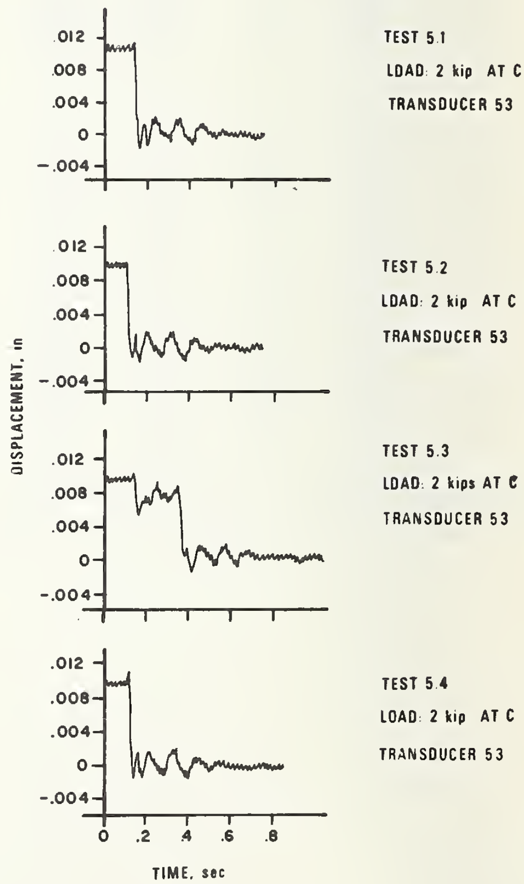

FIGURE A.1 *Oscillograms of Tests* 5.1-5.4.

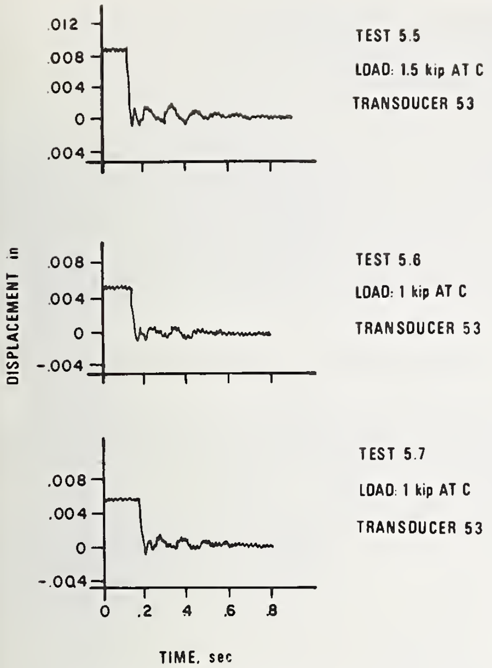

FIGURE A.2 *Oscillograms of Tests* 5.5-5.7.

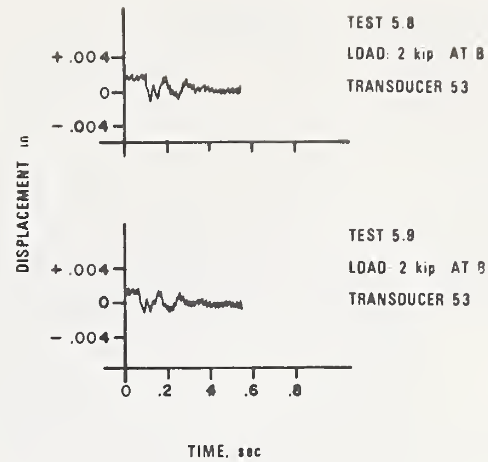

FIGURE A.3 *Oscillograms of Tests* 5.8 *and* 5.9.

3. Visual Inspection

No sign of distress or minor damage by cracking, spalling or separation of surfaces was observed.

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15. SUPPLEMENTARY NOTES

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.)

Tests were carried out on a house to determine its deflection characteristics under lateral loads. The house is a two-story building of conventional wood-frame construction. Two series of tests were conducted. The first of these was to determine the stiffness of the house when subjected to a simulation of wind loading. The second was to determine the dynamic response of the house to a single impulse load.

The report presents the results of these tests from which the following primary conclusions were derived:

1. The measured second-story drift of the building under the test load was considerably less than the drift permitted for medium and high-rise buildings by present design criteria for most areas of the United States.

2. Only a small portion of the distortion of the exterior walls was transmitted to the interior gypsum board.

3. The upper ceiling diaphragm experienced significant in-plane deformation. On the other hand, the floor/ceiling diaphragm at the lower ceiling level tended to act as a rigid diaphragm and to translate as a rigid body when the building was subjected to lateral load.

4. The natural frequency of the structure was approximately 9 Hz and damping averaged approximately 6 percent of critical damping varying from 4 to 9 percent.

17. KEY WORDS (Alphabetical order, separated by semicolons) Building damping; drift; dynamics; earthquake; frequency; housing; lateral resistance; racking; stiffness; structural deflections; vibration ; wind load; wood frame construction.

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