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EXPERIMENTAL FORCED VIBRATION RESPONSES OF TWO TEST HOUSES USED DURING THE EDWARDS AIR FORCE BASE PHASE OF THE NATIONAL SONIC BOOM TEST PROGRAM

by

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June 1975

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16. Abstract

Experimental vibration studies were conducted on two houses to determine some of the dynamic response characteristics, resulting from sonic boom. The primary objectives of the vibration tests were to identify the mode shapes associated with the various frequencies determined from the sonic boom response data, and to obtain some basic information about the vibration behavior of buildings in general.

This paper presents the results of forced sinusoidal vibration studies of some components of the test structures. Included are acceleration response data on selected walls, wall surface modal patterns, and vibration induced noise measurements at various locations in the test structures.

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EXPERIMENTAL FORCED VIBRATION RESPONSES OF TWO TEST HOUSES USED DURING THE EDWARDS AIR FORCE BASE PHASE OF THE NATIONAL SONIC BOOM TEST PROGRAM

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INTRODUCTION

During the National Sonic Boom Test Program conducted at Edwards Air Force Base, California, experimental vibration studies were conducted to determine some of the dynamic response characteristics of the two houses used in the program. The primary objectives of the vibration tests were to identify the mode shapes associated with the various frequencies determined from the sonic boom response data (references 1 and 2), and to obtain some basic information about the vibration behavior of buildings in general.

This paper presents the results of forced sinusoidal vibration studies of some components of the test structures. Included are acceleration response data on selected walls, wall surface modal patterns, and vibration induced noise measurements at various locations in the test structures.

APPARATUS AND TEST PROCEDURE

Test Structures

The test structures were two precut residence type houses of conventional frame construction that were erected at the Edwards Air Force Base, California, by an Air Force contractor. The structures, shown in figure 1, were in an area containing about ten other residences. Test structure No. 1 on the left was a single-story three bedroom house whereas test structure No. 2 on the right was a two-story four-bedroom house. Both houses were finished inside and out, were appropriately furnished, and were instrumented with microphones, accelerometers, and strain gages. In the vibration tests, only the accelerometers and microphones were used from the instruments available.

Instrumentation

A permanent magnet shaker, capable of a maximum vector force of 25 pounds, was used to excite the vibratory responses of the test houses. The shaker was attached to either the walls or floors of the structures with a vacuum plate attachment. The oscillator signal used to drive the shaker was also applied to the horizontal trace of an oscilloscope and to a frequency-period counter. A crystal accelerometer was attached to the walls of the building and the output was applied to the vertical trace of the oscilloscope. The pattern referred to as a "Lissajous" figure that resulted on the oscilloscope was used to determine a resonant condition. A hand-held velocity probe was used to survey the structure to determine nodal locations for defining mode shapes.

For the forced vibration response phase of the vibration tests, existing instrumentation for the sonic boom program in both houses was used for recording structural responses.

Test Procedure

The same test procedure was used for all the vibration survey tests. Wall sections or floors of the test structures were excited with the permanent magnet shaker to determine the natural frequencies and mode shapes. Approximate frequencies determined from available sonic boom records (references 1 and 2) were used to narrow the frequency band of interest in searching for a resonant condition. A crystal accelerometer was placed on the wall or floor and the driving frequency varied until the resonant condition was established. The nodal lines were then traced by moving a hand-held velocity probe over the walls, ceiling, and floors throughout the test house.

After completion of the vibration modal surveys, the response of the building as measured by the various instruments located throughout the building was recorded on FM tape. In these tests, structure No. 1 and structure No. 2 were excited at sinusoidal force levels of 16, 12, and 8 pounds force peak to peak.

RESULTS AND DISCUSSION

Results of on site experimental vibration studies of two sonic boom test houses at Edwards Air Force Base, California, are presented in figures 2 to 7. Included in the results are modes, frequencies, and forced vibration responses of the test structures.

Vibration Data for Structure No. 1

Presented in figure 2 are typical wall and floor acceleration responses and the associated sound pressure levels (noise) in bedroom No. 1 of the one-story test structure (see floor plan sketch). The results are for a constant force excitation of the bedroom wall. The data indicate that at low frequencies, mainly floor motions contribute to the sound pressure environment whereas the higher frequencies from the wall motions contribute to the higher frequency portion of the sound pressure spectrum in the room.

Experimentally determined modes and frequencies of portions of house No. 1 are presented in figure 3. From sinusoidal excitation of the east bedroom wall, the first resonance occurred at 16.6 Hz. The associated mode was a diaphragm motion with nodes at the edges of the wall. Further velocity probe surveys of adjacent walls, floors, and ceilings, and adjoining rooms revealed that a major portion of the north end of the structure was vibrating as illustrated by the sketches in figure 3. Although the north bedroom wall and floor had resonant frequencies of 21.4 Hz and 26.0 Hz, respectively, the mode shapes were readily determined by exciting the east wall. Conversely, by exciting the north wall or floor, one could determine the other modal patterns as well. Thus, the mode surveys revealed that what appeared to be a fundamental wall mode of a room was actually part of the overall house or building modal behavior as indicated in figure 3.

Responses of the bedroom No. 1 floor and east wall as a result of sonic boom excitation (see reference 1) indicated that the bedroom floor and east wall responded at about 21 Hz and 16 Hz, respectively, which agrees well with the frequencies determined by sinusoidal excitation.

Vibration Data for Structure No. 2

Structural vibration data and associated sound pressure levels (noise) for the two-story house are presented in figure 4(a) and 4(b). In figure 4(a), acceleration response in dB of various locations in the two-story house are plotted as a function of the excitation force. The top curve in figure 4(a) is referenced to 1g rms, the bottom curve to .05g rms. The excitation frequency is 21.2 Hz, the resonant frequency of the dining room wall. The data symbols are keyed to the location of the measurement in the building and are shown in the sketch of the floor plan at the right of the figure. For instance, the circles are for a location on the east dining room wall near the input force, the squares are for the north bedroom wall upstairs, the triangles are for the kitchen floor, and the diamonds are for the location in the center of the dining room floor.

The significance of the data is that the accelerations for all of the locations appear to be linear with input force level, at least for the range of input forces used in the tests. In addition, the data indicate that low force levels at a point are capable of inducing responses virtually throughout the entire building in a linear response range at levels comparable to those resulting from sonic boom excitation (ref. 2).

Figure 4(b) presents the sound pressure levels (noise) resulting from the excitation of the dining room east wall at 21.2 Hz. As in the case with the acceleration responses, the data appear to be linear in the range of input forces used and range from 90 to 95 dB near the source to 70 dB at about 20 to 25 feet away in the center of the family room.

It may be noted that the levels in the upstairs bedroom directly over the dining area are comparable to those in the dining area. This result can be partially explained with the aid of figure 5 which presents the building response modes for only part of the building. These modal patterns are similar to those presented in figure 3 for house No. 1. As indicated on figure 5, the north bedroom wall, the bedroom floor (dining room ceiling), and the other walls (no modes shown) were vibrating in the fundamental motion as a result of the excitation of the dining room wall – thus one would perhaps expect the noise levels to be comparable in these two rooms.

Resonant frequencies of the various areas of the two-story building were 21.4 Hz for the north dining room wall, 21.2 Hz for the east wall, and 21 Hz for the floor. For the living room, the frequencies were 22.2 H. for the east wall, and 26.9 Hz for the south wall.

From analyses of the response data from the sonic boom studies (reference 1 and 2), it was noted that low amplitude, higher frequency harmonic signals were often superimposed on the lower frequency structural responses. During the modal vibration survey tests, the sources of the higher frequency responses were found to be high frequency panel modes similar to the panel mode at 405 Hz on the east dining room and bedroom wall shown in figure 6. This mode, for example, had a full wave length between the wall studs in the horizontal direction and 5 nodes vertically from the floor of the dining room to the ceiling of the upstairs bedroom.

Structural Interaction

From the modal data determined for the two test houses, strong interactions were found in the dynamic response patterns of floor, wall, and ceiling components. These interactions, which may involve both the structure and the trapped air in the rooms, resulted in preferred modal patterns involving not only adjacent components, but also those located remotely from each other. Figure 7 illustrates this interacting behavior for both structure No. 1 and No. 2. The sketch on the left illustrates the interaction for floor vibrations (also indicative of walls and ceilings) in the one-story house. The sketch on the right illustrates the interaction of the vibrations between stories in the two-story house.

The results from the sinusoidal vibration tests indicated that the fundamental natural frequencies (or first maximum responses) of the various wall and floor sections were in a relatively narrow frequency band between 15 Hz and 30 Hz. Thus, when a particular section was vibrated at its fundamental or maximum response, strong vibrations of the various other house sections occurred because of the closeness of their resonant frequencies to the one being excited. In the left hand sketch of figure 7 mainly structural interaction is responsible for the adjacent family room vibrations whereas in the right hand sketch both structural and air cavity interactions seem to be indicated. These results suggest some of the phenomena involved in the dynamic response of a house type structure, when excited at a single point. These responses are similar to those measured during sonic boom excitation (reference 2) for which the input loading was distributed, transient in nature, and impinged on all external surfaces of the house.

CONCLUDING REMARKS

Forced excitation results for two different houses indicated generally similar dynamic responses for which there were strong interactions between the floor, wall, and ceiling components. These interactions which may involve both the structure and the trapped air in the rooms resulted in preferred modal patterns involving not only adjacent components, but also those located remotely from each other. The fact that the fundamental frequencies associated with the framing of the structure occur in a rather narrow frequency range (15 to 30 Hz) enhences the above interaction.

The higher frequency responses of the houses were associated with the interior sheathing panels and the range of panel frequencies was about an order of magnitude higher than those of the frames.

The measured responses were noted to be linear for the range of force inputs of these tests and the results were generally consistent with those previously obtained during aircraft sonic boom and flyover noise studies.

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2. Findley, Donald S.; Huckel, Vera; and Hubbard, Harvey H.: Vibration Responses of Test Structure No. 2 During the Edwards Air Force Base Phase of the National Sonic Boom Program. NASA TMX 72704, June 1975.

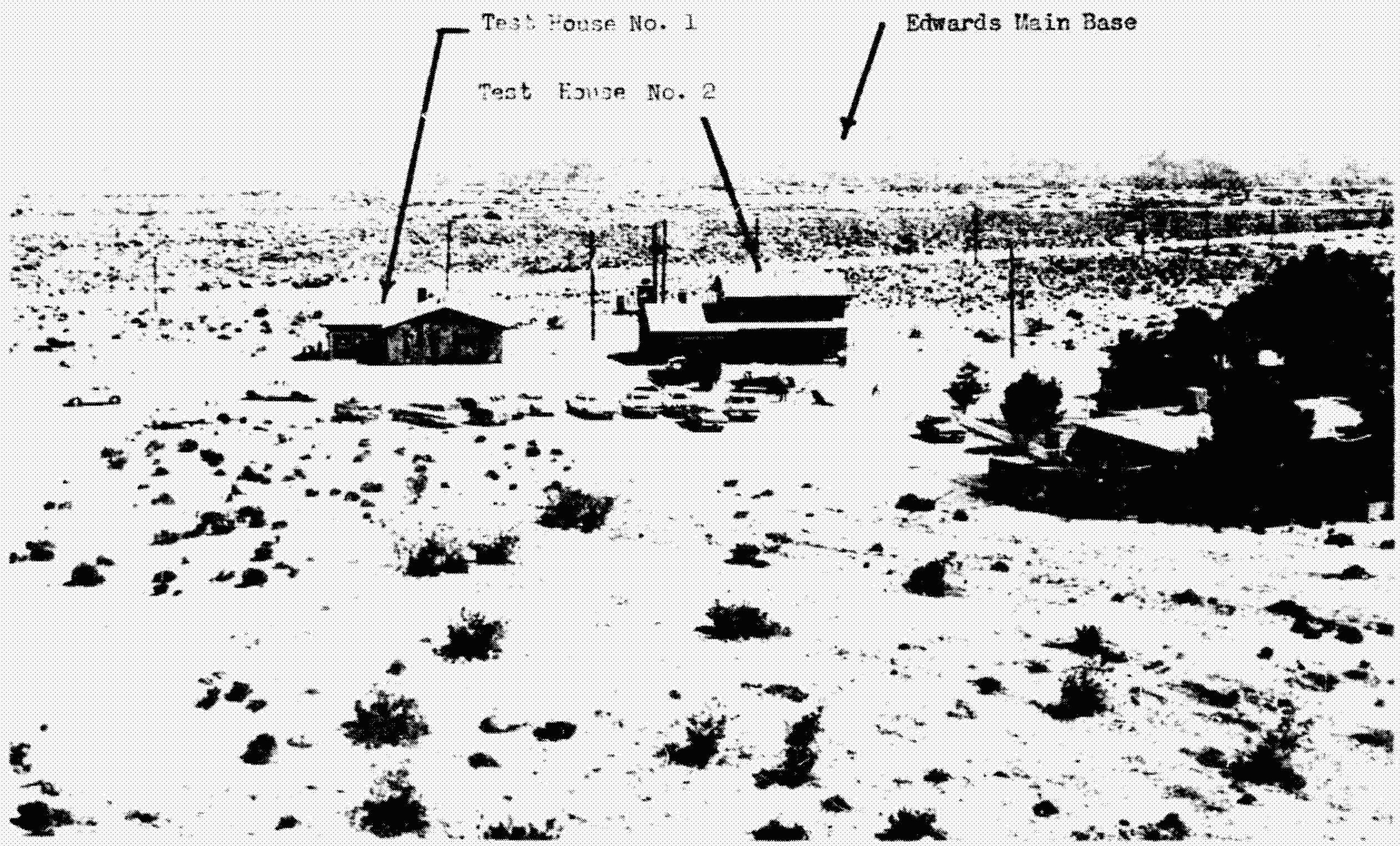


Figure 1. - Photograph of test structures.

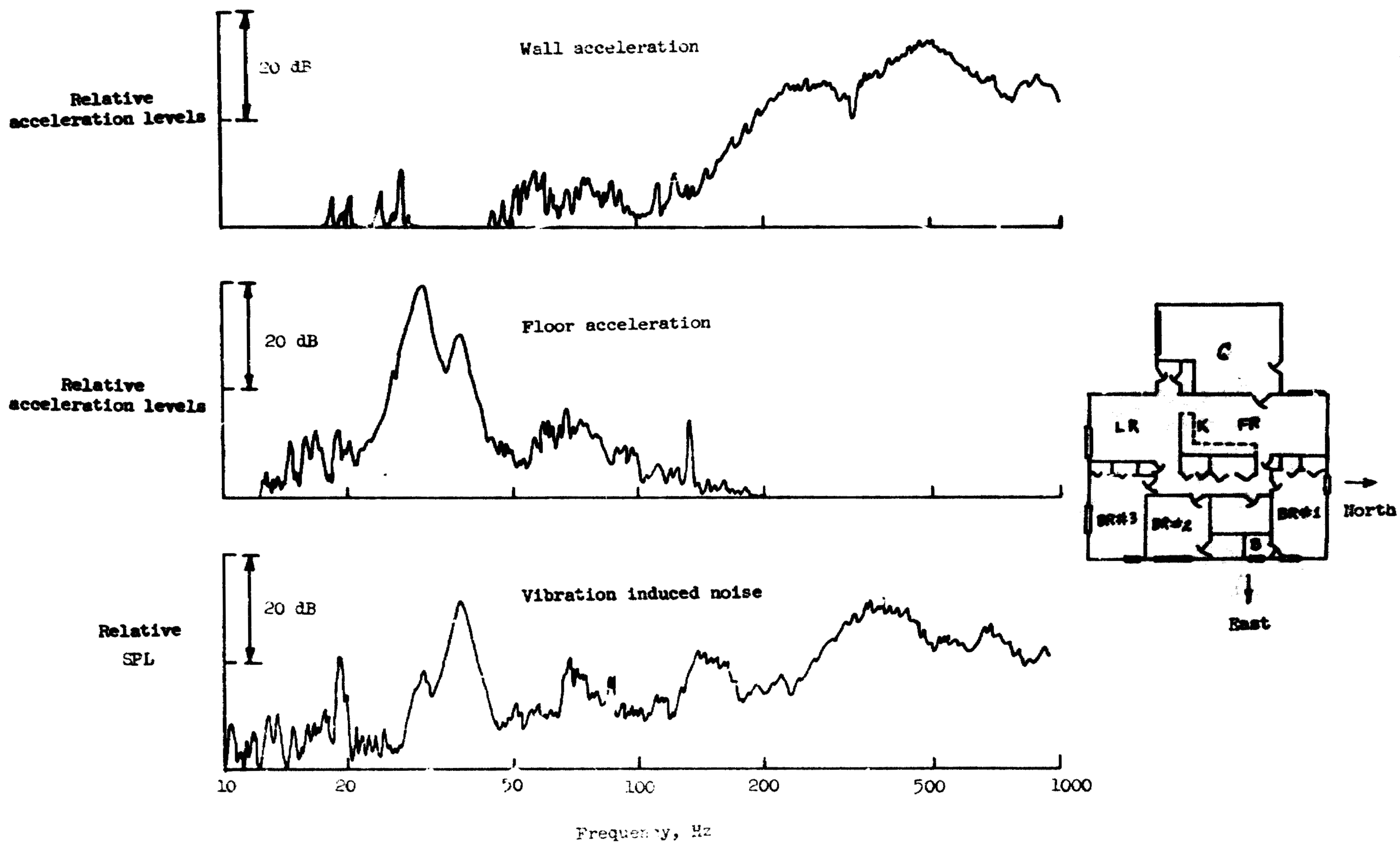


Figure 2. – Response of test house No. 1 as a function of excitation frequency. Constant input force.

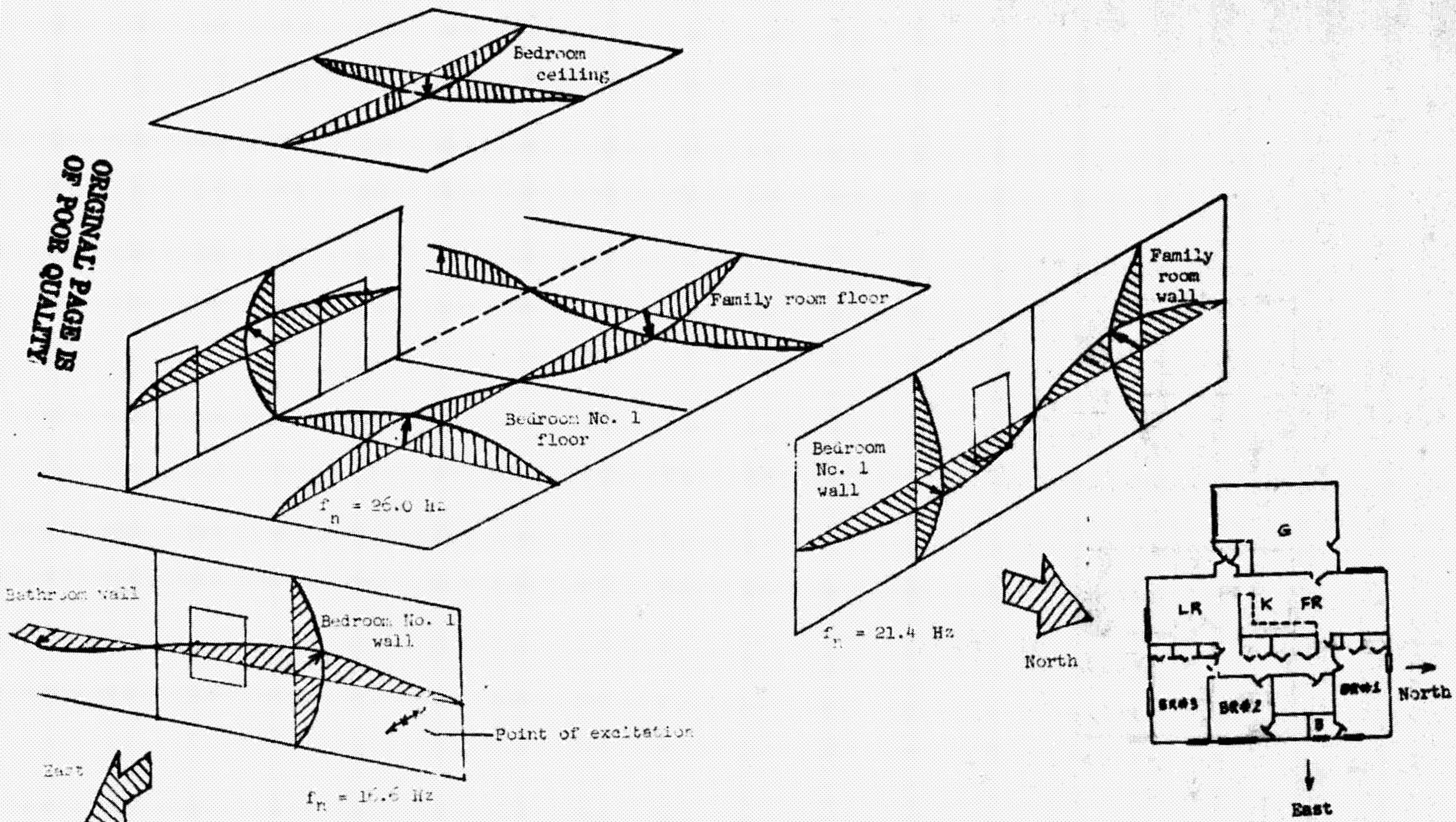
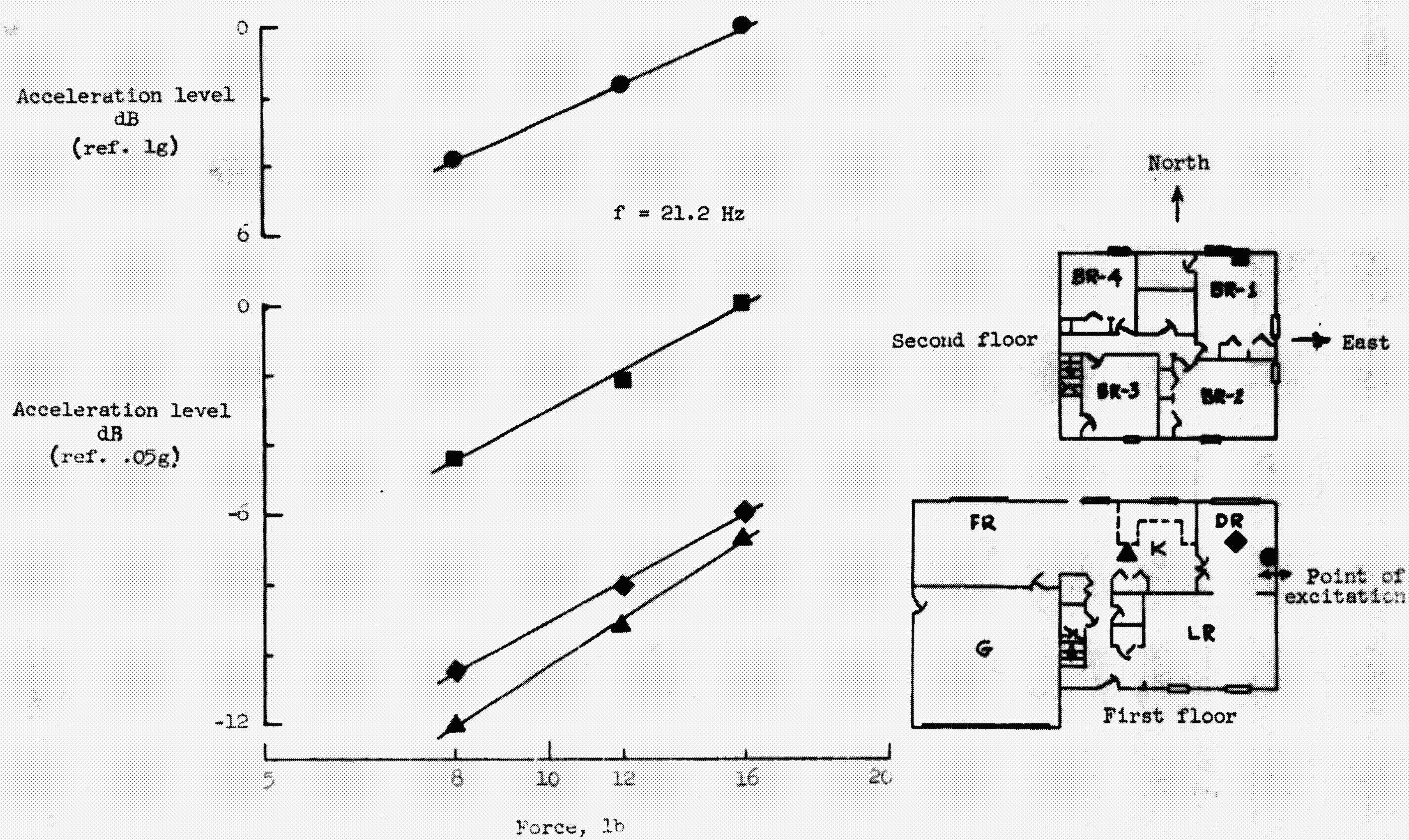
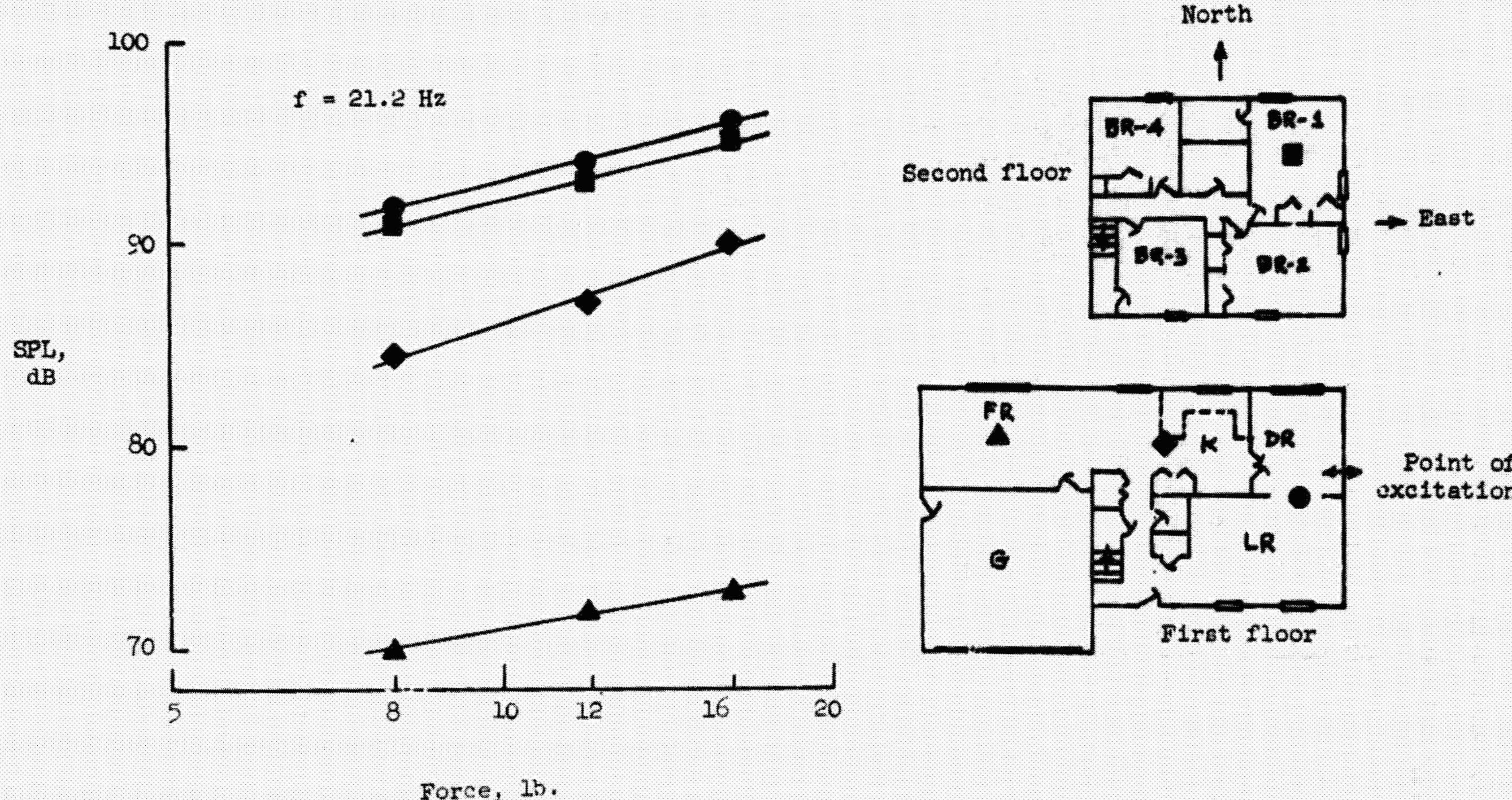


Figure 5. – Modes and frequencies of structure No. 1.



(a) Acceleration response

Figure 4. – Acceleration response of structure No. 2 as a function of excitation force.



(b) Noise pressures

Figure 4. – concluded.

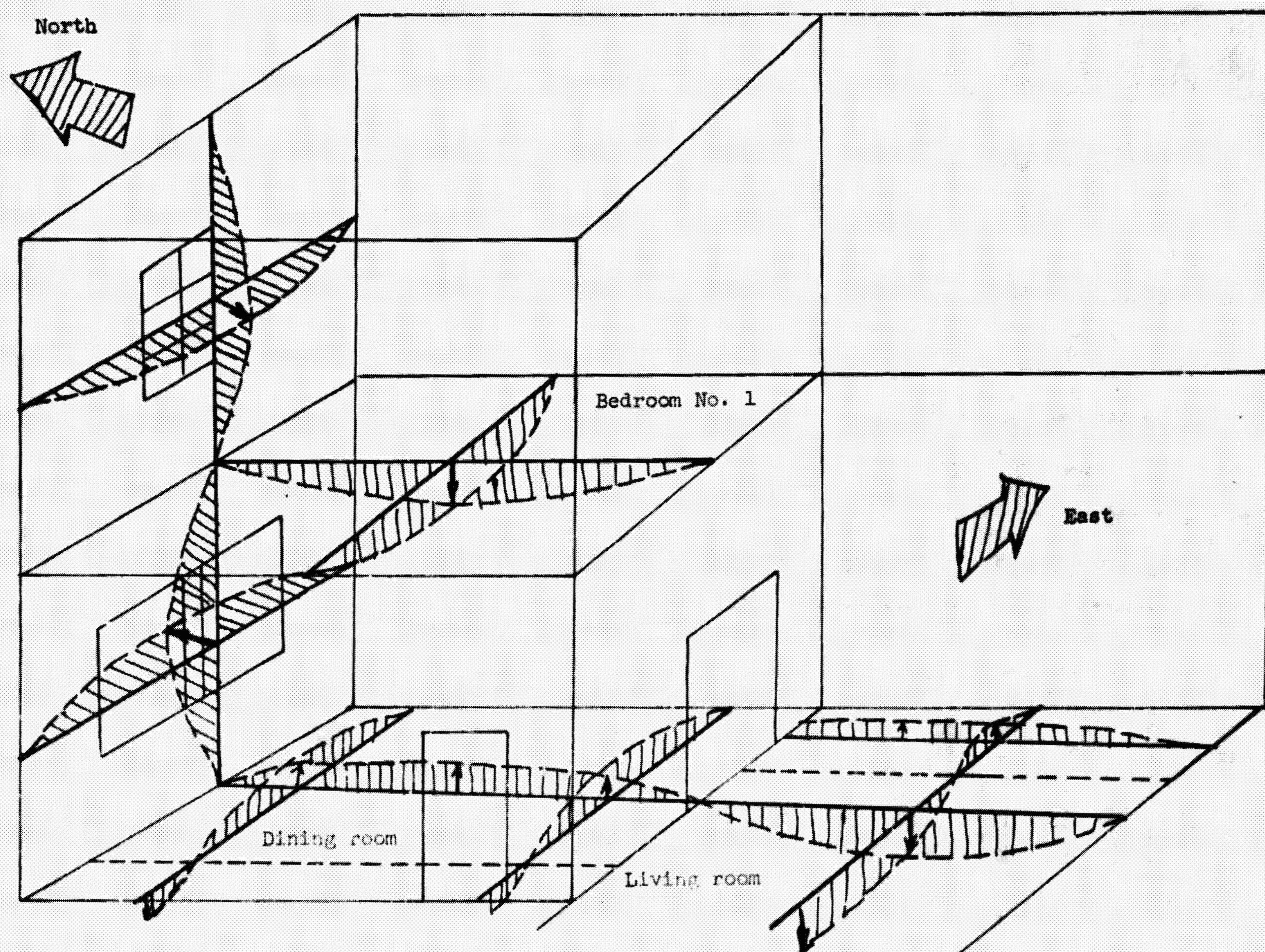


Figure 5. – Vibration modes of structure No. 2.

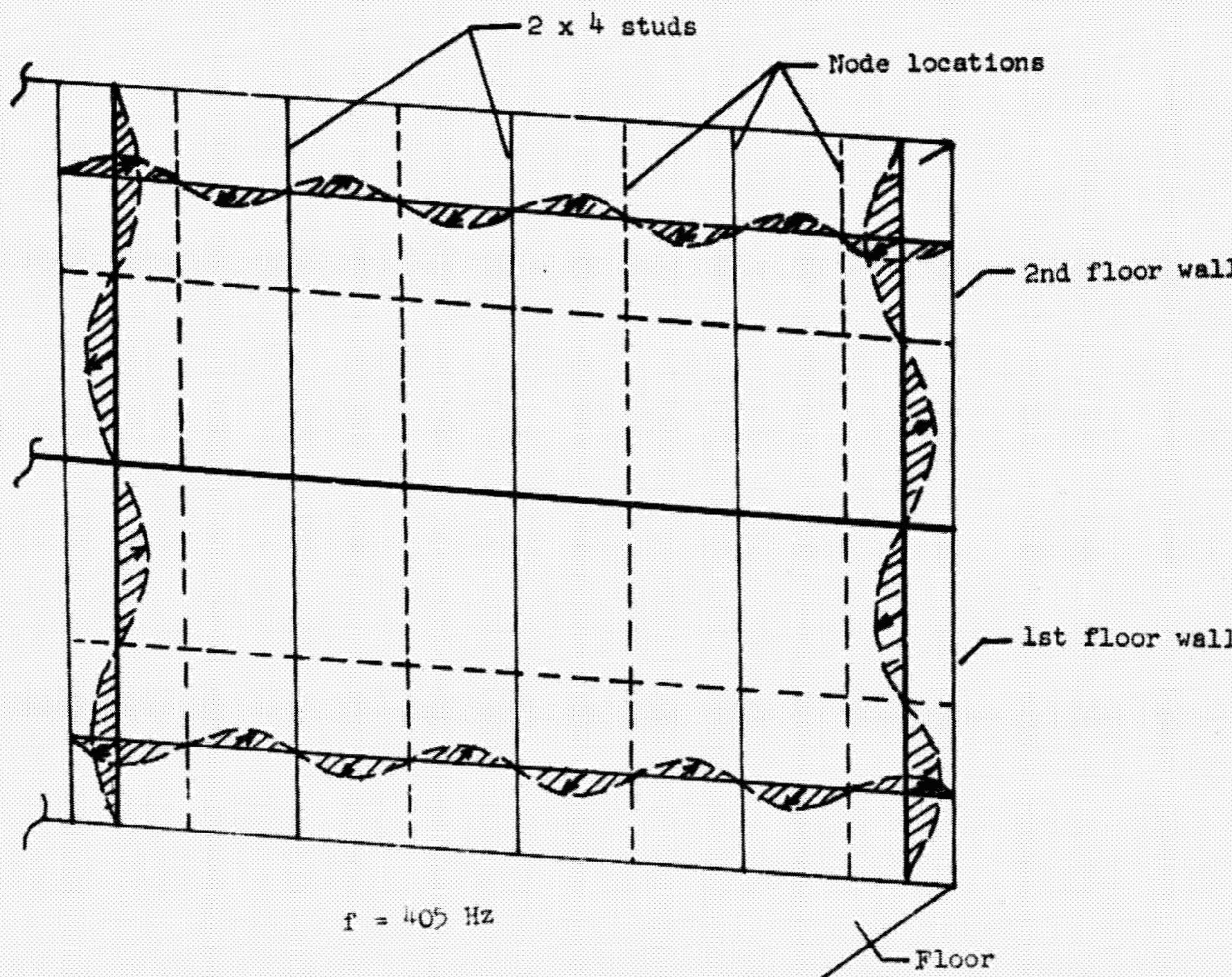


Figure 6. - High frequency panel mode in structure No. 2.

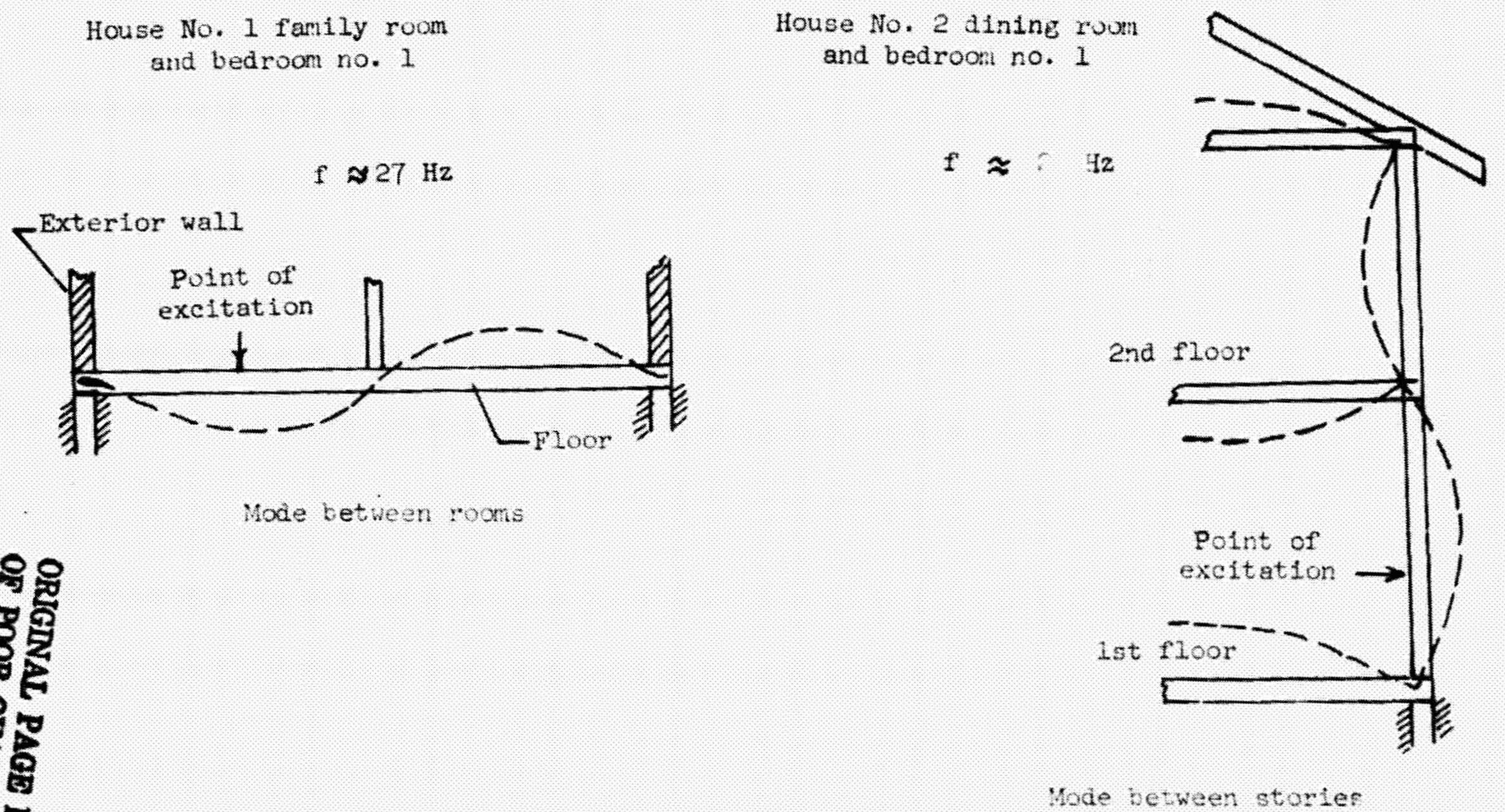


Figure 7. – Vibration modes illustrating structural interaction.