NASA Technical Paper 1447

Vibration Characteristics of Walls and a Plate Glass Window Representative of Those of a Wood-Frame House

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SUMMARY

Experiments were conducted to determine vibration characteristics of structural components representative of wood-frame house construction using various face sheet materials. The components were a vertical section and a horizontal section from a typical wall, a complete wall section, and a plate glass window. Mechanical excitation was used, and measurements of acceleration response, natural frequencies, and nodal patterns were performed.

Results indicate that the wall sections and the complete wall did not act as a unit in responding to sinusoidal vibration inputs. Calculated frequencies of the components that account for this independent behavior of the studs and face sheets agreed reasonably well with experimental frequencies. Experimental vibrations of the plate glass window agreed with calculated behavior, and responses of the window exposed to airplane flyover noise were readily correlated with the test results.

INTRODUCTION

Langley Research Center has for several years been actively engaged in research on noise problems associated with aircraft operations and sonic-boom phenomena. (See refs. 1 and 2.) In view of concern about aircraft noise-induced vibrations and internal noise of residential structures and the related comfort of residential occupants, experiments were undertaken to obtain the vibrational characteristics of house structures. (See ref. 3.) In this study response properties of house components were determined and their responses to airplane noise excitation were evaluated. More recent concern over supersonic airplane (Concorde) operations (ref. 4) in this country has led to studies to measure building vibrations induced by Concorde noise for both historical and residential structures. (See refs. 5 to 9.)

To provide additional detailed data on the vibration characteristics of house structures, experiments were conducted on sections of typical structural wall panels, a complete wall section, and a plate glass window. The purpose of this report is to document the results of these experiments. These data are believed to be of general importance in understanding and dealing with vibrations of house structures resulting from airplane noise and sonic-boom exposure. Experimental data presented include acceleration response spectra, natural frequencies, and nodal patterns for the structural sections or components resulting from sinusoidal force inputs. Comparisons of experimental frequencies with computed frequencies are also presented.

APPARATUS AND TEST PROCEDURE

Wall Sections

In the experimental studies of the present report, two types of symmetric-face wall sections using representative residential wall facing materials were used; one represented a full-size vertical section of a complete residential wall, and the other represented a full-size horizontal section of a wall. Four specimens of each section type were constructed, each having a different facing material. Typical residential wall sections used in these vibration studies are illustrated in figure 1.

Details of the vertical wall sections are shown in figures 2(a) and 2(b). These sections were 243.84 cm (96 in.) high and 40.64 cm (16 in.) wide. One-half of a standard two-by-four fir stud was used on each side and two full sections of studs were used as the top and bottom of the wall section frame. (See fig. 2(a).) The section with face sheets is shown in figure 2(b).

The horizontal wall section details are illustrated in figure 2(c). Each section was 207.01 cm (81-1/2 in.) wide and 40.64 cm (16 in.) high with segments of vertical two-by-four studs located 40.64 cm (16 in.) on-center. Face sheets were nailed to the fir studs as done in typical house construction.

Facing materials were either 1.27-cm (1/2-in.) sheetrock, 1.27-cm (1/2-in.) plywood, 1.98-cm (25/32-in.) Gyp-lap[1] sheathing, or 0.953-cm (3/8-in.) plaster on 0.953-cm (3/8-in.) gypsum lathe. Standard construction nailing was used in the fabrication of the wall section. Table I gives the mass and surface density of each section. Surface density was calculated on the assumption that all material is distributed uniformly over the cross section.

In addition to the wall section models, four subelement samples of the two-by-four studs and three samples of each of the facing materials were tested to determine the material modulus of elasticity. Full details and results of this phase of the study are presented in the appendix.

Complete Wall and Plate Glass Window

Additional studies were also conducted to determine the response characteristics of a complete wall and a plate glass window. The complete wall or the plate glass window was mounted for testing in the open side of a 3.96- by 2.44- by 2.44-m (13- by 8- by 8-ft) structural steel cubicle, which was built to insure high stiffness of three walls, the top, and the bottom. The cubicle is shown in figure 3 with the window in place.

The 2.44- by 3.66-m (8- by 12-ft) test wall, constructed to fit the open side of the structural steel cubicle, was built using two-by-four pine studs, 40.62 cm (16 in.) on-center with 1.27-cm (1/2-in.) thick sheetrock on the

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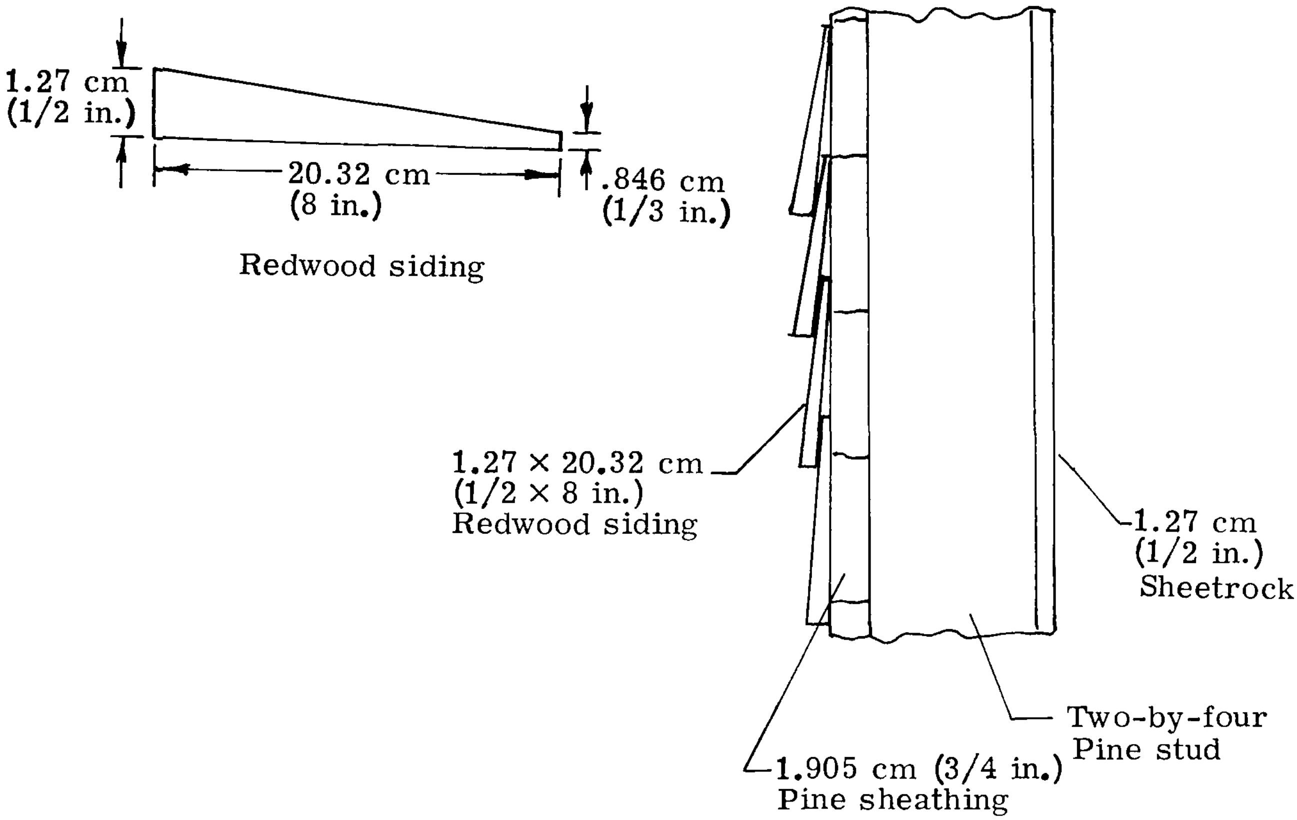
[1] Gyp-lap: Trade name of United States Gypsum Co.

interior surface and 1.98-cm (0.781-in.) thick pine board sheathing on the exterior surface. The pine sheathing was placed diagonally on the studs and nailed at each stud interface and overlaid with 20.32-cm (8-in.) horizontally oriented redwood siding. Sketch (a) shows the details of the wall construction. Total mass of the wall was 321.14 kg (708 lbm) with a surface density (assuming uniformly distributed material) of 36.00 kg/m^2 (0.229 slug/ft^2).



Sketch (a)

The plate glass window, shown in figure 3, was approximately 3.12 m (10-1/4 ft) wide, 1.93 m (6-1/3 ft) high, and 0.635 cm (1/4 in.) thick and was supported as one wall of the structural steel test cubicle. The frame of the glass window was aluminum channel with typical clip supports around the perimeter of the glass. The window was installed in a special frame which was mounted on the test cubicle for tests.

Instrumentation and Test Methods

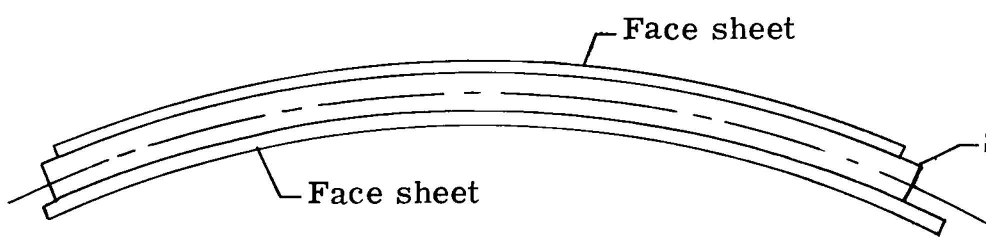
For simplicity of testing and to avoid possible boundary condition problems, the wall sections were suspended with free-free boundaries on cables in series with springs to give a soft suspension. (See fig. 4.) Both the complete wall and the window were clamped along their edges as shown in figure 3. A permanent magnet shaker, capable of a maximum vector force of 111 N (25 lbf), was used to excite all test specimens. The shaker was attached to the specimens with a vacuum plate attachment in series with a force gage. The shaker was controlled by a sweep oscillator operating through a power amplifier. The force output of the shaker was measured with the force gage and used as a servo signal to the sweep oscillator to maintain a constant input force amplitude with frequency. A crystal accelerometer was placed at selected locations on the test specimens to determine the vibratory response. The output of the accelerometer was recorded against frequency on a calibrated x-y platter. The acceleration output, in conjunction with the input signal, was used to obtain a Lissajous figure on an oscilloscope to determine a desired resonant condition. A handheld velocity probe was then used to survey the vibrating horizontal wall sections, the complete wall, and the window to determine node lines for defining mode shapes. As shown in figure 4(a), the vertical wall sections were suspended to permit fine sand to be sprinkled over the face sheets. During vibrations at a natural frequency, the sand collected at nodal locations and defined the nodal patterns.

ANALYSIS

Natural frequencies of the wall sections were computed for correlation with the experimental data. Determinations of the flexural stiffness of the sections for these calculations were guided by particular experimental behavior observed on the vertical and horizontal wall sections, as described in the subsequent sections.

Vertical Wall Sections

Based upon experimental observations, the assumption was made that the nails through the face material into the studs offered little or no resistance in preventing the face sheets from sliding over the studs. This assumption leads to the (exaggerated) behavior illustrated in sketch (b). Each part of



Sketch (b)

the vertical wall section is shearing relative to other parts and therefore is bending about its own neutral axis. Thus, the wall section flexural stiffness D_y for this situation is

$$D_y = E_{stud}\left[\frac{h_1{}^3}{12} + 2\left(\frac{E_{face}}{E_{stud}}\right)\left(\frac{h^3}{12}\right)\right] \tag{1}$$

or

$$D_y = D_{stud} + 2D_{face} \tag{2}$$

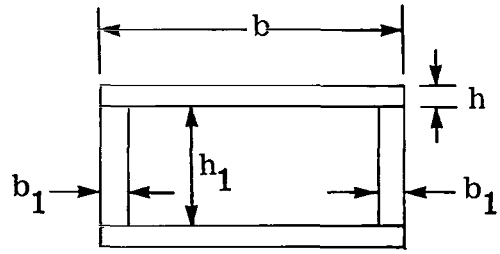
where (from sketch (c))

b width of face sheet

b_1 thickness of side studs

h thickness of face sheet

h_1 height of side stud



Sketch (c)

and

D_{stud} flexural stiffness of stud

D_{face} flexural stiffness of face

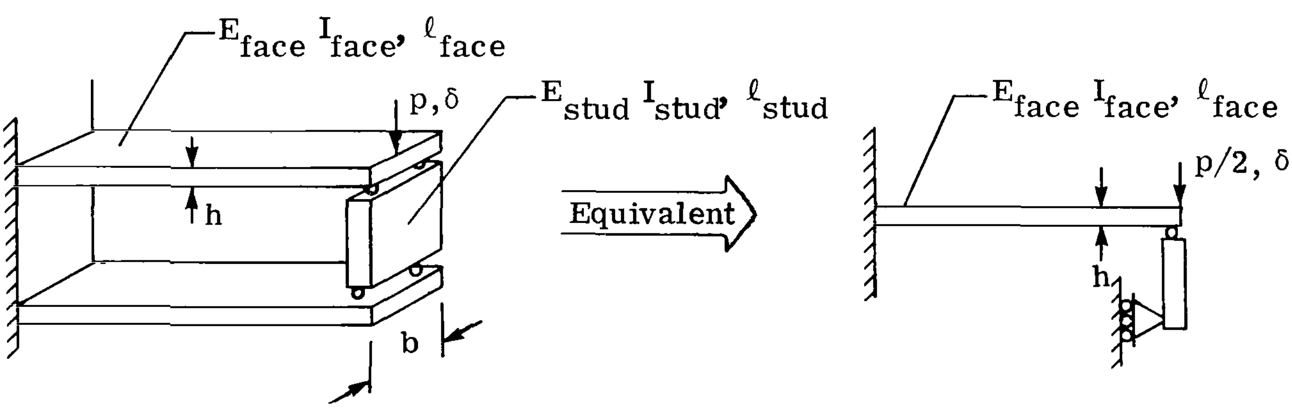
E_{stud} modulus of elasticity of side stud

E_{face} modulus of elasticity of face sheet

To compute the beamlike vibration frequencies of the vertical wall sections, equation (1) was used as the section stiffness.

Horizontal Wall Sections

To determine the flexural stiffness D_x of the horizontal sections, a cantilever beam approach was used. One bay of the wall section was assumed to be cantilevered as shown in sketch (d). The face sheets were assumed to



Sketch (d)

be pinned to the studs, since during vibration tests the nails and face sheets seemed to be effectively acting in this manner. Thus the deflection equation for the equivalent cantilever beam model (sketch (d)) of the horizontal bay

$$\delta = \frac{(p/2)\ell^3}{3(E_{face}I_{face})},$$ rearranged and divided by the element width b, gives

$$2\,\frac{E_{face}I_{face}}{b} = \frac{p}{\delta}\,\frac{\ell^3}{3b} \qquad (3)$$

where I_{stud} and I_{face} are the section moments of inertia and p denotes the force or load. However,

$$\frac{E_{face}I_{face}}{b} = \frac{Eh^3}{12} = D_{x,face} \qquad (4)$$

Thus,

$$D_{x,eq} = 2\,\frac{Eh^3}{12} = 2D_{x,face} \qquad (5)$$

which indicates that the equivalent flexural stiffness $D_{x,eq}$ of the horizontal wall section is simply twice the flexural stiffness of the face sheets. To compute the frequencies of the horizontal wall sections, equation (4) was used as the section stiffness.

RESULTS AND DISCUSSION

Results of vibration tests performed with the vertical and horizontal wall sections, the complete wall, and the plate glass window are presented in figures 5 to 13. Results include (1) forced response for constant-amplitude vibratory input force, (2) measured nodal patterns for several resonant responses, and (3) comparisons of measured and computed frequencies.

Vertical Wall Sections

Experimental and analytical results for vertical wall sections with four different facing materials are presented in figures 5 to 7.

Acceleration response.- Figure 5 presents acceleration response in root mean square (rms) g units of the various wall sections as a function of frequency. The responses in figure 5 are for a constant-amplitude vibratory input force of ±13.34 N (±3.0 lbf). The fundamental frequency of the acceleration response of the four vertical wall sections occurs between 20 and 40 Hz, and the acceleration magnitudes of the sheetrock (fig. 5(a)), the plywood (fig. 5(b)), and the plaster (fig. 5(d)) are approximately the same throughout the frequency range presented. The acceleration magnitudes of the Gyp-lap sheathing section, however, are generally higher for the initial response peak and for the higher frequency responses above approximately 300 Hz. The general trend of all the responses for the constant-amplitude sinusoidal input force is to increase with frequency at about 6 dB/octave as shown by the reference line in the figure. This trend is similar to data presented in reference 3 for residential walls and is consistent with impedance considerations for linear behavior.

Nodal patterns.- Measured nodal patterns for two selected modes of the Gyp-lap sheathing wall section are shown in figure 6. In the photographs, the broad white lines are node lines where the sand has collected during vibration at a resonant frequency. In figure 6(a) the nodal pattern is an $m = 5$; $n = 2$ mode at 132 Hz, and in figure 6(b) the pattern is an $m = 8$; $n = 2$ mode at 188 Hz, where m and n are the number of node lines in the length and width directions, respectively. Nodal patterns in figure 6 are typical of those measured for all vertical panels. The experimental nodal patterns did not always have nodal lines on both edges of the face sheets. This result is believed to be primarily due to the relatively few nails along the face sheet edges.

Natural frequencies.- Measured and computed frequencies as a function of the mode number m for the four vertical wall sections are shown in figure 7. Three computed frequency curves appear on each figure. The short-dash curve is the beamlike frequencies computed by use of the flexural stiffness of the wall section as developed in the "Analysis" section. The — - curve represents the frequencies of the face sheets with simply supported edges, whereas the long-dash curve represents those for the fixed edges. The frequency equation of reference 10 was used to compute the curves. The experimental data are represented by symbols connected by a solid line. The results in figure 7 show that the fundamental beamlike frequencies of the sheetrock, plywood, and Gyp-lap sheathing vertical wall sections agree well with those computed by using the stiffness as derived from data in the appendix and the equation for the flexural stiffness given in the "Analysis" section. For the plaster wall section, the results indicate a slightly higher stiffness than the assumption; however, the trend of the experimental data is in excellent agreement with the calculations. Also the experimental frequency data make a transition from the beamlike frequency and approach the computed frequencies of the face sheets with fixed edges at the higher m numbers. The behavior of the modal frequencies of all the face sheet materials on the vertical wall sections followed this trend (see fig. 7); however, those for the sheetrock and plywood sections were closer to the computed frequencies for the sheets with simply supported edges.

Results of the vertical wall section data indicate therefore that the fundamental frequency of full structural walls (composed of repeating vertical sections) is most probably determined by the sum of the stiffnesses of the studs and face sheets because of poor dynamic coupling resulting from standard nailing. Furthermore, the higher m number modes of complete walls should make the transition to modes of face sheets only.

Horizontal Wall Sections

Figures 8 to 10 present experimental and analytical results for vibration tests of horizontal wall sections with four different facing materials.

Acceleration response.- Acceleration responses in rms g units as a function of frequency are presented in figure 9 for four facing materials of the horizontal wall sections. A constant-amplitude sinusoidal input force of ±13.34 N (±3.0 lbf) was used except for the Gyp-lap section. The input force amplitude level was reduced to ±8.90 N (±2 lbf) for the Gyp-lap because large deflections of the wall occurred in this case. The responses of the horizontal wall sections are similar to those for the vertical sections; however, the lower frequency responses for all four horizontal sections are much lower (less than 10 Hz, generally) than the corresponding vertical wall sections. This result occurs because of the greater flexibility across the studs. A general increase in response of 6 dB/octave with frequency is observed for the horizontal wall sections similar to the increase observed for the vertical wall sections.

Nodal patterns.- Three nodal patterns of the horizontal sheetrock wall section are shown in figure 9. The patterns are for the first, second, and fifth beamlike resonances of the horizontal wall section at frequencies of 8.5, 17.5, and 74.5 Hz and are the $n = 0$; $m = 2$, 3, and 6 patterns, respectively. The straight-line nodal patterns in figure 9 are typical for all the horizontal wall sections used in the investigation.

Natural frequencies.- Figure 10 presents measured and computed frequencies as a function of mode number m for the four horizontal wall sections. Symbols are for experimental data; the curves are for results computed by using the stiffness data from the appendix for the various materials and the assumptions discussed in the "Analysis" section. Good agreement between the calculated frequencies using the stiffness of the face materials only and experimental frequencies indicates that the modes of the horizontal wall sections are governed by the stiffness of the face material. The frequencies of the sheetrock and Gyp-lap sections are about the same, since the D_x/Mass values of the two materials are essentially the same, although the difference in modulus of elasticity of the materials is large. (See appendix.) The plaster face material had the highest frequencies for a mode number m compared with the other three face materials because the D_x/Mass was the greatest for the plaster facing.

Complete Wall

To cover the spectrum from the section level of typical walls to a full-size wall section, vibration data for a complete test wall are presented in figure 11.

Acceleration response.- Figure 11(a) presents the response in rms g units as a function of frequency for the complete wall supported in the side of the special test cubicle. The response is for a constant-amplitude sinusoidal input force of ±22.24 N (±5 lbf) between 5 and 200 Hz. A comparison of the full-size wall section response with responses of the wall sections (figs. 5 and 8) and those of reference 3 for house structures indicates that the full-size wall behavior is similar to that of the wall sections. The trend of the response also shows the increase at about 6 dB/octave as indicated by the reference line in figure 11(a).

Nodal patterns.- Figure 11(b) presents four nodal patterns measured on the full-size wall section. The modes are for $n = 2$ (top and bottom edges are nodes) and $m = 2, 4, 6,$ and 8 at frequencies of 23.5, 34.0, 58.0, and 91.0 Hz, respectively. A comparison of these nodal patterns with the patterns presented in reference 3 for residential walls indicates identical type patterns, as might be expected.

Natural frequencies.- Figure 11(c) presents frequencies of the panel modes (including those of fig. 11(b)) as a function of mode number m for the full-size wall section. The broken curves are computed frequencies and the solid curve with symbols is measured data. The results shown in figure 11(c) illustrate the complex problems associated with determining the vibration behavior of typical wall structures. For example, the frequency of the first experimental wall vibration mode ($m = 2$; $n = 2$) occurred at approximately 24.0 Hz; however, the computed frequency (using the sum of the individual stiffness of the different materials and assuming simple edge support) is about twice the experimental value. Also, the frequency computed by using only the stiffness of the pine sheathing with either fixed or simple edge supports is about one-half the experimental value. On the other hand, at the higher m numbers the experimental frequencies approach the trend of the computed frequencies for the fixed supports with the stiffness assumed to be that of the pine sheathing.

In analyzing the vibration data of the complete wall section, the observed behaviors of the vertical and horizontal wall sections were similar to the full-size wall behavior, and knowledge of the effect of face-sheet—stud interface behavior on stiffness (discussed under "Analysis" section) was very helpful in understanding the response of the full-size wall section. In addition, the data illustrated the understanding of vibration characteristics that can be obtained through sinusoidal vibration tests and, in some cases, such vibration tests may be necessary for interpreting the responses of structures exposed to airplane flyover noise. Furthermore, the substantial shear motions occurring in the wall structures lead to difficulty in computing frequencies of the wall, even when good modulus data of the individual materials are available. This result suggests that a systematic laboratory study of wall structures would probably provide useful insight and better understanding of the vibration behavior of full-size wall structures.

As a consequence of the vibration results with the wall section and the full-size wall test section, a comment is offered relative to the discussion of wall modes and frequencies in reference 3. The statements in reference 3 were made by assuming the wall stiffness to be for the cross section bending about a neutral axis of the wall as a unit; however, based upon the results of the present study, the walls do not necessarily behave as a unit but each material bends basically about its own neutral axis. Thus, as discussed in the present report, the responses of the higher m number modes are associated with the face sheet stiffness only and are therefore much lower in frequency.

Plate Glass Window

Figure 12 presents results of forced sinusoidal tests conducted to gain insight into vibration behavior of plate glass windows which are often exposed to flyover noise such as investigated in reference 2.

Acceleration response.- Figure 12(a) presents acceleration response at the center of the window, in g units, as a function of frequency. Responses of the window are similar to the structural wall section responses of figures 5 and 8. The lowest frequency window response was at approximately 9 Hz and the additional higher frequency responses are noted to generally occur about a straight line which has a positive slope of 6 dB/octave with frequency, as did the wall section responses.

Nodal patterns.- Nodal patterns of the plate glass window corresponding to several peaks (noted by numbers in parentheses) in figure 12(a) are presented in figure 12(b). The 9-Hz response is the $m = 2; n = 2$ mode. At 18 Hz the response is the $m = 4; n = 2$ mode, at 48 Hz the response is the $m = 4; n = 4$ mode, and at 70 Hz the response is the $m = 6; n = 4$ mode. These results indicate that the odd or unsymmetrical patterns are the prevalant ones which occurred during forced vibrations at the center of the window.

Natural frequencies.- Comparisons of experimental and computed frequencies of the plate glass window as a function of mode number m for various values of n are presented in figure 12(c). The calculated frequencies were obtained by using the analysis in reference 11, which accounts for the stiffness of the enclosed air volume, in conjunction with the frequency equation for plates given in reference 10, with assumed simple edge supports. Curves are computed data and symbols are measured data. The comparison in the figure indicates excellent agreement between the computed and measured frequencies for the plate glass window using handbook values (ref. 12) for the modulus of elasticity of glass.

To illustrate further the usefulness of sinusoidal vibration test data in assessing the behavior of structural components when exposed to flyover noise, a typical oscillograph trace of the responses (no scale) of the plate glass window to one flyover of an airplane is reproduced in figure 13. The top trace illustrates a typical time slice of the random outside noise environment produced by the airplane. Immediately below that (curve labeled (1)) is the inside noise at some time which consists basically of a 9-Hz frequency with a higher frequency superimposed. At a different time during the flyover time history (curve labeled (2)), the acceleration at the center of the window was an 18-Hz response; at still a later time the inside noise (curve labeled (3)) was around a 48-Hz response; and at still a different time the acceleration response (curve labeled (4)) was essentially at 70 Hz. Since these frequencies correspond to frequencies of peaks in the sinusoidal acceleration data (fig. 12(a)), the results indicate that as the frequency of the noise energy corresponds to a window natural frequency, the window vibrates in one of the various nodal patterns shown in figure 12(b). Thus, either acceleration or inside noise response of the window may be measured to assess the vibration behavior and such data can be understood by correlation with response data from sinusoidal inputs.

CONCLUDING REMARKS

Experiments were conducted to determine the vibration characteristics of structural components representative of wood-frame house construction using various face sheet materials. The components were vertical sections and horizontal sections from a typical wall, a complete wall section, and a plate glass window. Mechanical excitation was used and measurements of acceleration response, natural frequencies, and nodal patterns were performed.

Results indicate that the wall sections and the complete wall did not act as a unit in responding to sinusoidal vibration inputs. Lower frequency response modes (mode number $m < 4$, except for plaster section where $m < 7$) of the vertical sections and the full-size wall were basically determined by the sum of the stiffnesses of the studs and the face sheets acting independently. Responses at higher m numbers for all the vertical sections and the complete wall as well as all frequencies of the horizontal wall sections tended to be dominated by platelike vibrations of the wall face sheets acting independently of the studs. Trends of the calculated frequencies of the structural components that accounted for the poor dynamic coupling from standard construction nailing between the studs and face sheets (nonunit behavior of cross section) agreed well with experimental frequencies. Vibrations of the plate glass window agreed with calculated behavior, and responses of the window exposed to airplane flyover noise were readily correlated with sinusoidal vibration test results.

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APPENDIX

DETERMINATION OF MATERIAL PROPERTIES

This appendix presents the results of tests conducted to determine the modulus of elasticity of the various materials used in the construction of the vertical and horizontal wall sections discussed in the main text.

Material Samples

Four samples of each of the fir studs and three samples of each of the four facing materials were cut from the excess length of the various materials used in the wall sections. The fir stud samples were 1.27 cm (1/2 in.) thick, 60.96 cm (24 in.) long, and 4.06 cm (1.6 in.) wide. The three material samples of each of the four facing materials were, generally, 6.35 cm (2.5 in.) wide, 40.64 cm (16 in.) long, and the thicknesses were 1.27 cm (1/2 in.) for the sheetrock and plywood; 1.98 cm (25/32 in.) for the Gyp-lap sheathing, and 1.91 cm (3/4 in.) for the plaster on gypsum lathe.

Test Methods and Analysis

Figure 14 is a photograph of the test setup used in the determination of the modulus of elasticity of the materials in the vertical and horizontal wall sections. Each material sample was clamped to a rigid base as a cantilever beam. Beam length was 50.80 cm (20 in.) for the fir studs and 35.56 cm (14 in.) for the various facing materials. The air shaker shown in the photograph was used to excite the first three or four cantilever beam modes at their natural frequency. Prior to the vibration tests, each sample's dimensions and mass were measured. From these data the mass per unit length and area moment of inertia were determined.

To obtain the material modulus of elasticity, the measured properties were used in conjunction with the cantilever beam frequency equation to compute this quantity. Specifically,

$$E = \frac{(2\pi f)^2 \mu \ell^4}{A_n{}^2 I}$$

where

E modulus of elasticity (desired)

f frequency of cantilever modes, Hz (measured)

μ mass per unit length of beam (measured)

ℓ length of beam (measured)

A_n coefficient depending on mode number and boundary condition of beam (known)

I area moment of inertia of beam cross section (calculated from measured values)

Table II presents the measured frequencies of the various material samples, the mass per unit length, and the average value of the modulus of elasticity obtained from the individual experimental frequency values. The average values of the modulus were used in the "Analysis" section of the main text of this report.

REFERENCES

1. Sonic Boom Experiments at Edwards Air Force Base. NSBEO-1-67 (Contract AF 49(638)-1758), CFSTI, U.S. Dep. Com., July 28, 1967.

2. Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft. NASA SP-189, 1968.

3. Carden, Huey D.; and Mayes, William H.: Measured Vibration Response Characteristics of Four Residential Structures Excited by Mechanical and Acoustical Loadings. NASA TN D-5776, 1970.

4. Concorde Supersonic Transport Aircraft. Final Environmental Impact Statement - Volume I. FAA, Sept. 1975.

5. Staff, Langley Research Center: Concorde Noise-Induced Building Vibrations for Sully Plantation, Chantilly, Virginia. NASA TM X-73919, 1976.

6. Staff, Langley Research Center: Concorde Noise-Induced Building Vibrations, Sully Plantation - Report No. 2, Chantilly, Virginia. NASA TM X-73926, 1976.

7. Staff, Langley Research Center: Concorde Noise-Induced Building Vibrations, Montgomery County, Maryland - Report No. 3. NASA TM X-73947, 1976.

8. Staff-Langley Research Center: Concorde Noise-Induced Building Vibrations - International Airport Dulles - Final Report. NASA TM-74083, 1977.

9. Staff-Langley Research Center: Concorde Noise-Induced Building Vibrations - John F. Kennedy International Airport - Report Number 1. NASA TM-78660, 1978.

10. Leissa, Arthur W.: Vibration of Plates. NASA SP-160, 1969, pp. 42-44.

11. Freynik, Henry S., Jr.: The Nonlinear Response of Windows to Random Noise. NASA TN D-2025, 1963.

12. Strength of Plate and Laminated Glass. Technical Glass Bulletin, Pittsburgh Plate Glass Co., July 30, 1941.

TABLE I.- WALL SECTION MASS AND SURFACE DENSITY

Section material	Vertical section		Horizontal section	
	Mass, kg (slugs)	Surface density, kg/m^2 (slugs/ft^2)	Mass, kg (slugs)	Surface density, kg/m^2 (slugs/ft^2)
Sheetrock	47.45 (3.248)	47.88 (0.3045)	19.16 (1.312)	22.78 (0.1449)
Plywood	19.19 (1.314)	19.37 (0.1232)	17.98 (1.231)	21.37 (0.1259)
Gyp-lap	17.45 (1.195)	17.61 (0.1120)	13.97 (0.957)	16.61 (0.1057)
Plaster	60.69 (4.155)	61.24 (0.3895)	54.31 (3.718)	64.56 (0.4106)

TABLE II.- WALL SECTION MATERIALS DATA

(a) Sheetrock wall section

Mode	Stud 1	Stud 2	Stud 3	Stud 4	Stud 1	Stud 2	Stud 3	Stud 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1 2 3	34.85 223 580	33.8 215 565	35.4 225 646	30.5 203 524	0.2357 (4.919×10^{-3})	0.2304 (4.807×10^{-3})	0.2455 (5.124×10^{-3})	0.2604 (5.434×10^{-3})	8.370 (1.214×10^{6})

Mode	Sheetrock 1	Sheetrock 2	Sheetrock 3	Sheetrock 4	Sheetrock 1	Sheetrock 2	Sheetrock 3	Sheetrock 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1 2 3	25.55 158 440	23.5 147 425	25.1 145.5 408		0.5581 (1.165×10^{-2})	0.5581 (1.165×10^{-2})	0.5581 (1.165×10^{-2})		1.591 (2.308×10^{5})

TABLE II.- Continued

(b) Plywood wall section

Mode	Stud 1	Stud 2	Stud 3	Stud 4	Stud 1	Stud 2	Stud 3	Stud 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1 2 3	30.9 204.5 569	29.8 198 545	32.5 221 637	31.9 212 587.5	0.2084 (4.349×10^{-3})	0.2157 (4.502×10^{-3})	0.1936 (4.020×10^{-3})	0.1861 (3.883×10^{-3})	6.398 (9.28×10^{5})

Mode	Plywood 1	Plywood 2	Plywood 3	Plywood 4	Plywood 1	Plywood 2	Plywood 3	Plywood 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1 2 3	[a]54 [a]330	[b]37.5 [b]262.5 [b]659			0.3893 (8.124×10^{-3})	0.2857 (5.963×10^{-3})			7.205 [b](1.045×10^{6}) 10.184 [a](1.477×10^{6})

[a]Length of beam, 27.94 cm (11 in.); width, 4.92 cm (1.9375 in.) (vertical panel).
[b]Length of beam, 30.48 cm (12 in.); width, 3.86 cm (1.52 in.) (horizontal panel).

TABLE II.- Continued

(c) Gyp-lap wall section

Mode	Stud 1	Stud 2	Stud 3	Stud 4	Stud 1	Stud 2	Stud 3	Stud 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1	35.2	35.4	35.9	34.85	0.2232	0.2232	0.2161	0.2232	8.805
2	230	244	230	220	(4.658×10^{-3})	(4.658×10^{-3})	(4.510×10^{-3})	(4.658×10^{-3})	(1.277×10^{6})
3	618	669	639	608					

Mode	Gyp-lap 1	Gyp-lap 2	Gyp-lap 3	Gyp-lap 4	Gyp-lap 1	Gyp-lap 2	Gyp-lap 3	Gyp-lap 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1	11.9	12.8	12.5	12.3	0.4241	0.4161	0.4143	0.4161	0.2730
2	76.4	76.1	75.7	76.6	(8.851×10^{-3})	(8.603×10^{-3})	(8.646×10^{-3})	(8.603×10^{-3})	(3.96×10^{4})
3	214	213	210	221					

TABLE II.- Concluded

(d) Plaster wall section

Mode	Stud 1	Stud 2	Stud 3	Stud 4	Stud 1	Stud 2	Stud 3	Stud 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1	39.3	39.5	40.6	39.3	0.1786	0.1711	0.1711	0.1786	8.039
2	244	242	249	242	(3.727×10^{-3})	(3.570×10^{-3})	(3.570×10^{-3})	(3.727×10^{-3})	(1.166×10^{6})
3	655	674	681	669					

Mode	Plaster 1	Plaster 2	Plaster 3	Plaster 4	Plaster 1	Plaster 2	Plaster 3	Plaster 4	Average modulus of elasticity, GN/m^2 (lbf/in^2)
	Frequency, Hz				Mass/unit length, kg/m (slugs/ft)				
1	46.4	49.4	[b]66.2		1.0929	1.2840			3.385
2		294	[b]400		(2.281×10^{-2})	(2.680×10^{-2})			(4.91×10^{5})
3									

[b]Length of beam, 30.48 cm (12 in.); width, 3.86 cm (1.52 in.) (horizontal panel).

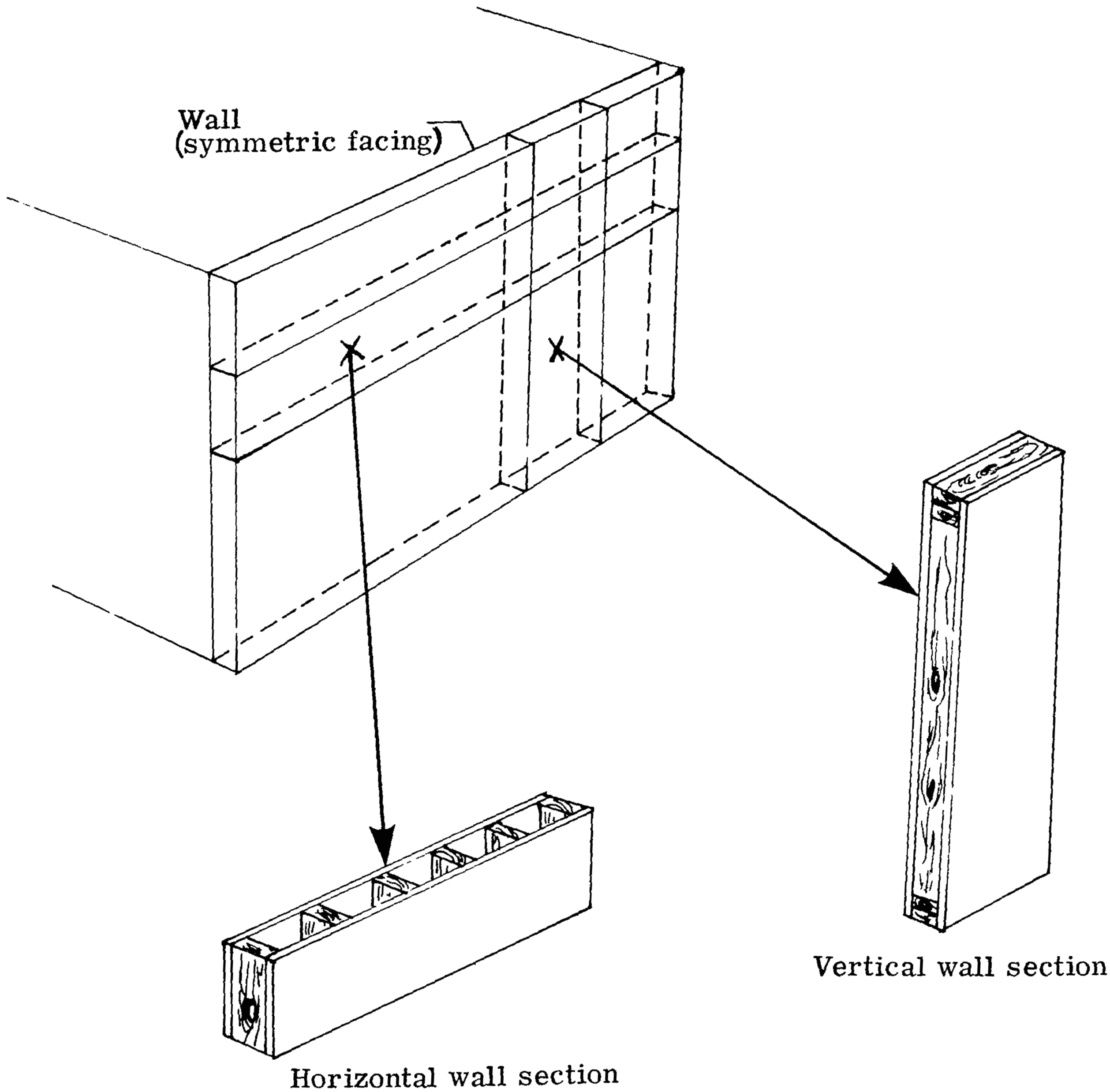
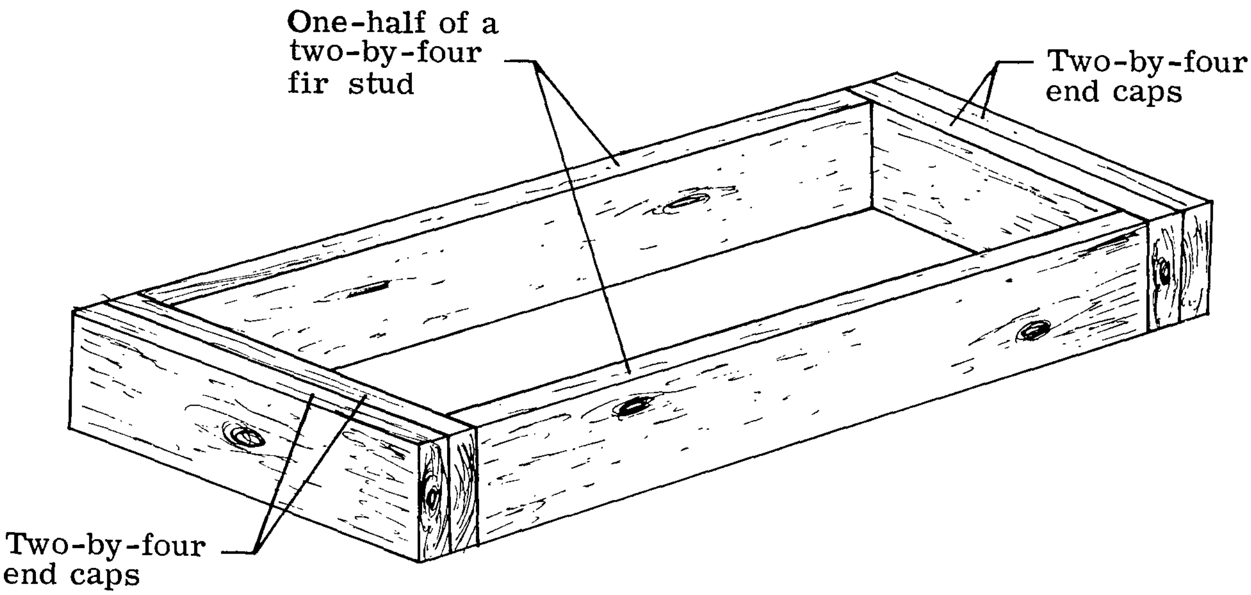
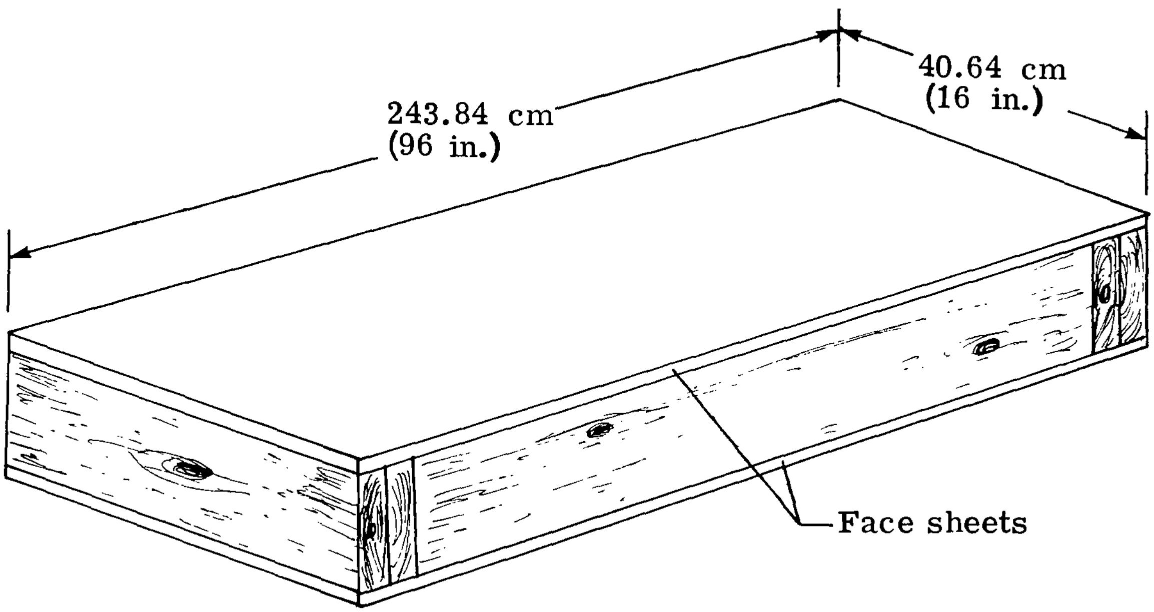


Figure 1.- Study approach using typical wall sections.

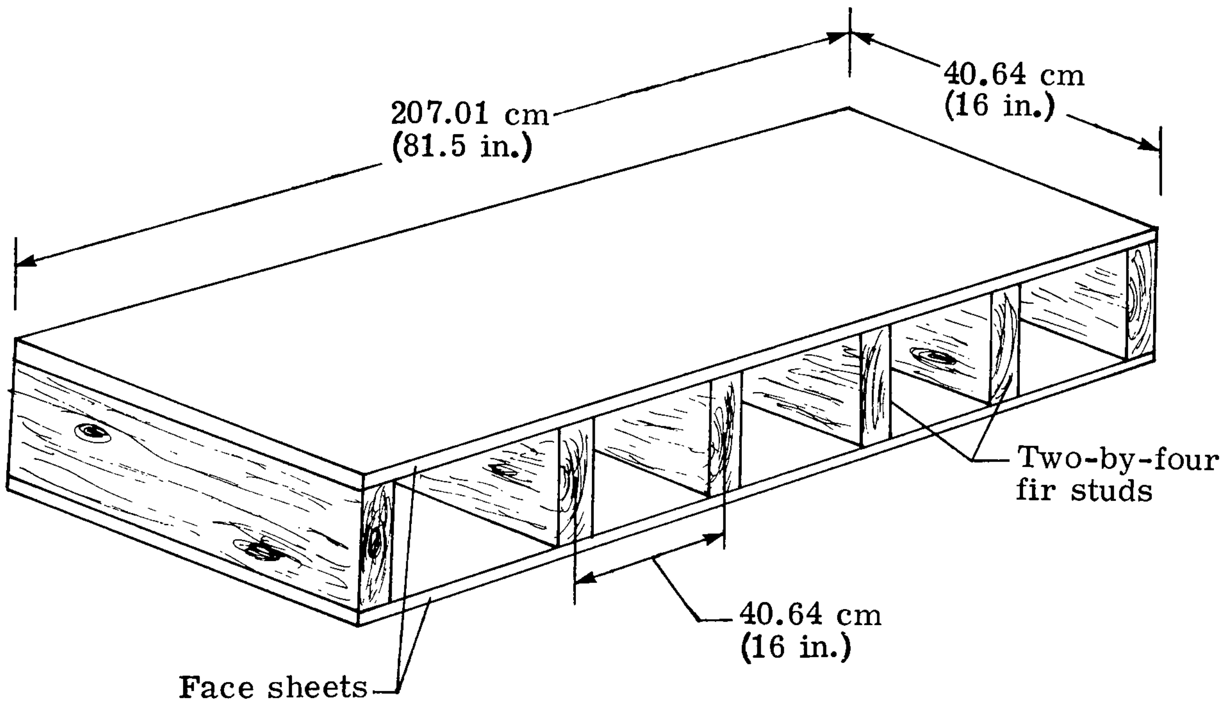


(a) Framing of vertical wall section.



(b) Completed vertical wall section.

Figure 2.- Construction details of wall sections.



(c) Horizontal wall sections.

Figure 2.- Concluded.

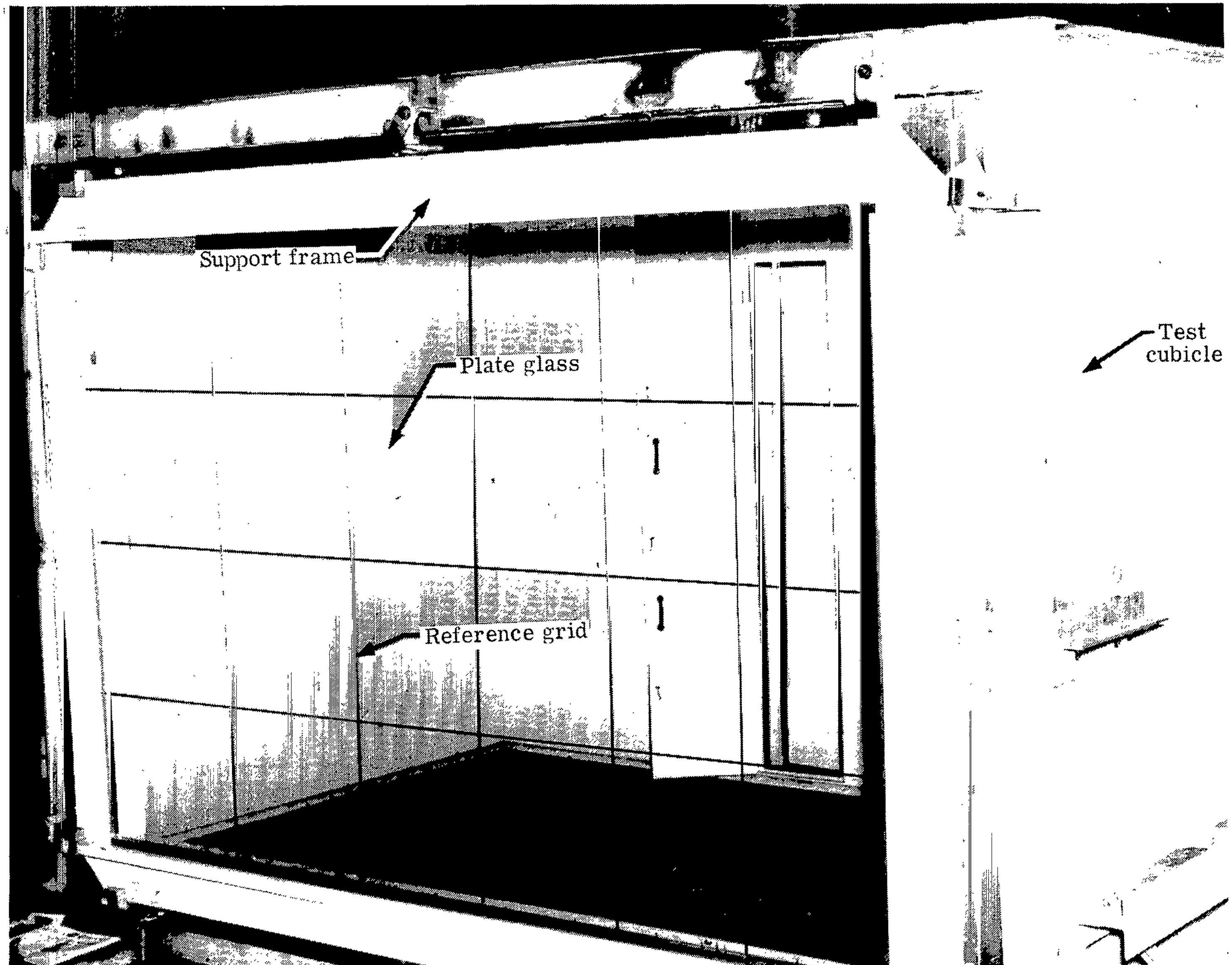
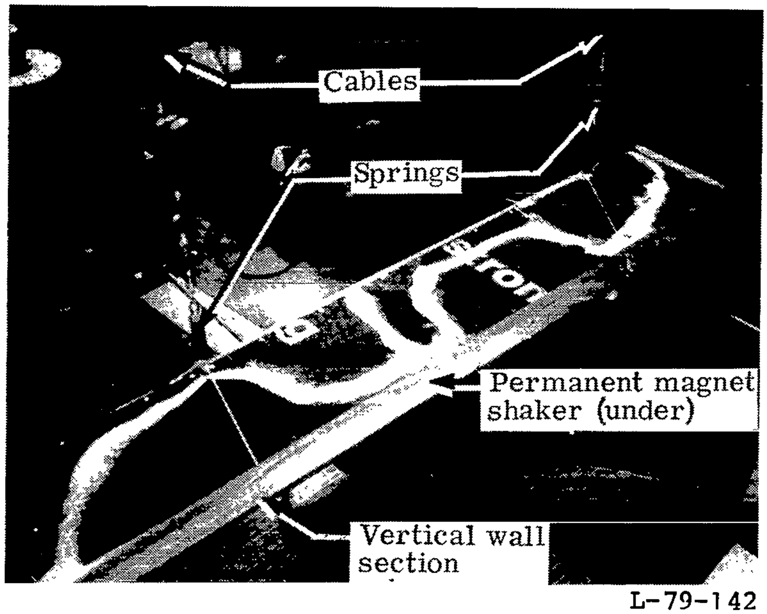
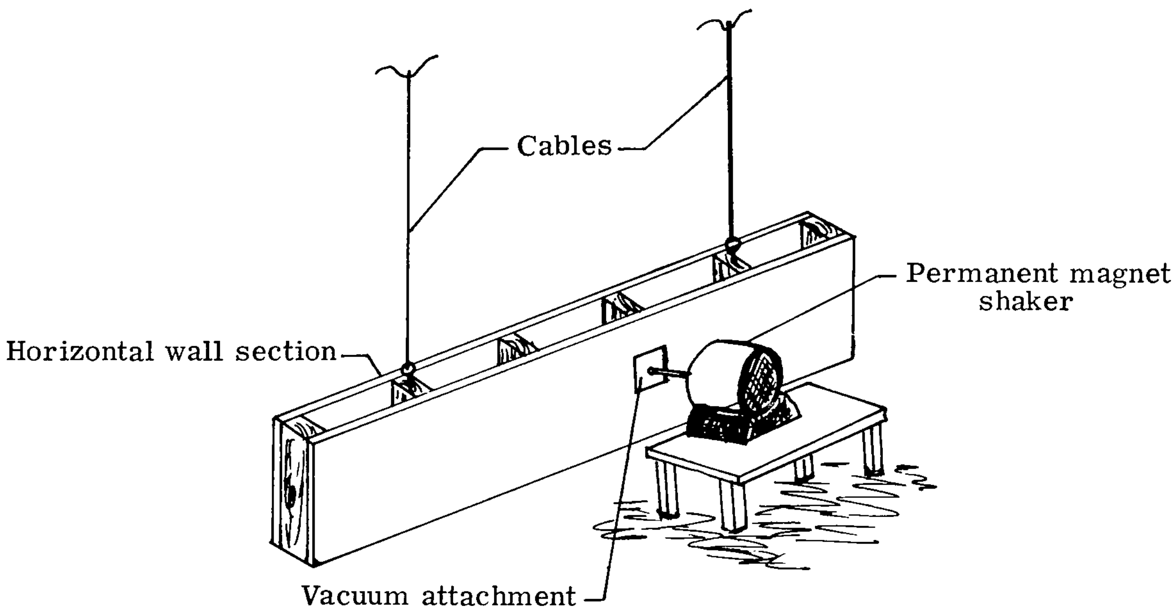


Figure 3.- Structural steel test cubicle with plate glass window installed.

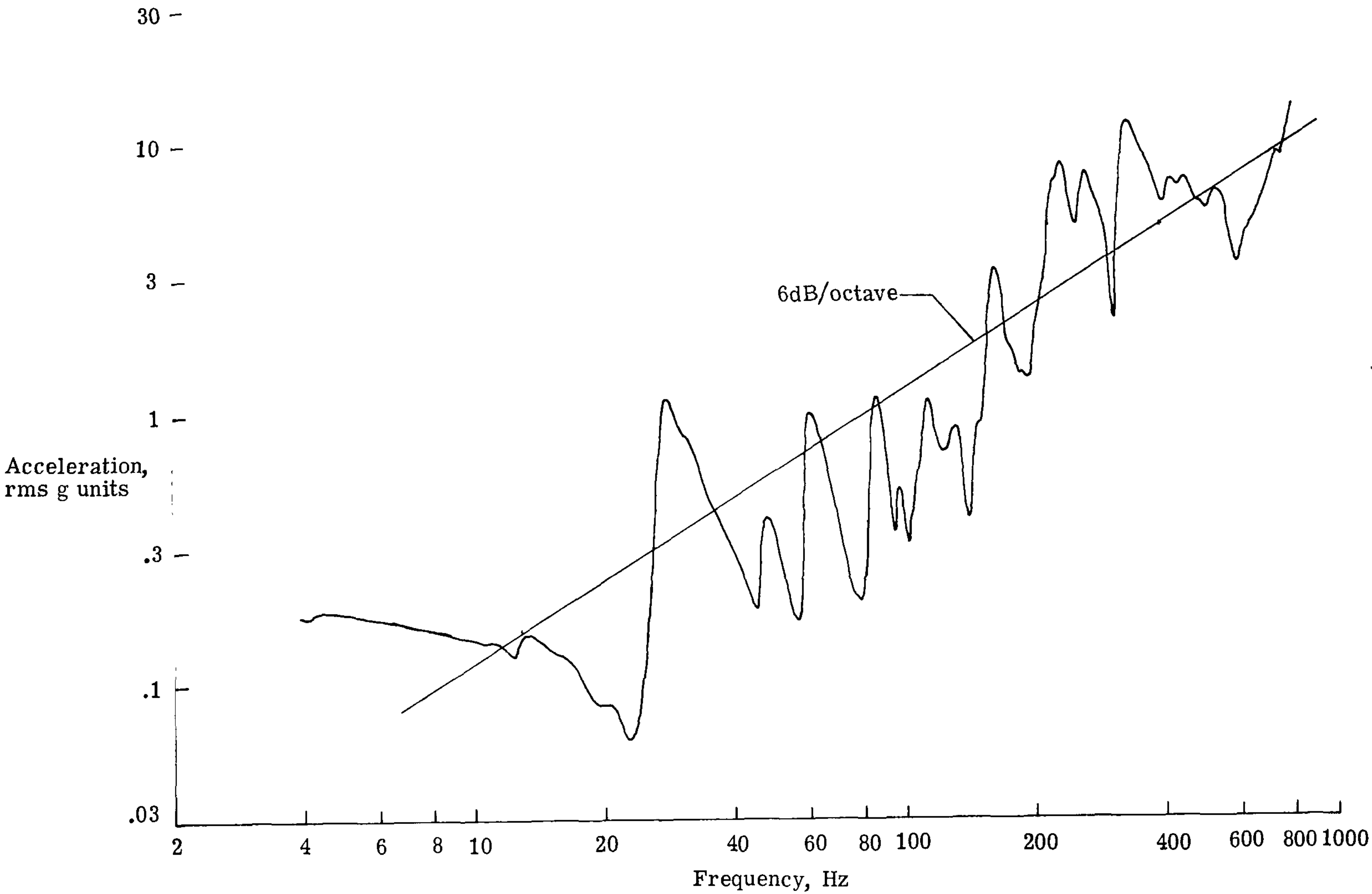


(a) Vertical wall section.



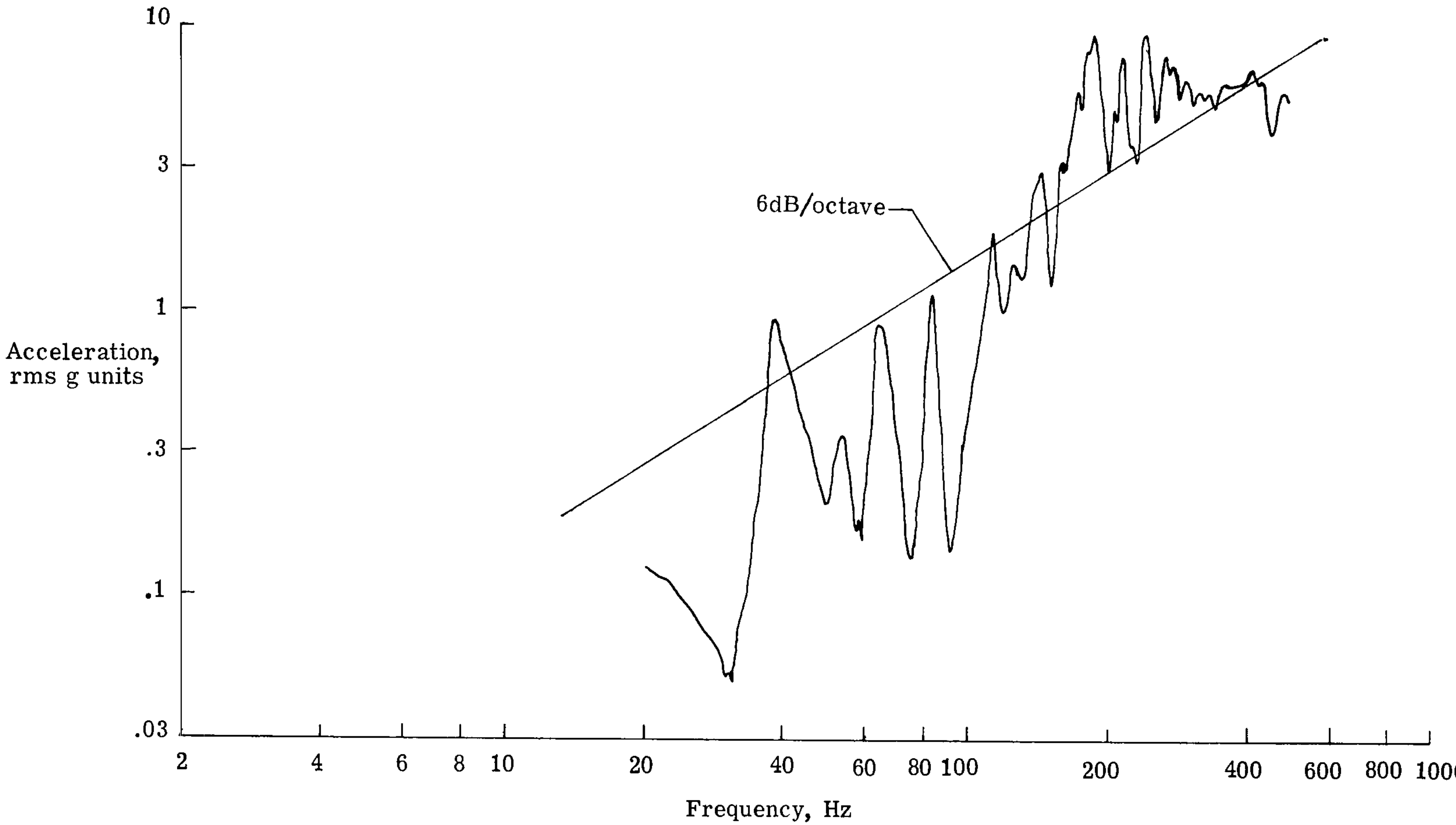
(b) Horizontal wall section.

Figure 4.- Experimental setup for vibration study of wall sections.



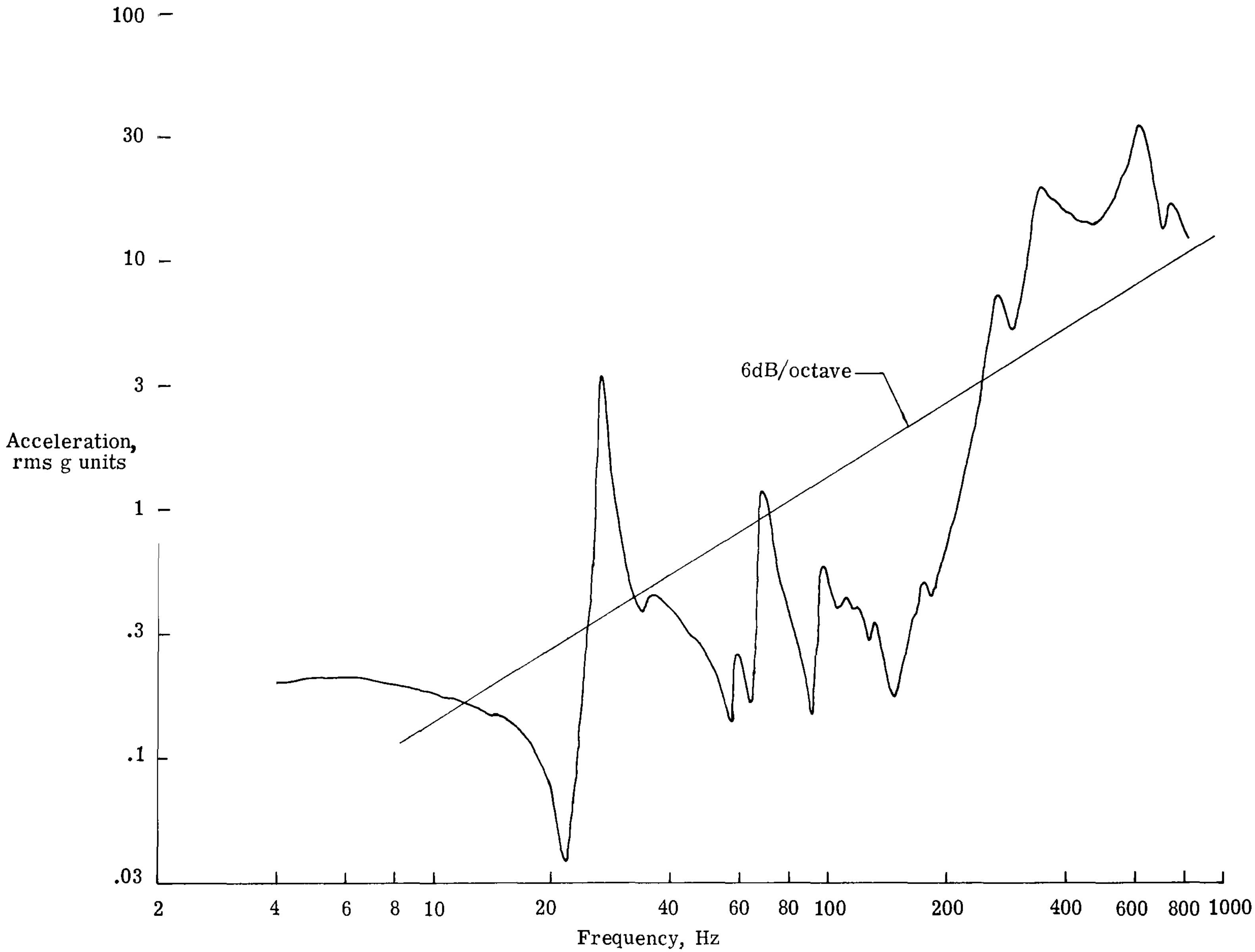
(a) Vertical sheetrock.

Figure 5.- Experimental acceleration response of vertical wall sections.
±13.34 N (±3 lbf).



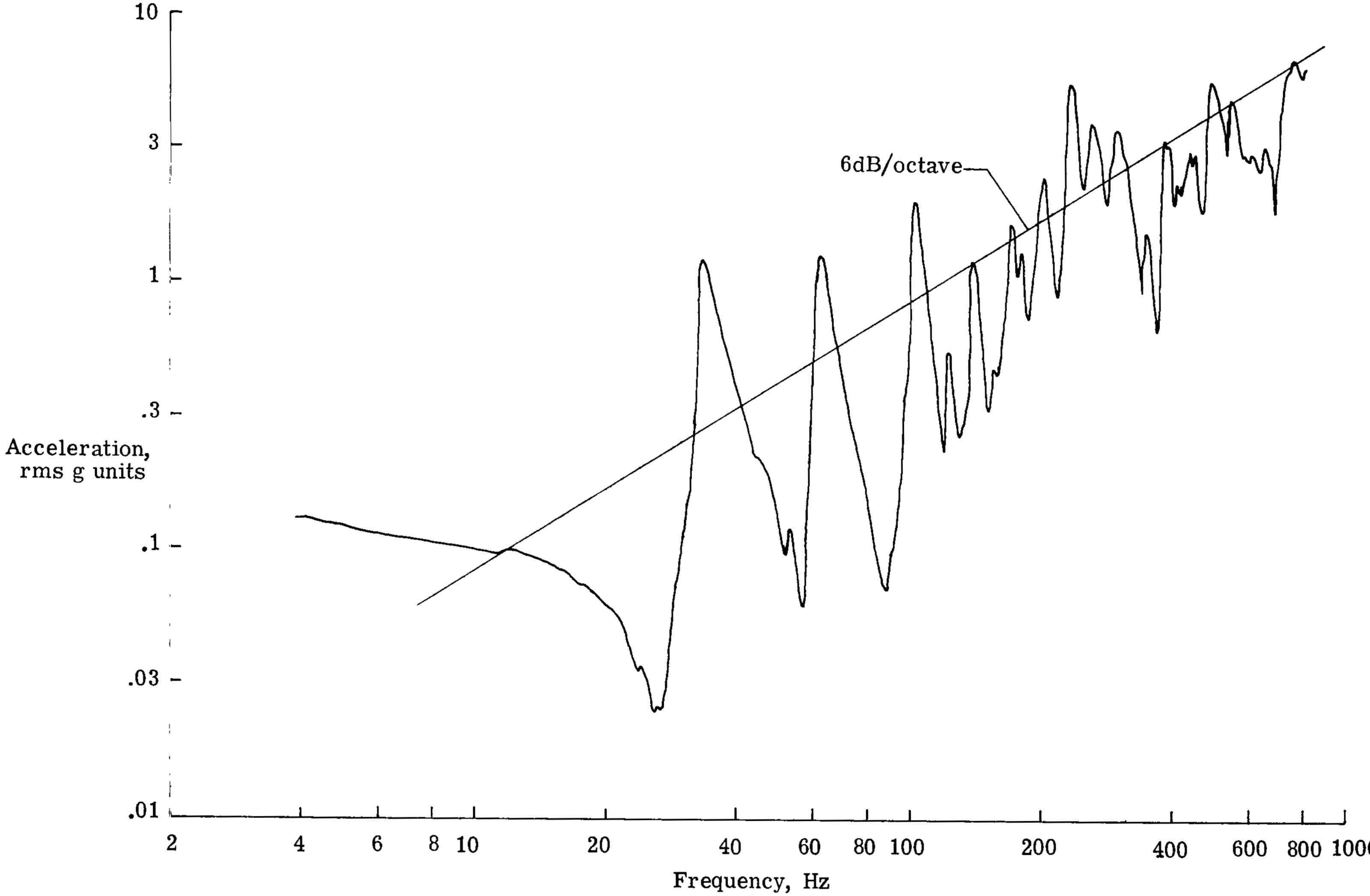
(b) Vertical plywood.

Figure 5.- Continued.



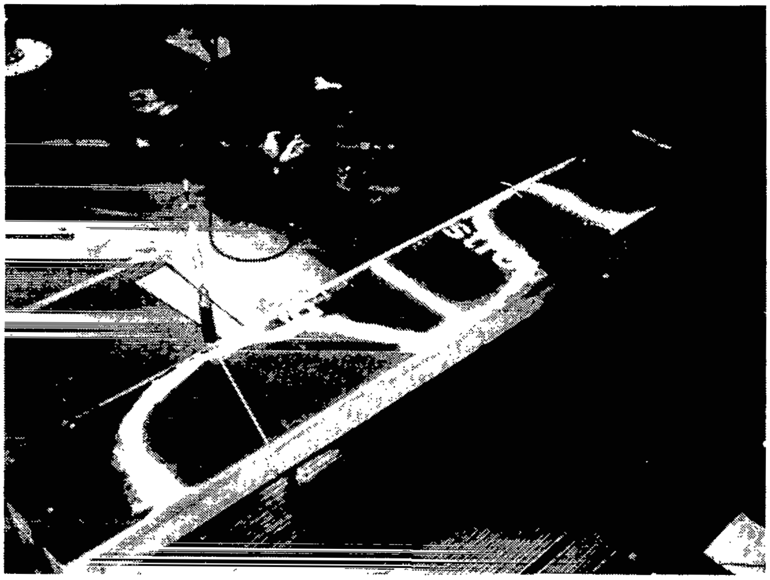
(c) Vertical Gyp-lap.

Figure 5.- Continued.



(d) Vertical plaster.

Figure 5.- Concluded.



(a) f = 132 Hz; m = 5; n = 2.

(b) f = 188 Hz; m = 8; n = 2.

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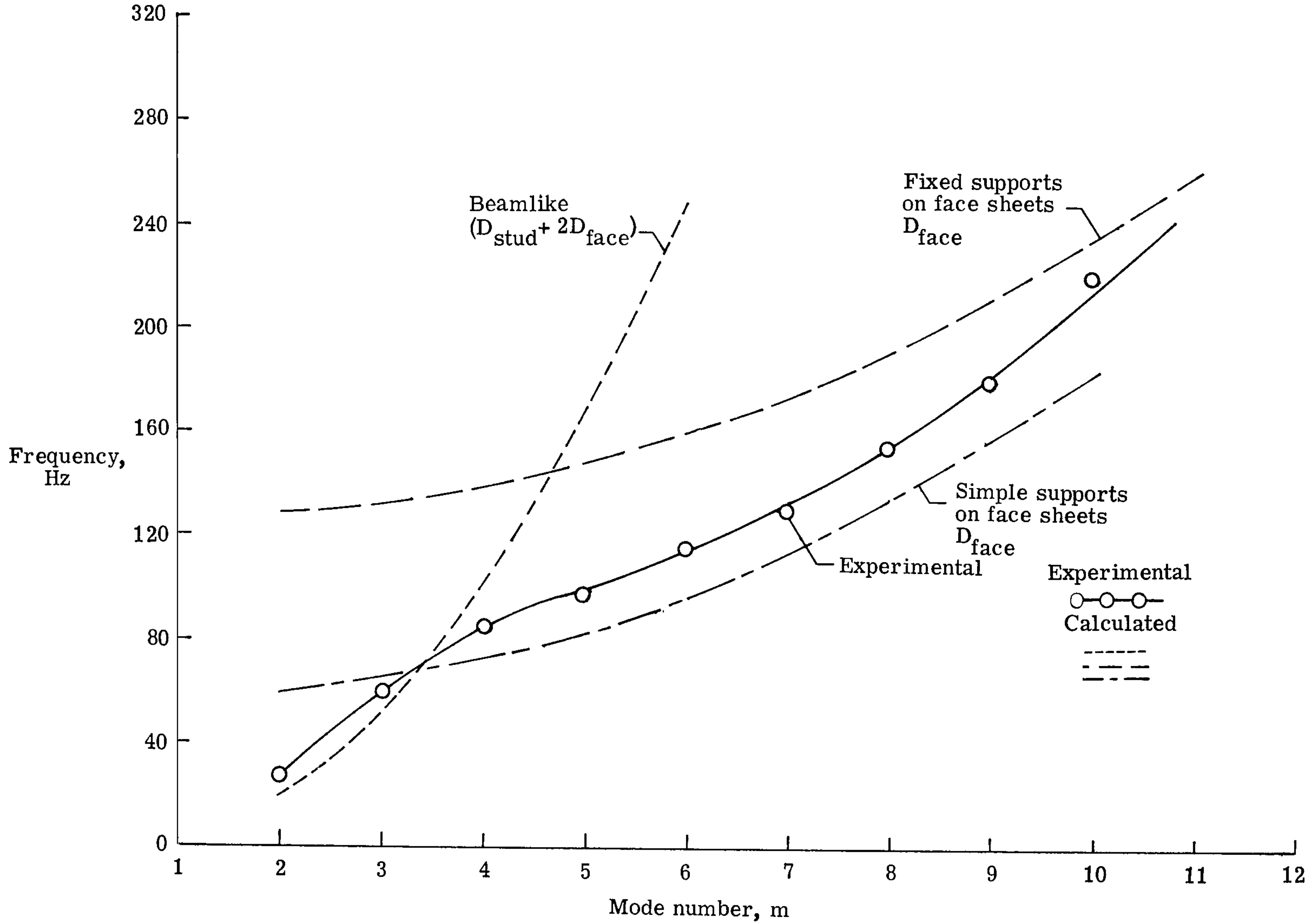
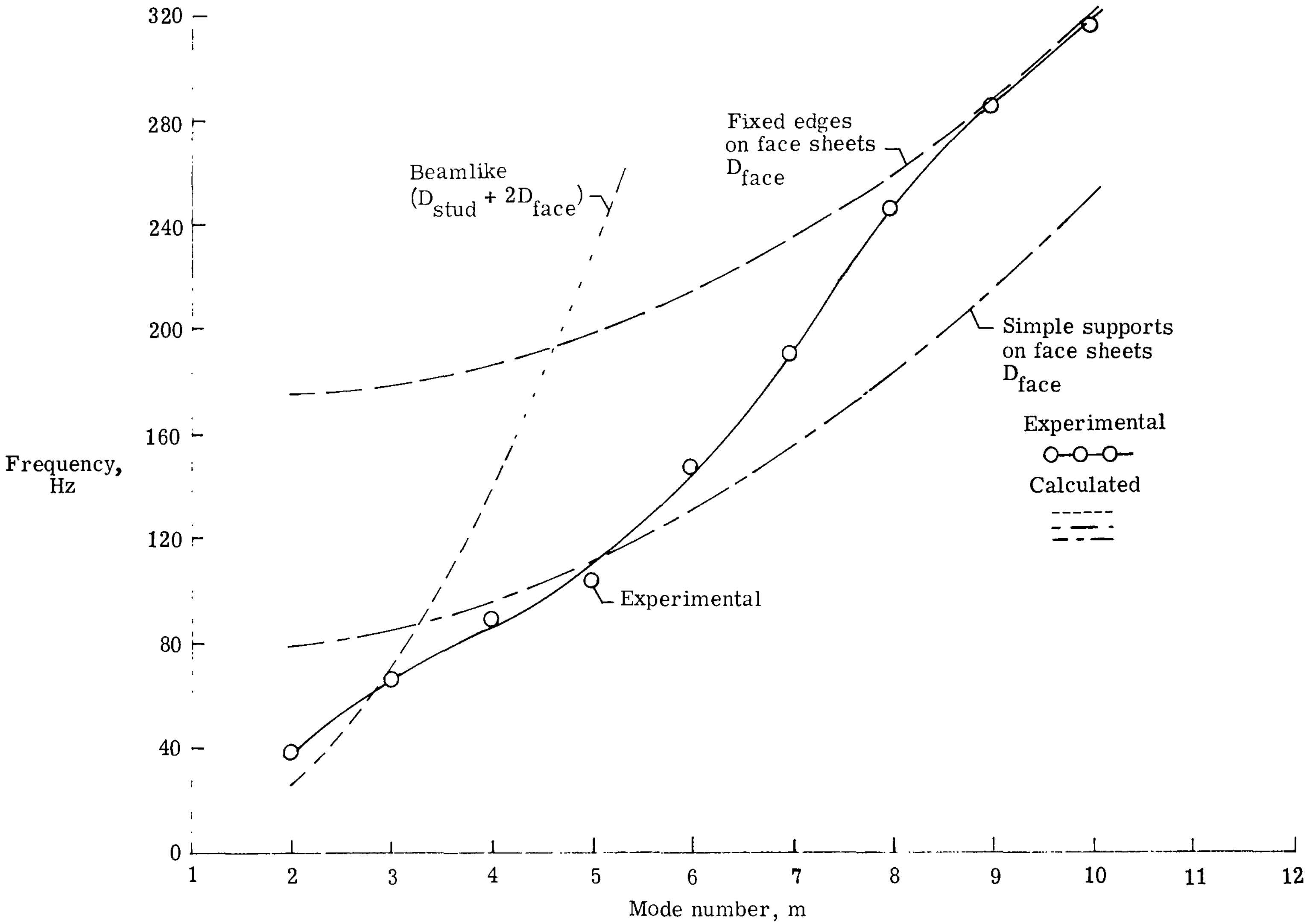
Figure 6.- Experimental nodal patterns of vertical Gyp-lap wall section. (These nodal patterns are typical for all vertical sections.)



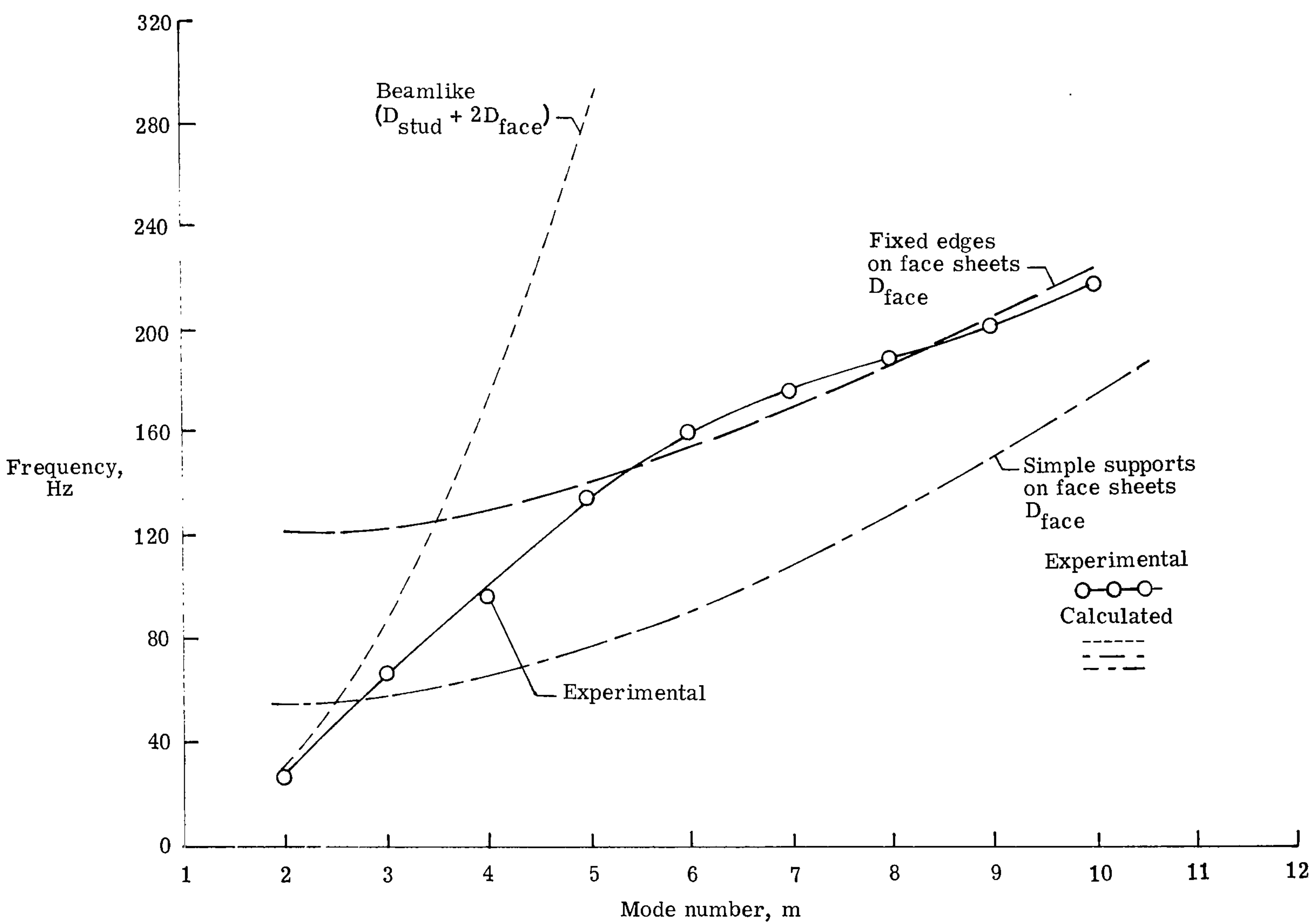
(a) Vertical sheetrock.

Figure 7.- Computed and experimental modal frequencies of vertical wall sections.



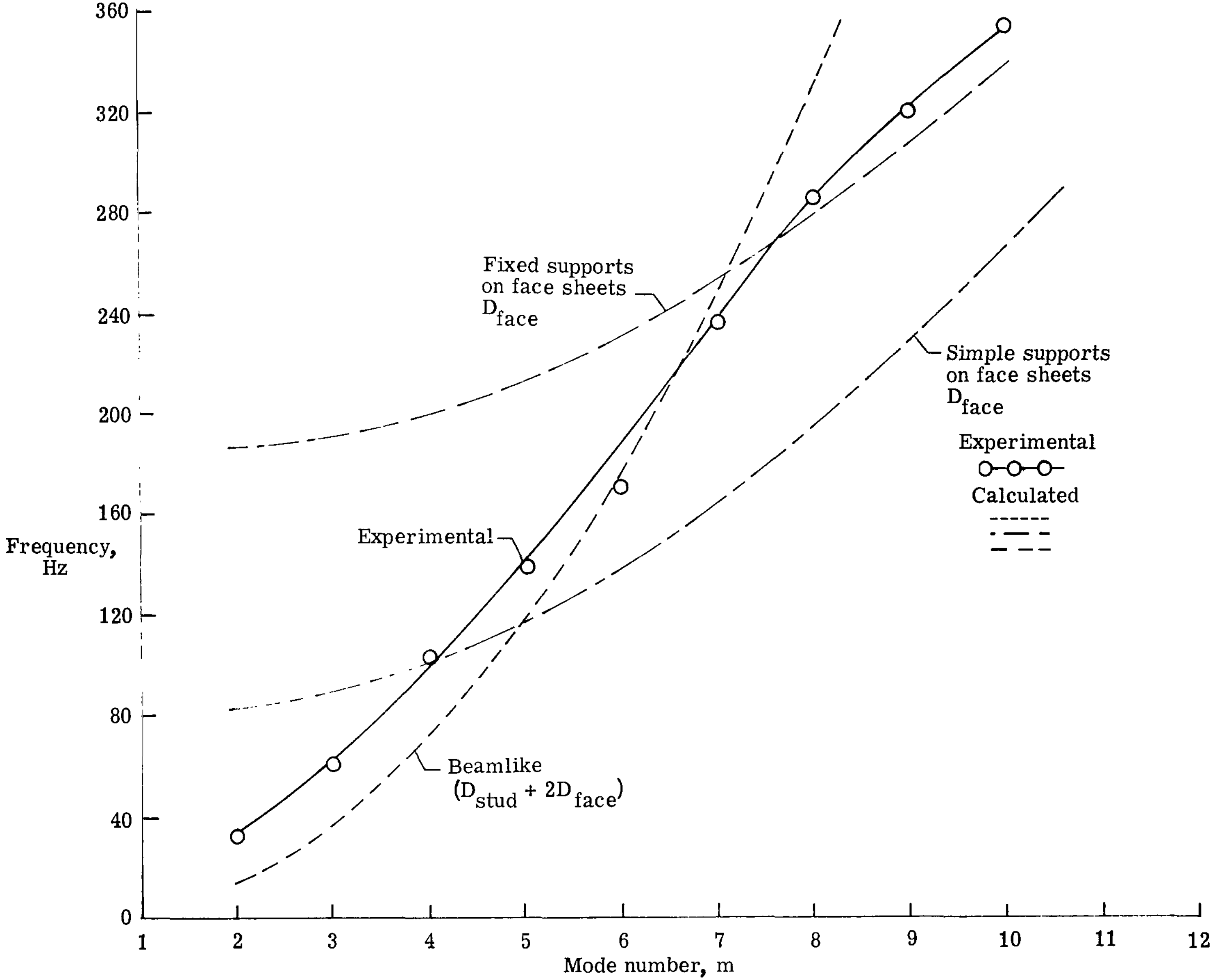
(b) Vertical plywood.

Figure 7.- Continued.



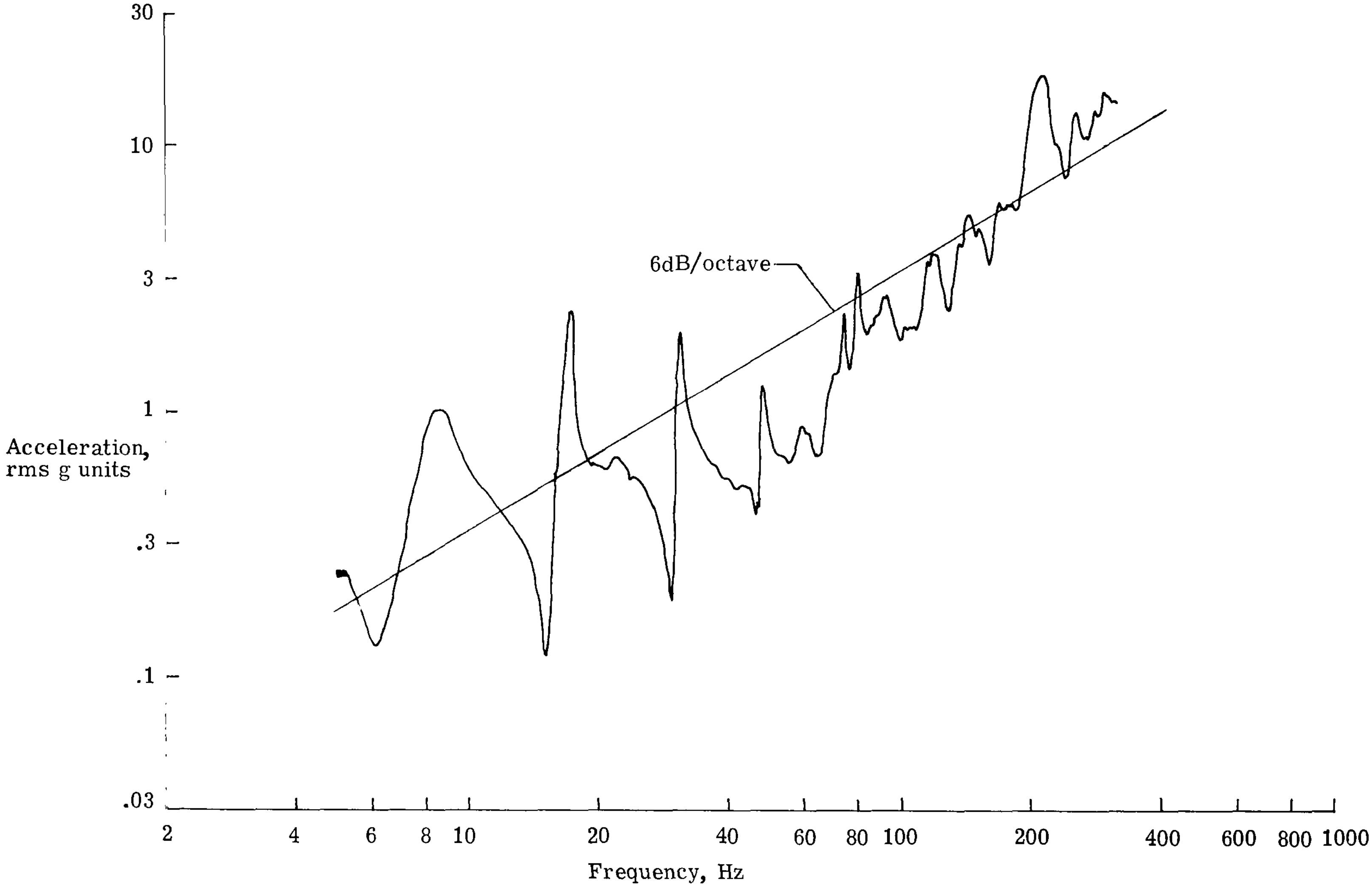
(c) Vertical Gyp-lap.

Figure 7.- Continued.



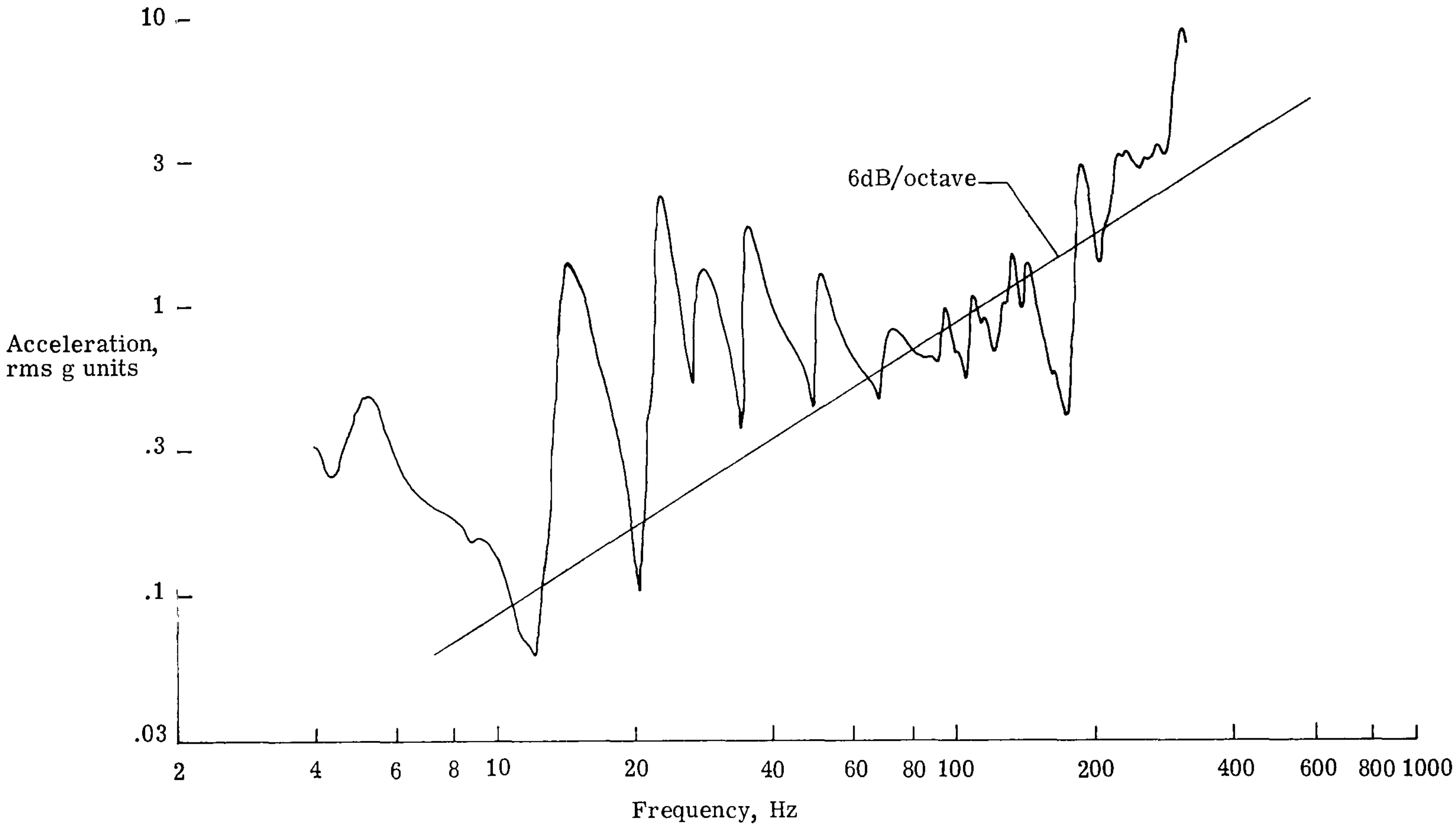
(d) Vertical plaster.

Figure 7.- Concluded.



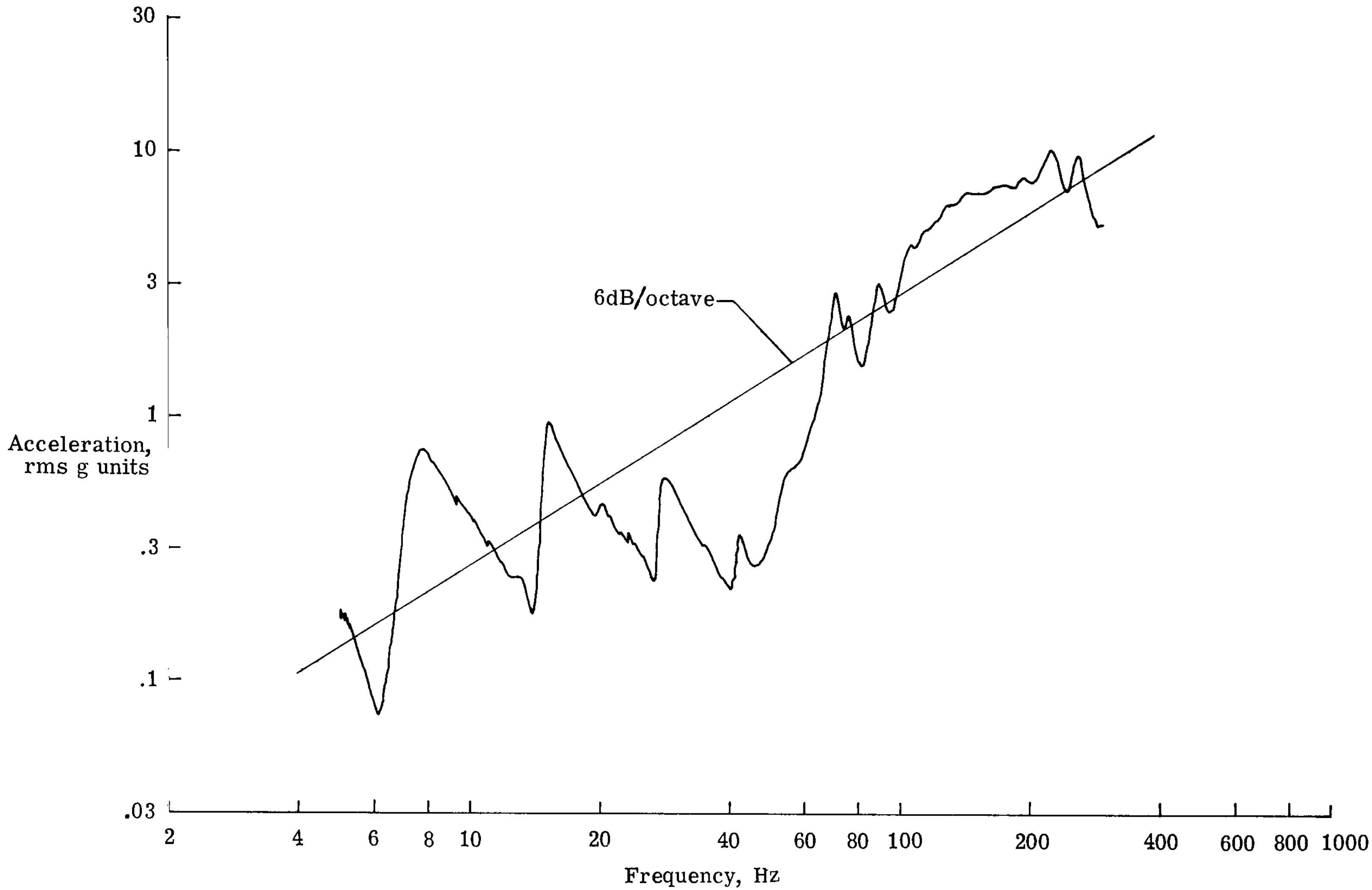
(a) Horizontal sheetrock. ±13.34 N (±3 lbf).

Figure 8.- Experimental acceleration response of horizontal wall sections.



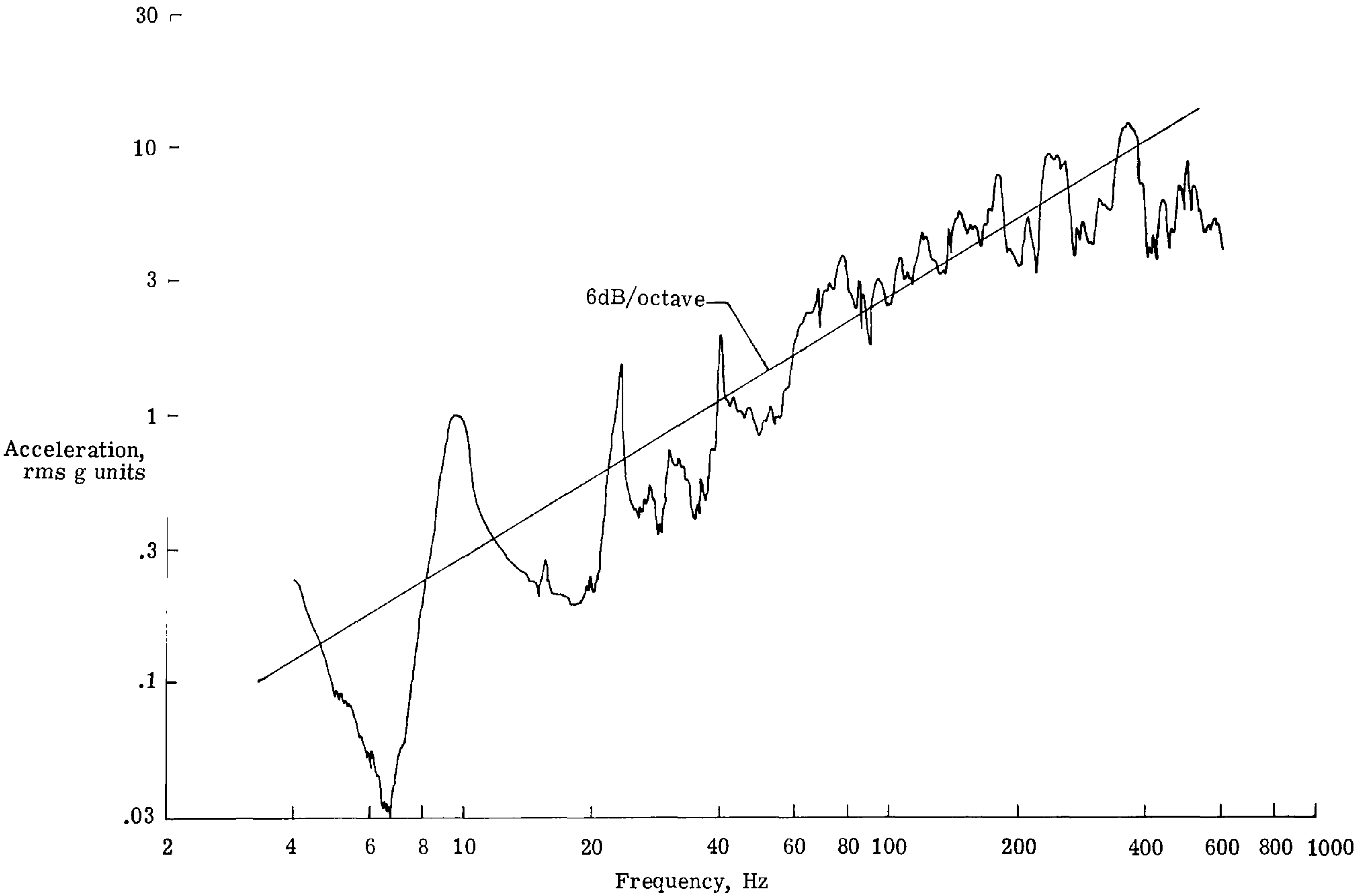
(b) Horizontal plywood.

Figure 8.- Continued.



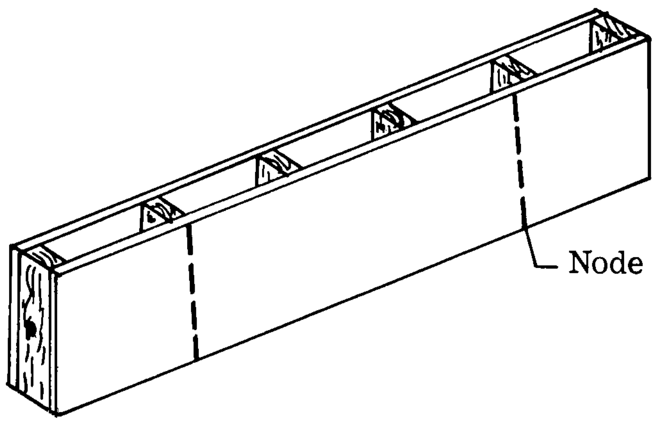
(c) Horizontal Gyp-lap. ±8.90 N (±2 lbf).

Figure 8.- Continued.

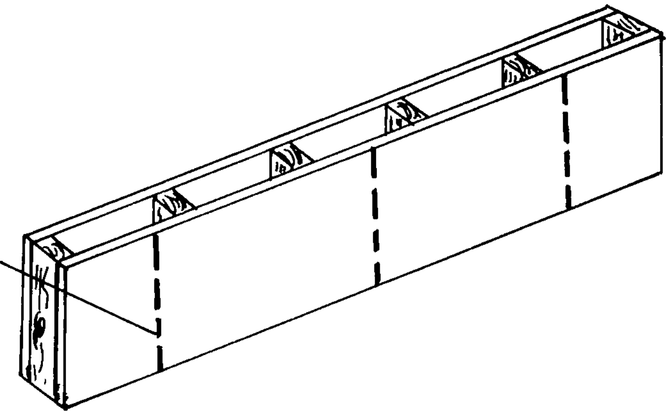


(d) Horizontal plaster.

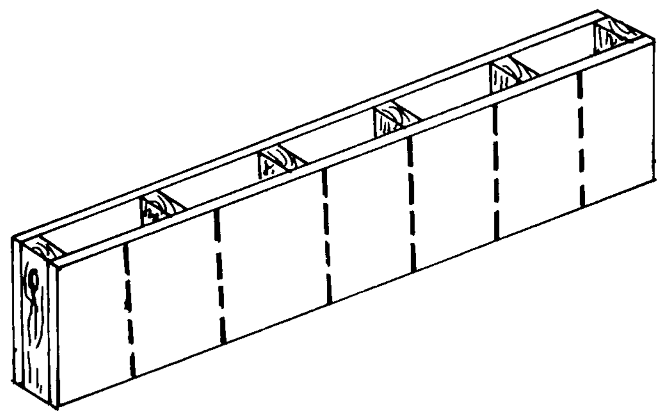
Figure 8.- Concluded.



(a) f = 8.5 Hz; m = 2; n = 0.

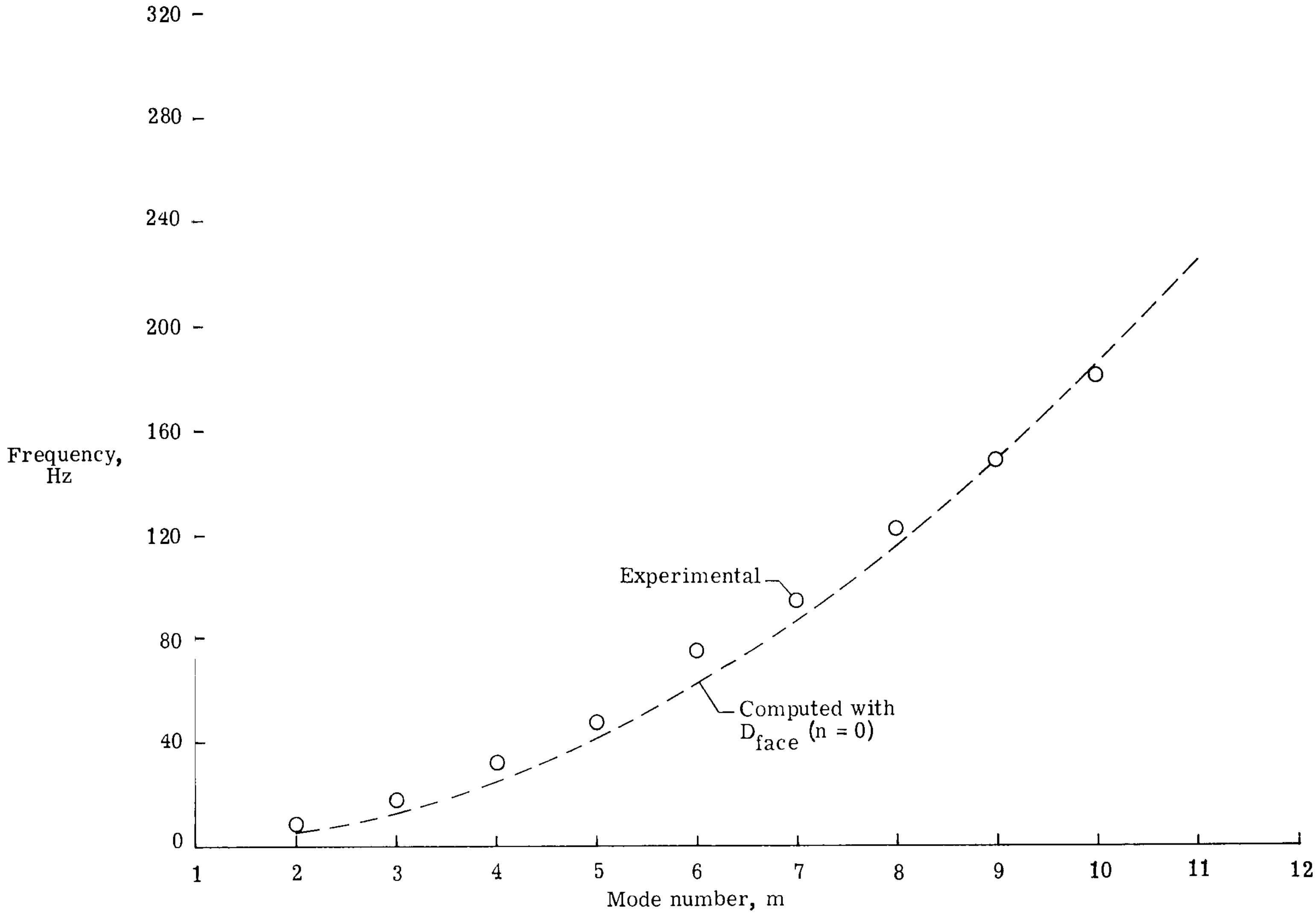


(b) f = 17.5 Hz; m = 3; n = 0.



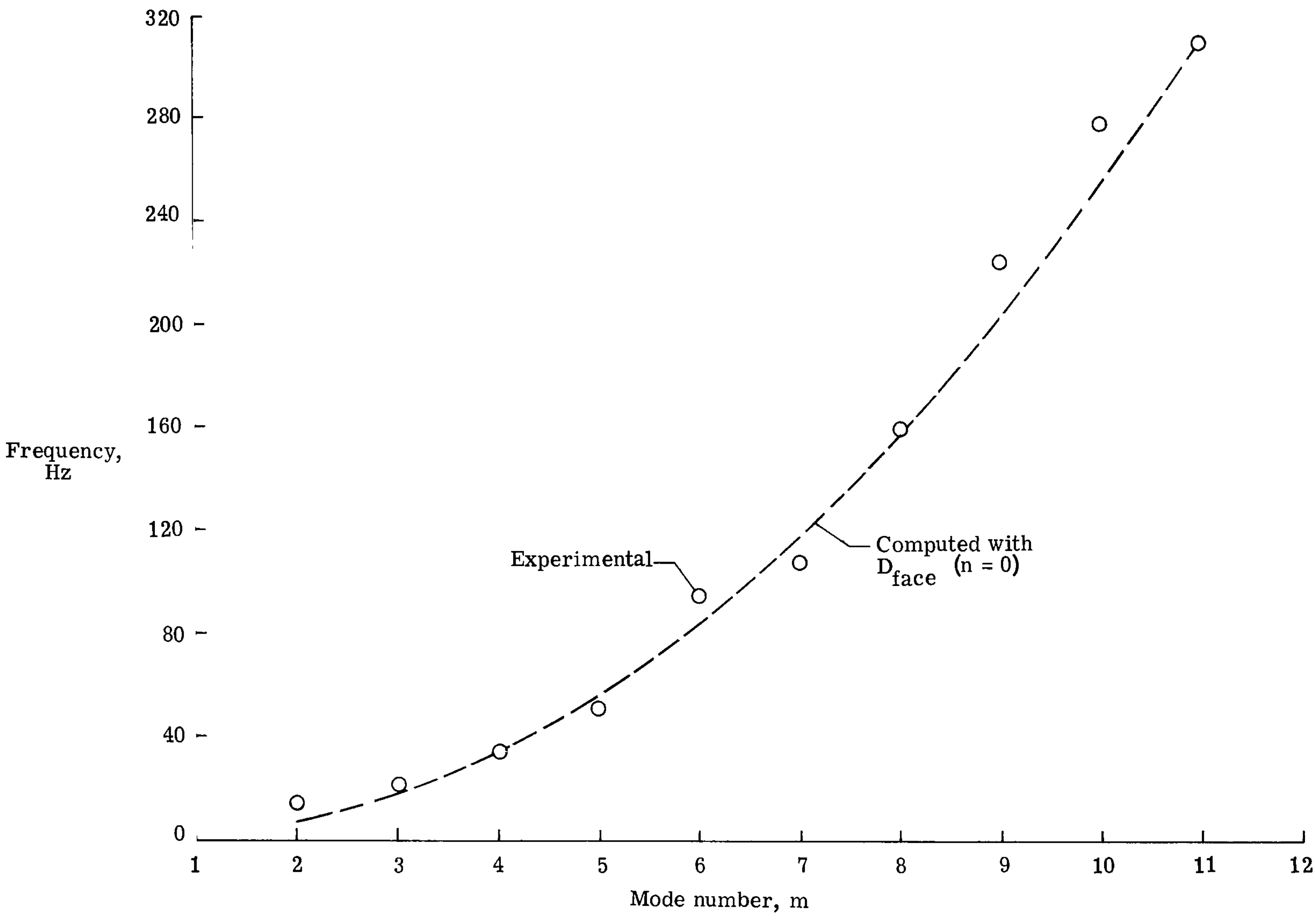
(c) f = 74.5; m = 6; n = 0.

Figure 9.- Nodal patterns of horizontal sheetrock wall section. (These patterns are typical for all horizontal wall sections.)



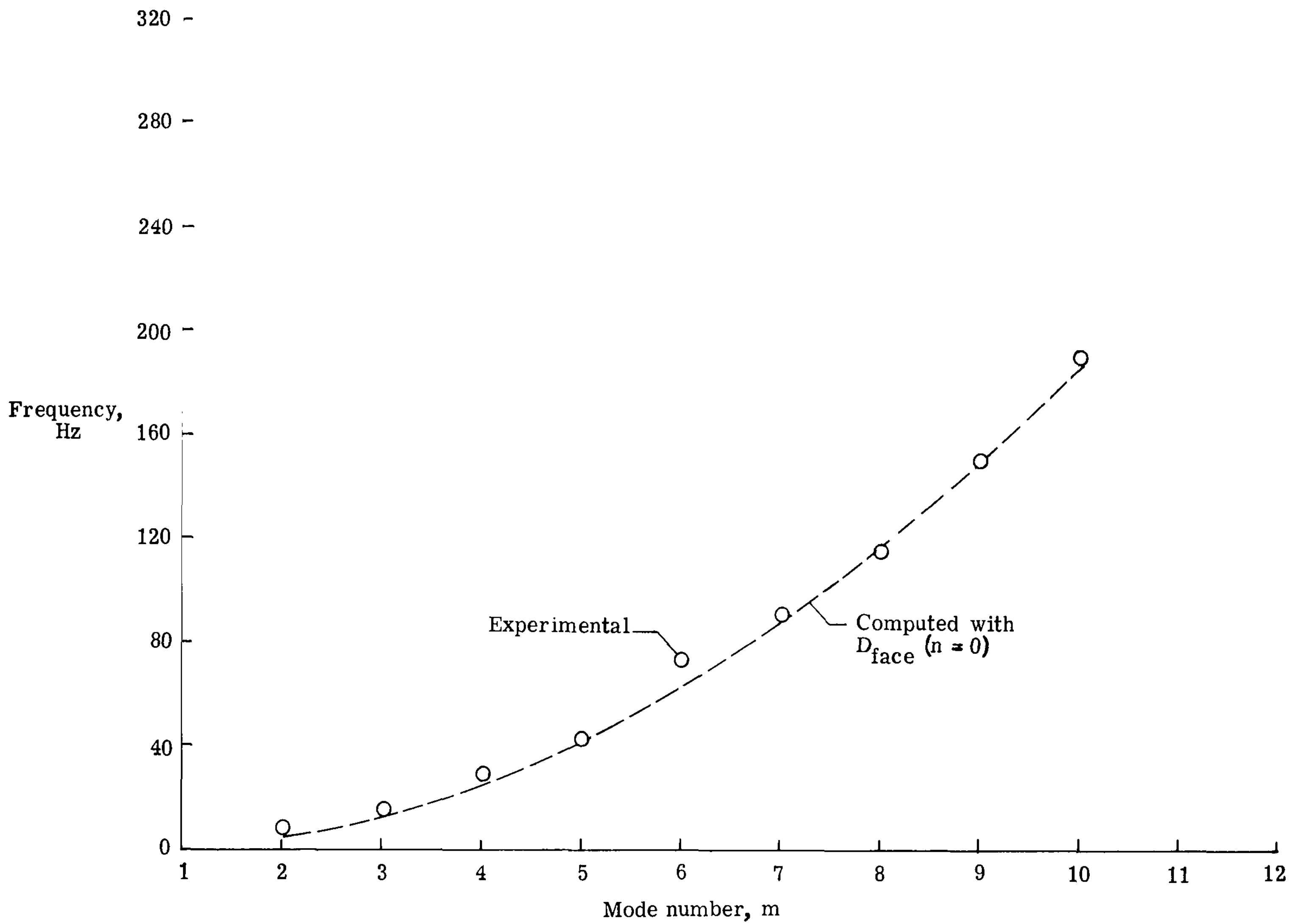
(a) Horizontal sheetrock.

Figure 10.- Computed and experimental modal frequencies of horizontal wall sections.



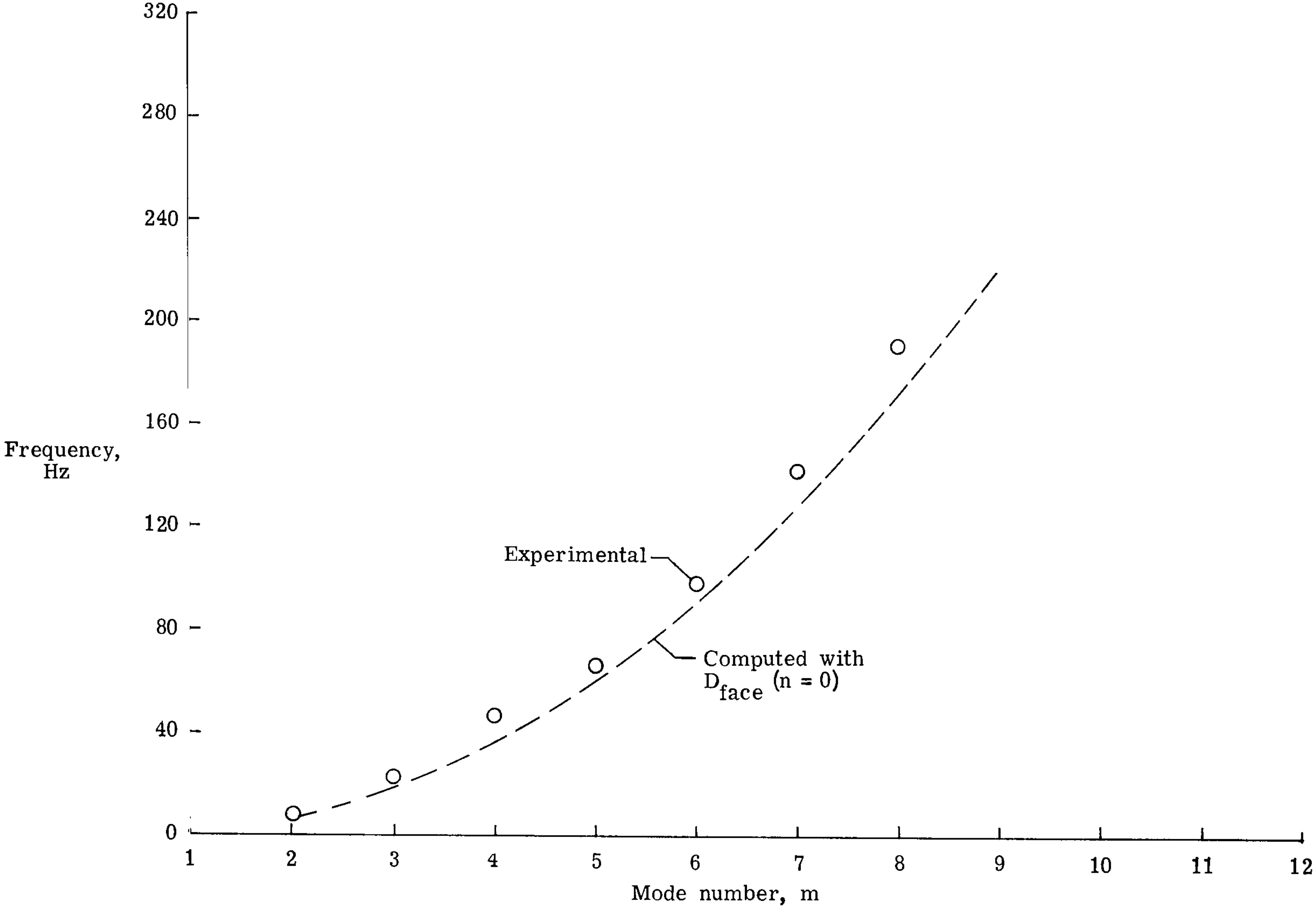
(b) Horizontal plywood.

Figure 10.- Continued.



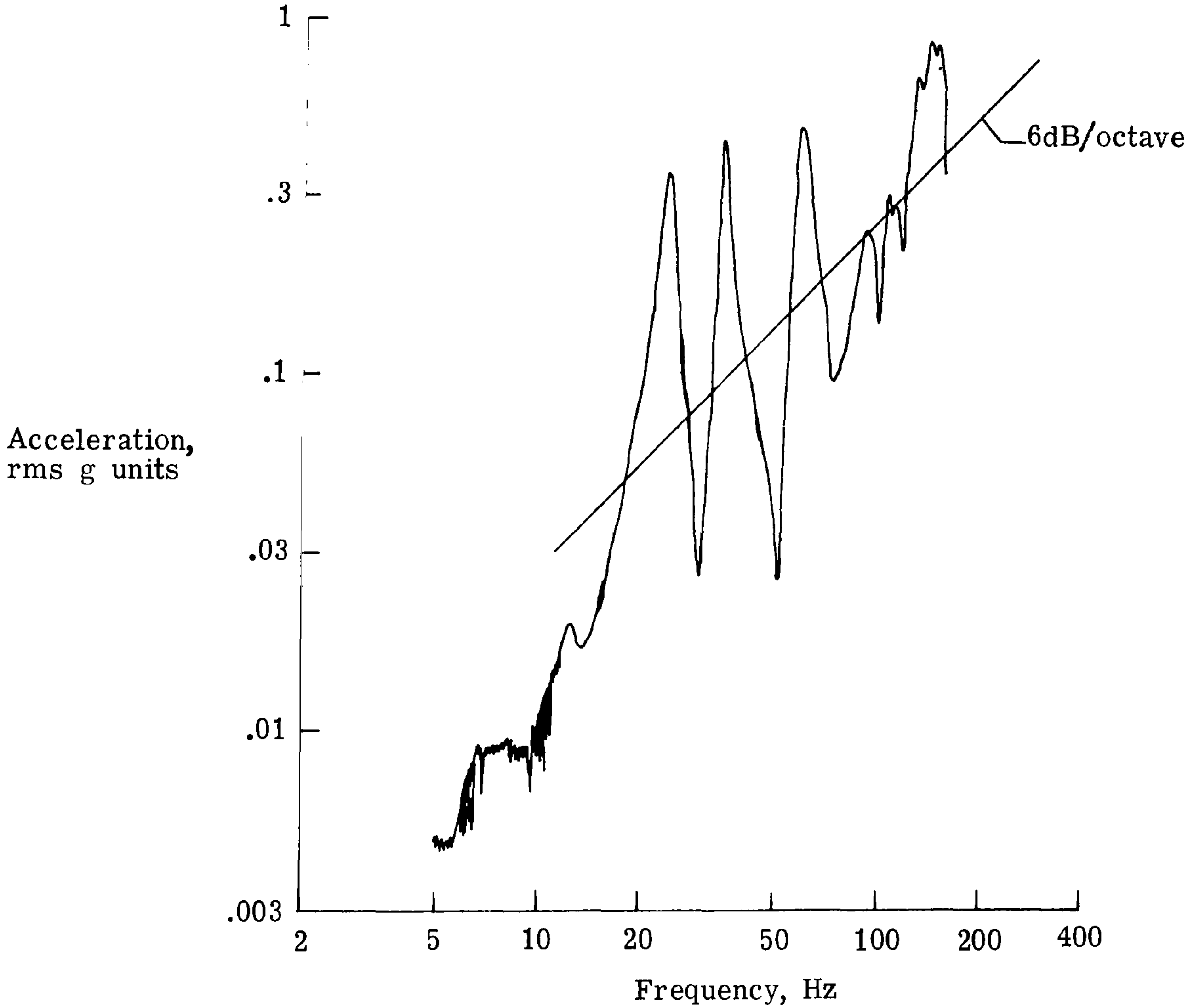
(c) Horizontal Gyp-lap.

Figure 10.- Continued.



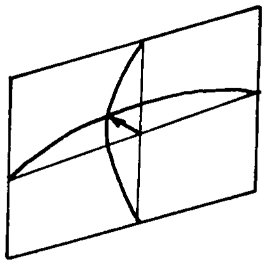
(d) Horizontal plaster.

Figure 10.- Concluded.

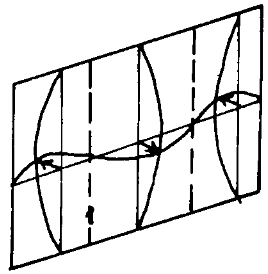


(a) Acceleration response.

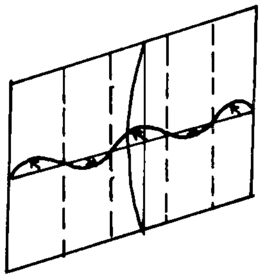
Figure 11.- Vibration response of full-size wall section to sinusoidal inputs.



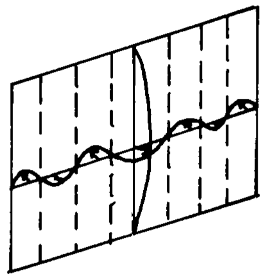
f = 23.5 Hz; m = 2; n = 2



f = 34.0 Hz; m = 4; n = 2



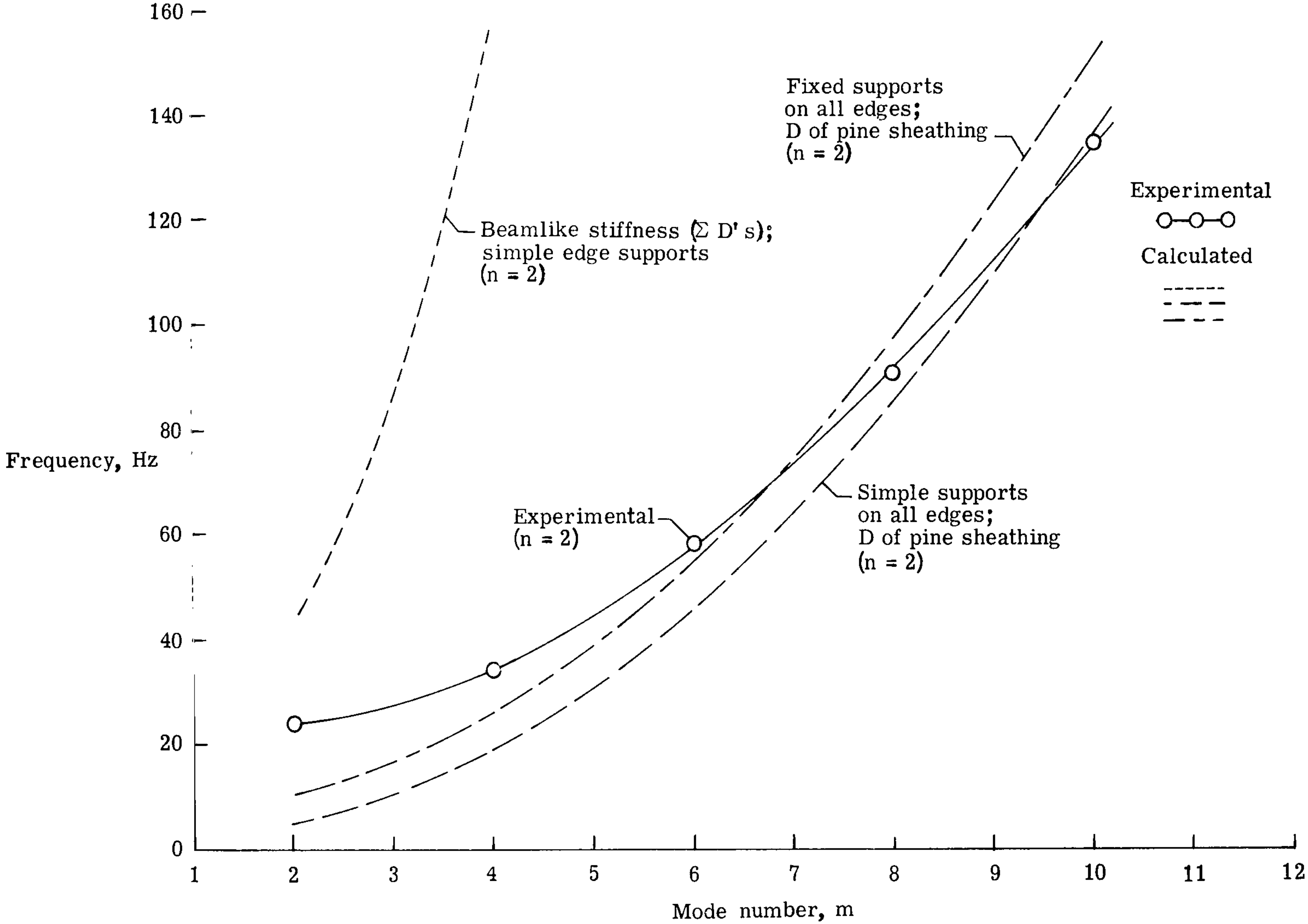
f = 58.0 Hz; m = 6; n = 2



f = 91.0 Hz; m = 8; n = 2

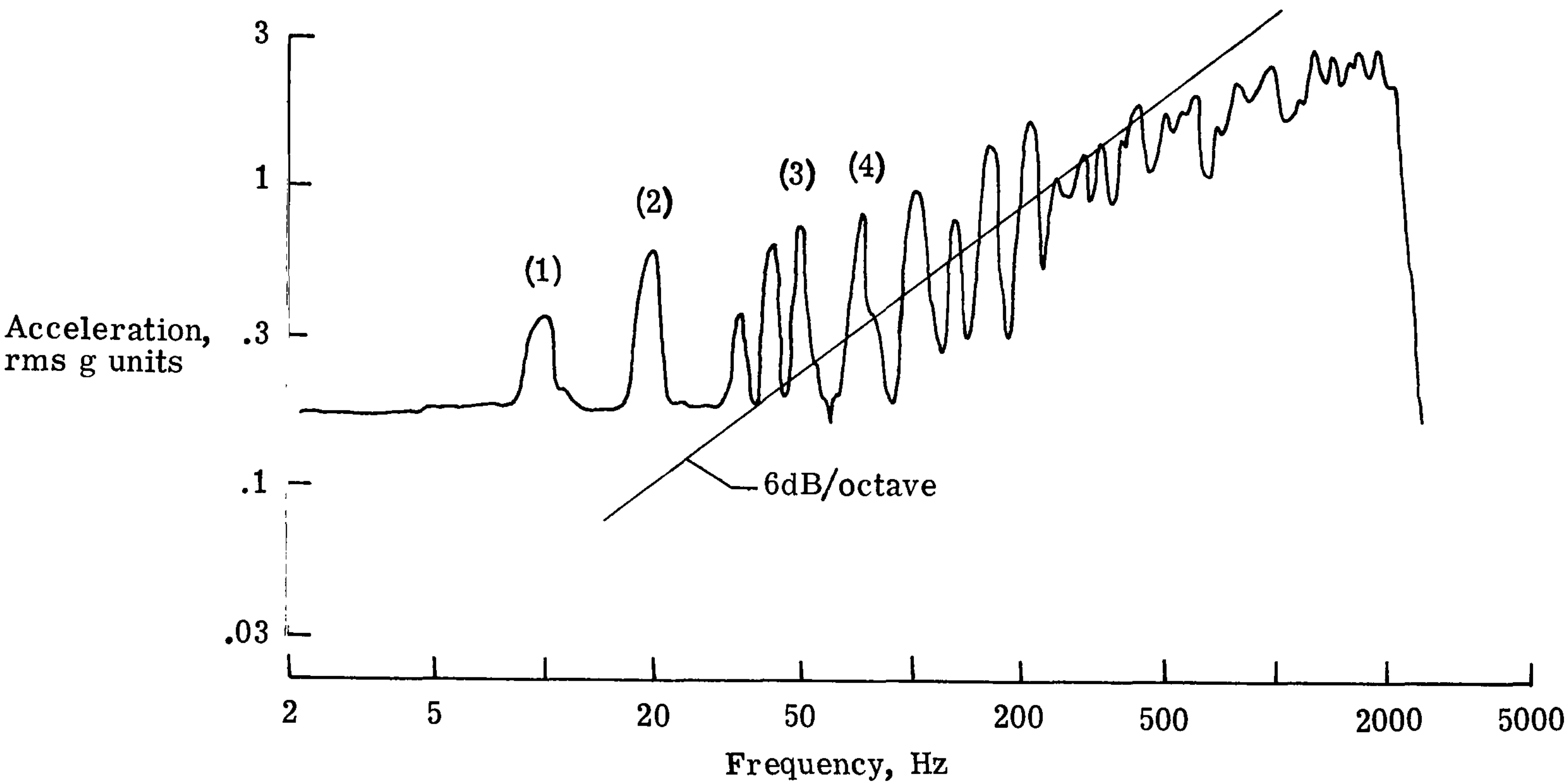
(b) Nodal patterns.

Figure 11.- Continued.



(c) Modal frequencies.

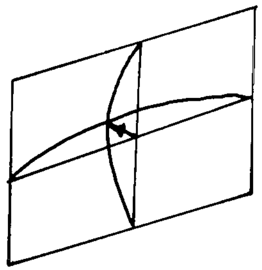
Figure 11.- Concluded.



(a) Acceleration response.

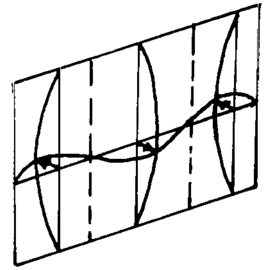
Figure 12.- Vibration behavior of large plate glass window for sinusoidal vibration inputs. Numbers in parentheses refer to patterns in (b) part.

(1)



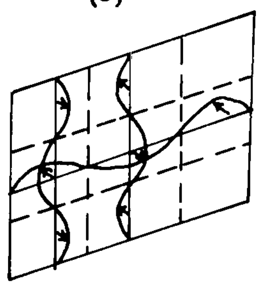
f = 9 Hz; m = 2; n = 2

(2)



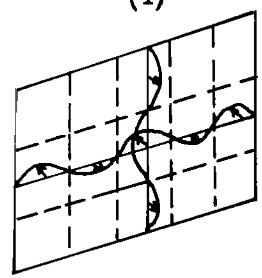
f = 18 Hz; m = 4; n = 2

(3)



f = 48 Hz; m = 4; n = 4

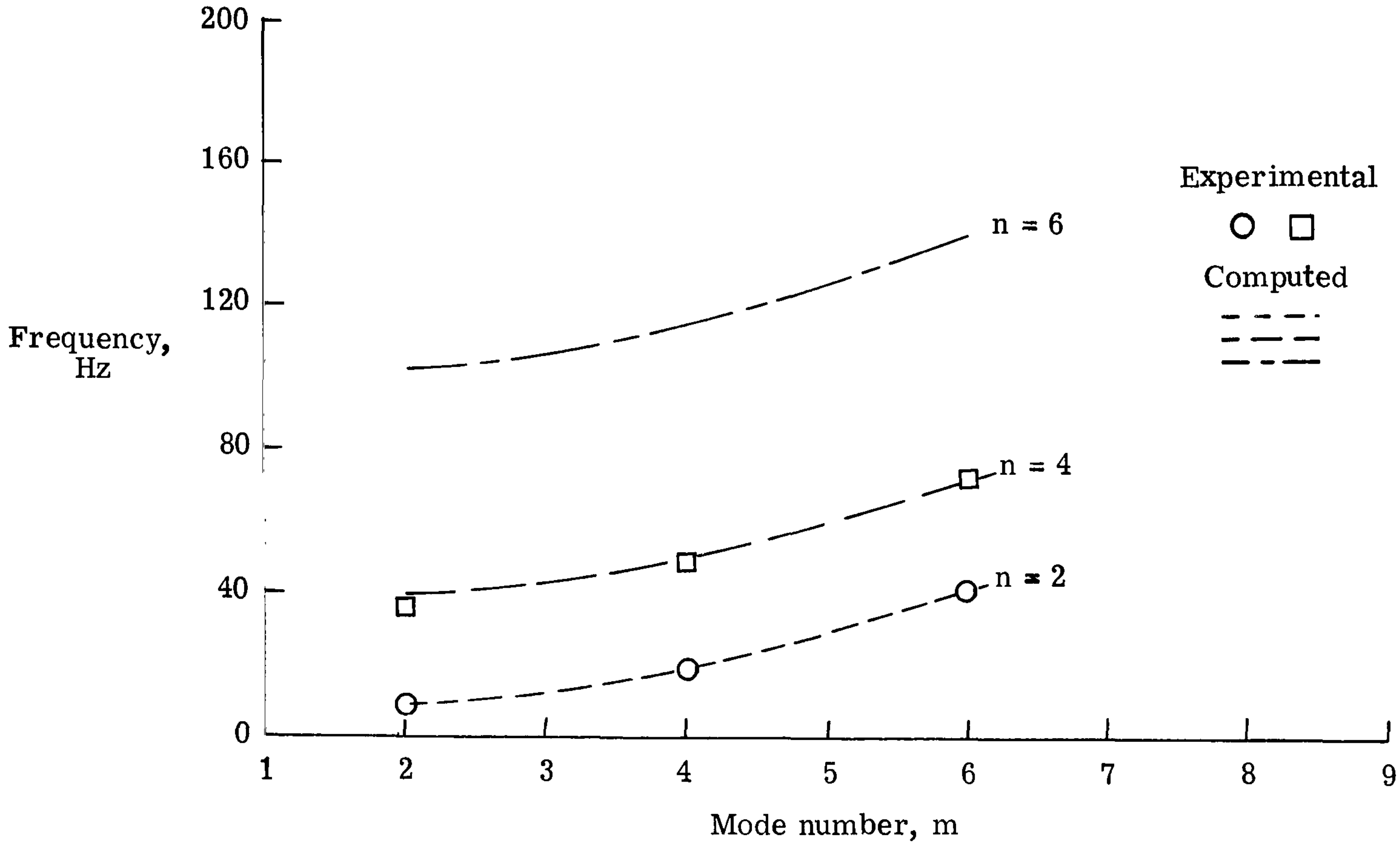
(4)



f = 70 Hz; m = 6; n = 4

(b) Nodal patterns.

Figure 12.- Continued.



(c) Modal frequencies.

Figure 12.- Concluded.

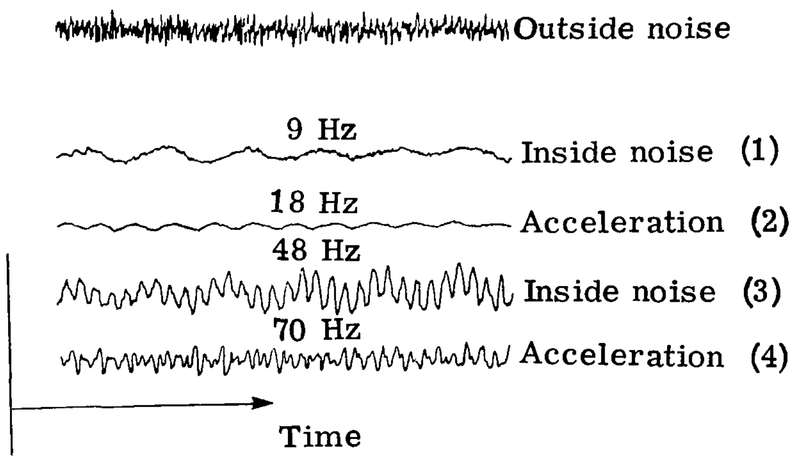


Figure 13.- Response of plate glass window to airplane flyover noise.

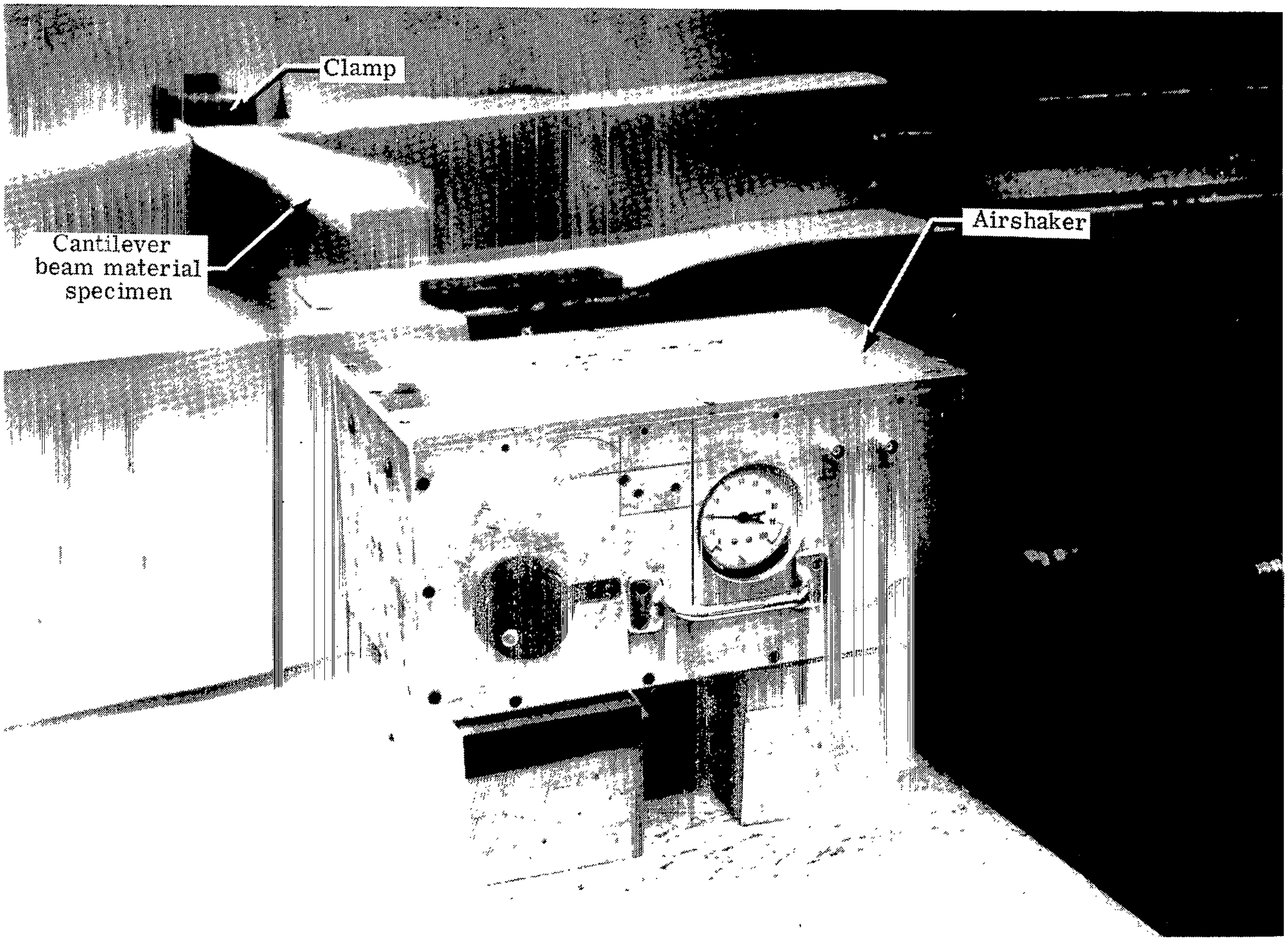


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Figure 14.- Test setup for determination of modulus of elasticity of materials used in construction of wall sections.

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15. Supplementary Notes

16. Abstract

Experimental studies of the vibration characteristics of structural components representative of wood-frame house construction were conducted with the use of various face sheet materials. Mechanical excitation was used, and measurements of acceleration response, natural frequencies, and nodal patterns were performed. Results indicate that the wall sections and the complete wall did not act as a unit in responding to sinusoidal vibration inputs. Calculated frequencies of the components that account for this independent behavior of the studs and face sheets agreed reasonably well with experimental frequencies. Experimental vibrations of the plate glass window agreed with the calculated behavior, and responses of the window exposed to airplane flyover noise were readily correlated with the test results.

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