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Acoustical Evaluation of a Single Family Attached Steel Frame Modular Housing System Constructed on an Operation Breakthrough Prototype Site

Thomas L. Quindry

Applied Acoustics and Illumination Section
Center for Building Technology (Building Research Division)
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
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ACOUSTICAL EVALUATION OF A SINGLE FAMILY ATTACHED STEEL-FRAME MODULAR HOUSING SYSTEM CONSTRUCTED ON AN OPERATION BREAKTHROUGH PROTOTYPE SITE

By

Thomas L. Quindry
Applied Acoustics and Illumination Section
Building Research Division

ABSTRACT

The acoustical performance of a single family attached steel-frame modular housing system was tested on an Operation BREAKTHROUGH prototype site.

Test results are given concerning the noise isolation of inter-dwelling walls, the noise isolation of intra-dwelling walls and floor-ceiling assemblies.

Key Words: Acoustics; noise isolation class; Operation BREAKTHROUGH

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1. INTRODUCTION

Drawings and specifications for the housing systems being demonstrated as a part of the Operation BREAKTHROUGH Program were reviewed in order to determine the acoustical performance of the dwelling units. Any potential deficiencies in acoustic performance were noted such that appropriate action could be taken prior to manufacture and site installation of the housing units.

Poor workmanship, however, can negate even the best planned acoustical improvement. The many unknowns associated with workmanship, possible damage to the housing modules during shipment, assembly of the housing modules on the building site, and even the modular concept of construction typical of many of the Operation BREAKTHROUGH housing systems, emphasized the importance of acoustical performance testing.

More builders than ever before are now at least aware that acoustic quality in buildings is becoming an essential consumer requirement. A great deal of information can ultimately be drawn from the acoustical performance testing of Operation BREAKTHROUGH housing.

2. OBJECTIVE

The objective of this work was to obtain information regarding the inter- and intra-dwelling noise isolation provided by this particular prototype housing system constructed within the Operation BREAKTHROUGH Program on one of the prototype sites, and to provide this information as a data base for possible comparison with the acoustical performance of conventional housing.

3. TEST PROCEDURE

All tests were performed in accordance with the methods outlined in the appropriate standards. The pertinent tests include:

Appendix A1 of ASTM E 336-71, "Recommended Practice for the Measurement of Airborne Sound Insulation in Buildings."

ASTM E 413-70T, "Tentative Classification for Determination of Sound Transmission Class." (This test method is used for the determination of Noise Isolation Class.)

ASTM C 423-66, "Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms," Section 9.1, for measurement of decay rate procedure.

ANSI S1.2-1962, "ANSI Standard Method for the Physical Measurement of Sound."

All measuremens were carried out using the NBS Mobile Acoustical Laboratory[1/]. A complete list of the equipment utilized for these measurements is given in Table 1.

Airborne noise reductions were measured using 1/3-octave bands of pink random noise[2/] to excite the speaker systems. A multiplex system which scanned the outputs of the microphones was used for simultaneous spatial averaging in both the source and receiving rooms. The output of the multiplexer was passed through a 1/3-octave band-pass filter set and then the measuring system.

A total of six microphones, in a modified spherical array as shown on Figure 1, was used in all rooms. The distribution of sound in the source room was improved by the addition of an 8 ft x 11 ft honeycomb

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1/ Winzer, George E., National Bureau of Standards Mobile Acoustical Laboratory, Sound and Vibration, May 1970.

2/ Pink random noise is a quantity (e.g., sound pressure) whose amplitude probability is a normal (Gaussian) distribution curve and whose frequency spectrum slopes at minus 3 dB per octave.

reflecting panel placed at an angle such that its top edge was resting across the entire wall that was opposite the primary test wall.

Temporal averages of sound pressure levels were obtained using a true root-means-square voltmeter in order to obtain less statistical error in sound pressure levels than can be obtained with the graphic level recorder recommended in ASTM E 336-71. A differential amplifier was used with two true r.m.s. voltmeters to obtain the differences in the r.m.s. sound pressure levels of the random noise between the source and the receiving room. Airborne noise reduction determination averaging times of 100 seconds for tests at frequencies from 125 through 400 Hz and 30 seconds for tests at frequencies from 500 to 4000 Hz were used in order to achieve a statistical error (due to temporal averaging) of less than $\pm$0.4 dB (at a confidence level of 95 percent).

The uncertainty in measured sound pressure levels, due to random and systematic uncertainties associated with the overall data acquistition system, is estimated (95 percent confidence level) to be less than $\pm$1 dB for relative sound pressure levels (measured to determine airborne noise reductions) over a range of band-center frequencies from 100 to 4000 Hz. ASTM E 336-71 specifies that for suitable accuracy in determining the average sound pressure levels in the source and receiving rooms, the rooms should be large enough that there are at least 10 normal modes per measurement bandwidth. The lower limit of frequency for which this would occur using 1/3-octave bands was: 220 Hz for the bathroom, 150 Hz for the back bedroom and 140 Hz for the living room.

For the airborne noise reduction measurements the background noise in the receiving room was at least 10 dB below the transmitted signal. The evaluation sound absorption of the receiving rooms was determined by the reverberation decay method described in ASTM C 423-66.

During the field measurements the temperature was nominally 68°F and the relative humidity 43%.

4. DESCRIPTION OF HOUSING SYSTEM

The housing unit tested is classified as a single family attached housing system. Four modules are placed longitudinally, two on top of two, to form three living units. The lower two modules are anchored to a concrete foundation wall which forms a full basement. The upper modules rest on, and are structurally connected to, the lower modules. Each adjacent dwelling unit is identical in layout and orientation with a typical floor plan shown in Figure 1. The units were unfurnished except for floor coverings and kitchen equipment. The living room, stairway to the second floor, bedrooms and second floor hall were carpeted with the remaining areas covered with vinyl asbestos tile finish flooring.

The party wall shown in Figure 2 is constructed of two layers of 1/2-inch gypsum drywall placed on each side of 1-1/2 inch x 3-1/2 inch x 18 Ga steel channel shaped studs spaced 24 inches on center. The studs are supported continuously top and bottom by 2 x 4 (nominal) wood plates and 1 inch x 3-1/2 inch x 20 Ga steel channel. Four-inch thick friction fit fiberglass insulation is placed between the studs. The wall is supported on a continuous 3/4-inch plywood floor which is common to both units.

The floor assembly for both the first and second floor as shown in Figure 2 consists of 1-3/4 inch x 7-1/4 inch x 18 Ga steel channel shaped joists spaced 24 inches on centers to which is attached 3/4-inch plywood subfloor. The ceiling assembly consists of 2 x 4 (nominal) inch wood joists spaced 16 inches on center with 1/2-inch gypsum drywall as the finish ceiling. The floor/ceiling space between the second floor and first floor party walls consists of: two 2 x 4 (nominal) inch wood joists, 2 x 8 (nominal) inch wood joist, 1-3/4 inch x 7-1/4 inch x 18 Ga steel channel, and 5/8-inch gypsum drywall.

The walls between modules within a given dwelling unit consist of double 1-1/2 inch x 2-1/2 inch x 18 Ga steel channel shaped studs placed with the webs parallel to the wall at 24 inches on centers with 1/2-inch gypsum drywall on the outer surfaces as shown in Figure 3. The floor is not continuous under these walls.

Interior doors are of a hollow core wood construction and undercut approximately 3/4 to 1 inch.

5. TEST RESULTS

5.1 Noise Isolation of Inter-Dwelling Walls

Each measured noise reduction was normalized to a reference receiving room absorption, A_o, of 10 m^2 (100 ft^2) according to the following equation:

$$NR_n = NR - (10 \log_{10} \frac{A}{A_o})$$

where NR_n = Normalized noise reduction

NR = Noise reduction before normalization

A = Total sound absorption of the receiving space.

In the housing system that was tested, the partywall on the first floor which separated the living rooms of two units included a stairway of one of the units, thereby creating a buffer zone as shown in Figure 1. Measurements of noise reduction and absorption were carried out on this wall and also the inter-dwelling partition separating the bathroom and back bedroom. The normalized noise reductions obtained are shown as a function of frequency in Figures 4 and 5. The three-segmented solid line represents the Noise Isolation Class (NIC) contour fitted to these data according to the specified procedure in ASTM E 413-70T. The dotted line points to the normalized NIC value. The normalized NIC values obtained are given in Table 2.

5.2 Intra-Dwelling Walls and Floor-Ceiling

The results of measurements of the normalized noise reductions between the front bedroom and the horizontally adjacent back bedroom with both bedroom doors closed, the bathroom and the horizontally adjacent back bedroom with both doors closed, and the front bedroom and the vertically adjacent living room with the bedroom door closed are given in Figures 6, 7, and 8 respectively. The NIC contours are fitted to the data and the normalized NIC values are given in Table 2.

6. DISCUSSION

During the testing several observations were made. For instance, the steel studs in the partition separating the front bedroom and the stairway, as shown in Figure 1, vibrated noticeably when 1/3-octave band pink noise at 125 Hz center frequency was generated in the front bedroom through the speakers. In addition, by pushing on the plywood paneling on this wall in the bedroom the rattling noise characteristics changed. It appeared that the paneling was loosely fastened to the studs.

Subjective observations were made to try and determine the cause of the lesser acoustical performance of the party wall separating the bathroom and back bedroom of two units. The generated sound seemed to have less attenuation through the party wall in the area of the shower stall. According to available plans and specifications two layers of gypsum drywall are supposed to cover the entire party wall in the bathroom including the area behind the shower stall. The NIC value obtained from the measured data along with the subjective observations indicate that a major sound flanking path occurs in the shower stall area. This might indicate that one or both layers of gypsum drywall had not been placed full length in the area behind the shower stall.

TABLE 1

Instrumentation*

1. Brüel & Kjaer 1402 Random Noise Generator
2. (3) Brüel & Kjaer Models 1612, 5004 Band-Pass Filter Sets
3. JBL Speaker Systems
4. (2) Brüel & Kjaer 2606 Measuring Amplifier
5. (2) Brüel & Kjaer 215 RMS Converter & Log Amplifier
6. (2) Brüel & Kjaer 221 Microphone Energizer - Multiplixer
7. Brüel & Kjaer 2305 Graphic Level Recorder
8. (12) Brüel & Kjaer 4132 Condensor Microphones
9. (12) Brüel & Kjaer 2619 FET Preamplifier
10. (2) Brüel & Kjaer 4220 Pistonphone
11. NBS Differential Amplifier
12. NBS Reverberation Time Measuring System
13. HP 5325 A Counter

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* Commerical instruments are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.

TABLE 2

The Measured Noise Isolation Characteristics of the Housing System

Partition	Source Room Unit	Receive Room Unit	Normalized NIC
Inter-dwelling Wall	Living Room 13-SFA/03-15	Living Room 13-SFA/03-14	52
Inter-dwelling Wall	Bathroom 13-SFA/03-13	Bedroom (Back) 13-SFA/03-14	42
Intra-dwelling Wall	Bedroom (Front) 13-SFA/03-14	Bedroom (Back) 13-SFA/03-14	41
Intra-dwelling Wall	Bathroom 13-SFA/03-14	Bedroom (Back) 13-SFA/03-14	29
Intra-dwelling Floor/Ceiling	Bedroom (Front) 13-SFA/03-14	Living Room 13-SFA/03-14	40

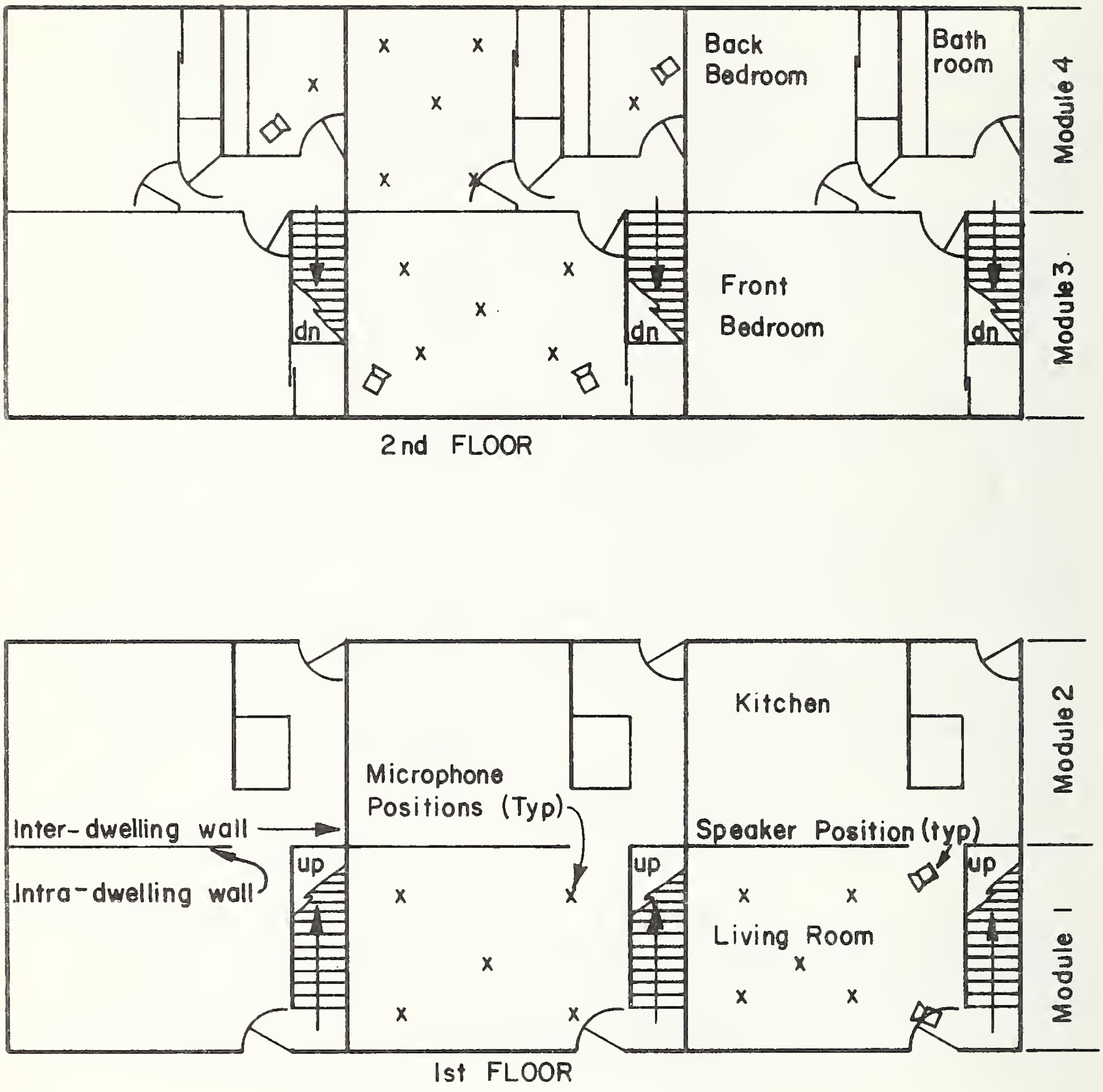

Figure 1. Floor plan of housing system showing microphone and speaker positions.

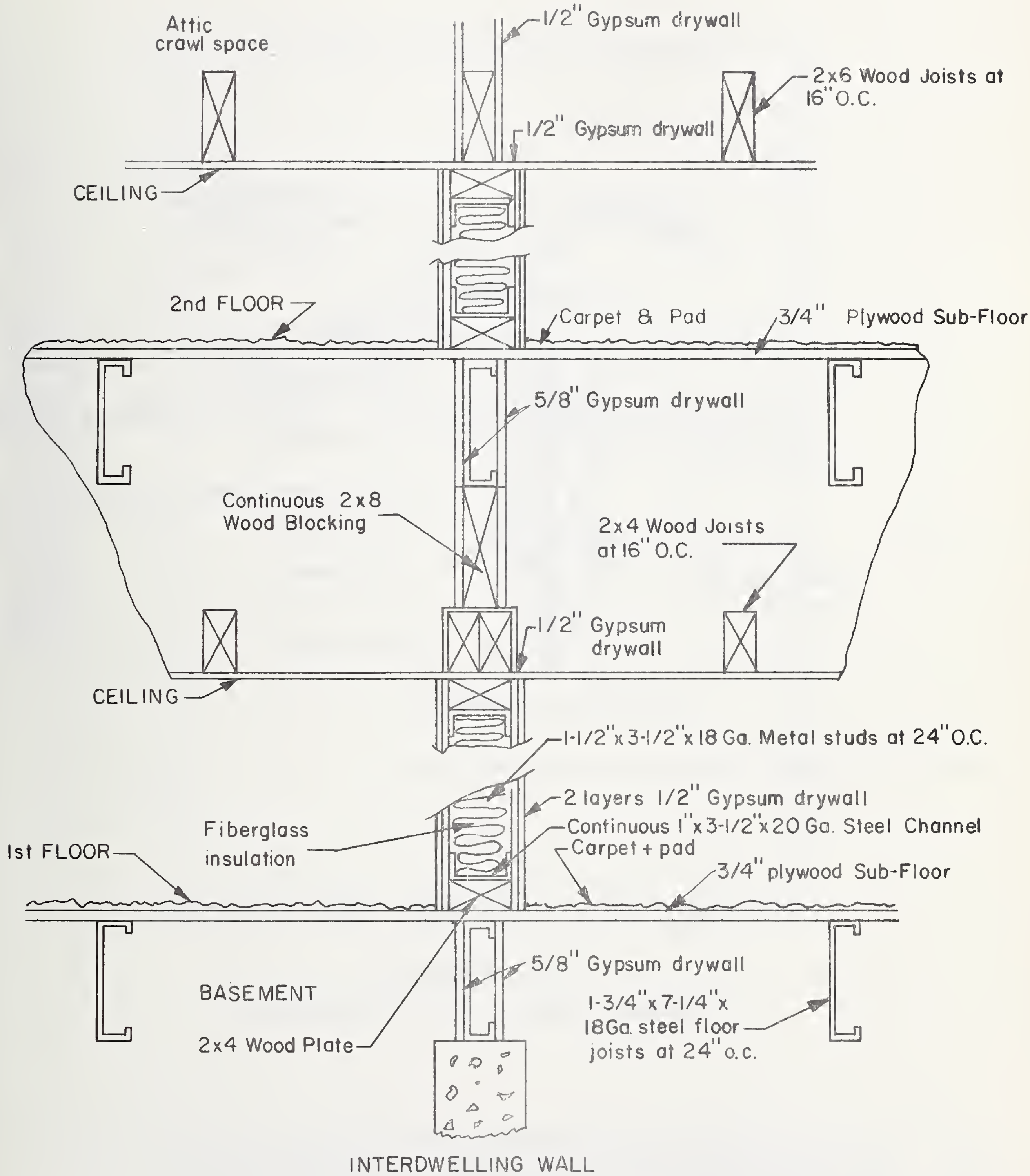

Figure 2. Section through inter-dwelling wall and intra-dwelling floor-ceiling assemblies.

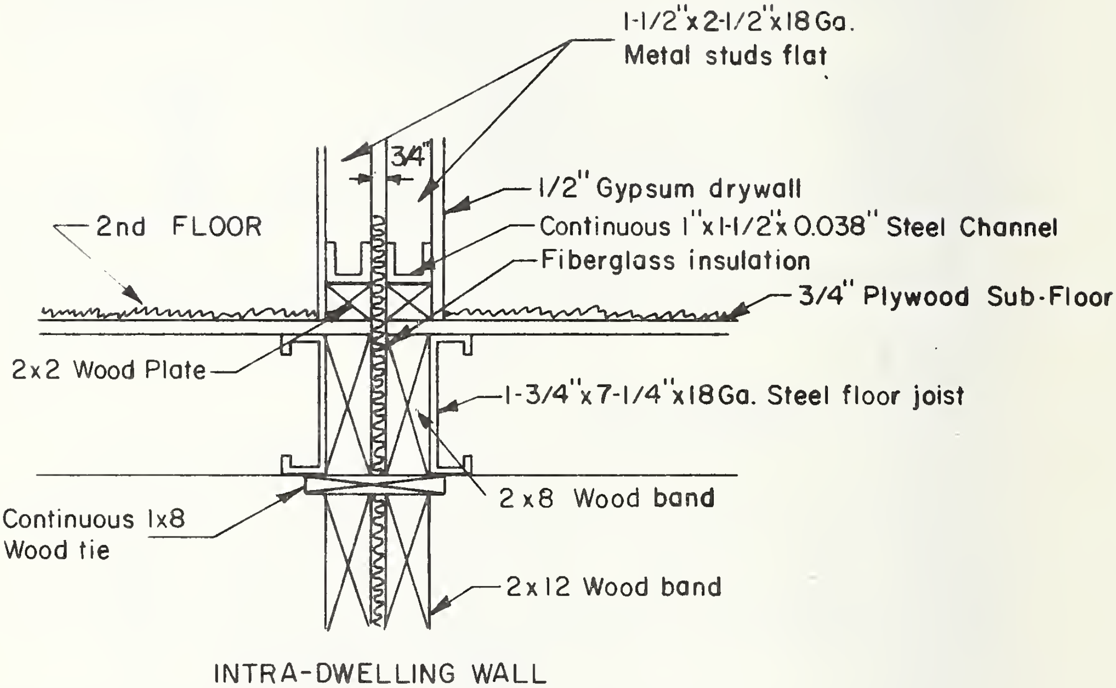

Figure 3. Section through intra-dwelling wall.

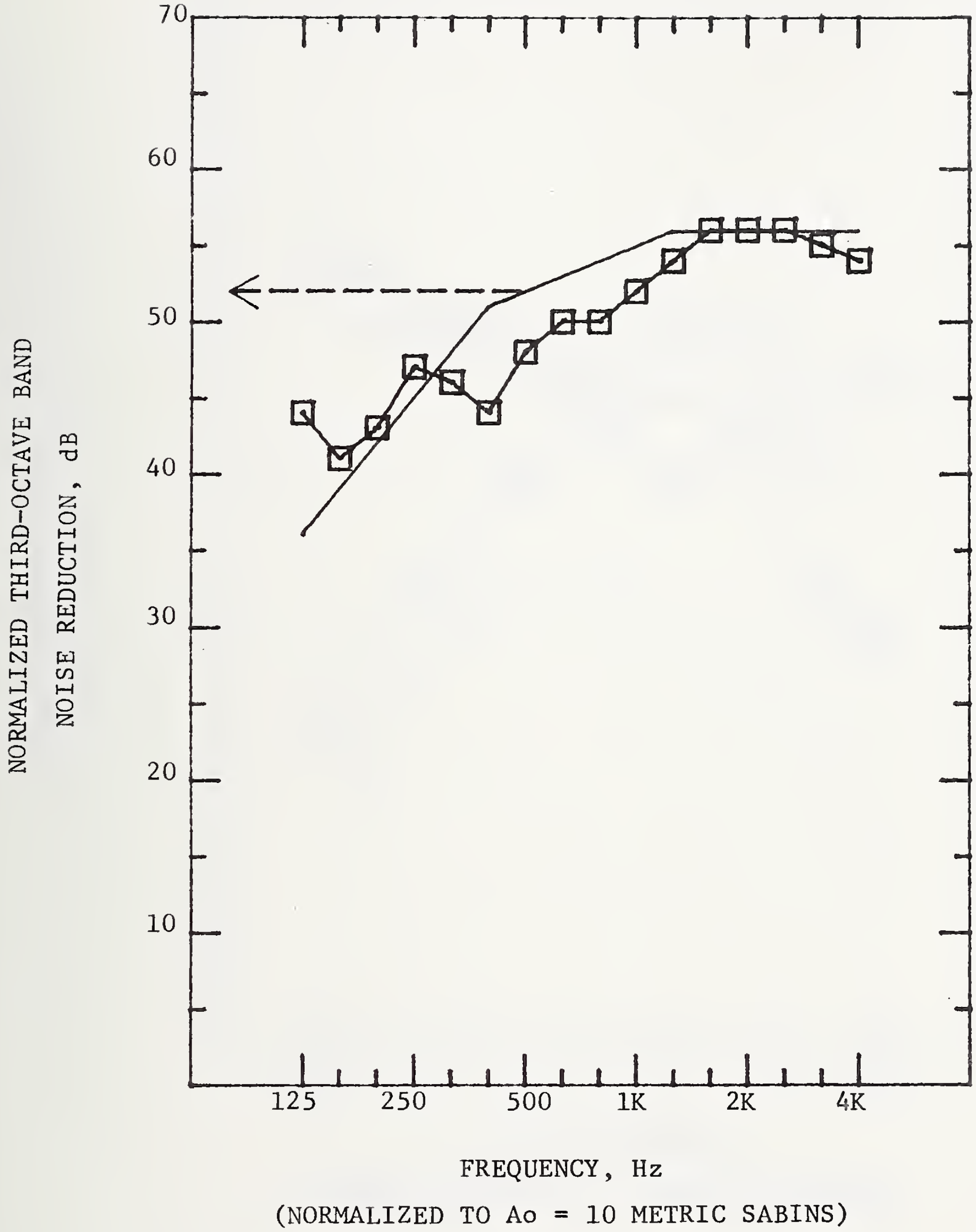

Figure 4. Normalized 1/3-Octave Band Noise Reduction Between Two Living Rooms Separated by an Inter-Dwelling Wall. Units 13-SFA/03-15 and 13-SFA/03-14 (includes stairway buffer zone) (NIC - 52).

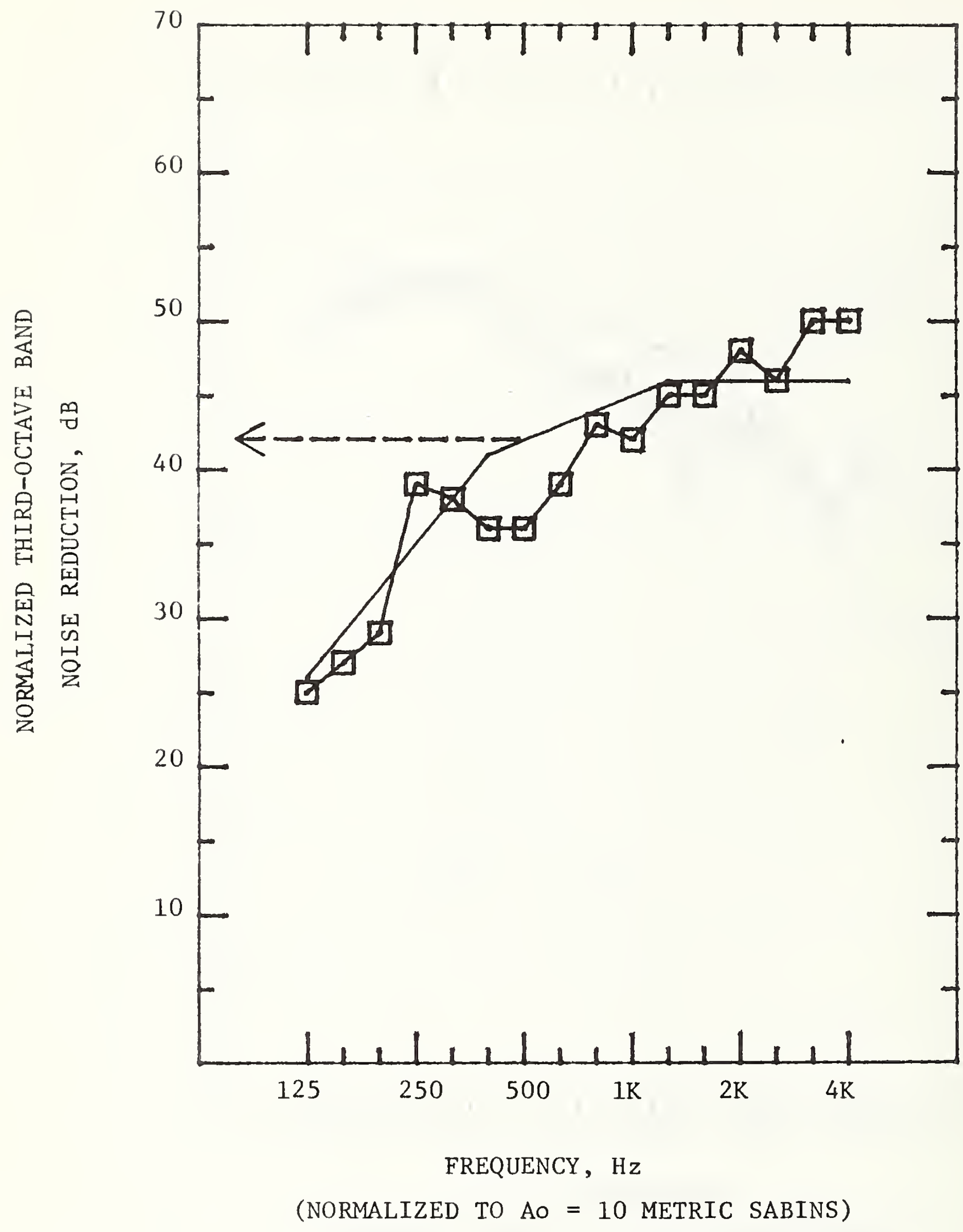

Figure 5. Normalized 1/3-Octave Band Noise Reduction Between a Bathroom and a Back Bedroom Separated by an Inter-Dwelling Wall. Units 13-SFA/03-13 and 13-SFA/03-14 (NIC - 42).

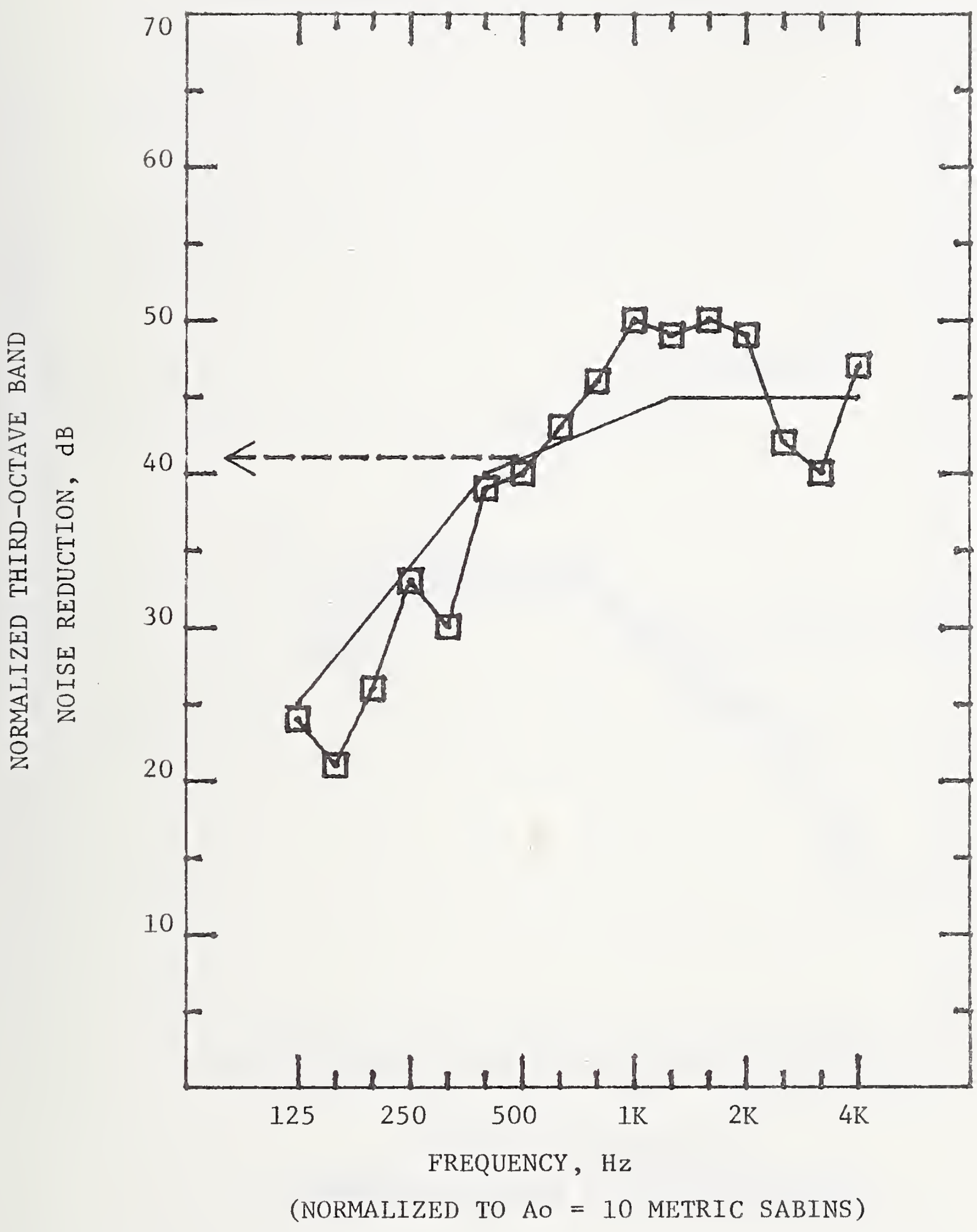

Figure 6. Normalized 1.3-Octave Band Noise Reduction Between the Front Bedroom and a Back Bedroom Separated by an Intra-Dwelling Wall. Unit 13-SFA/03-14 (NIC - 41).

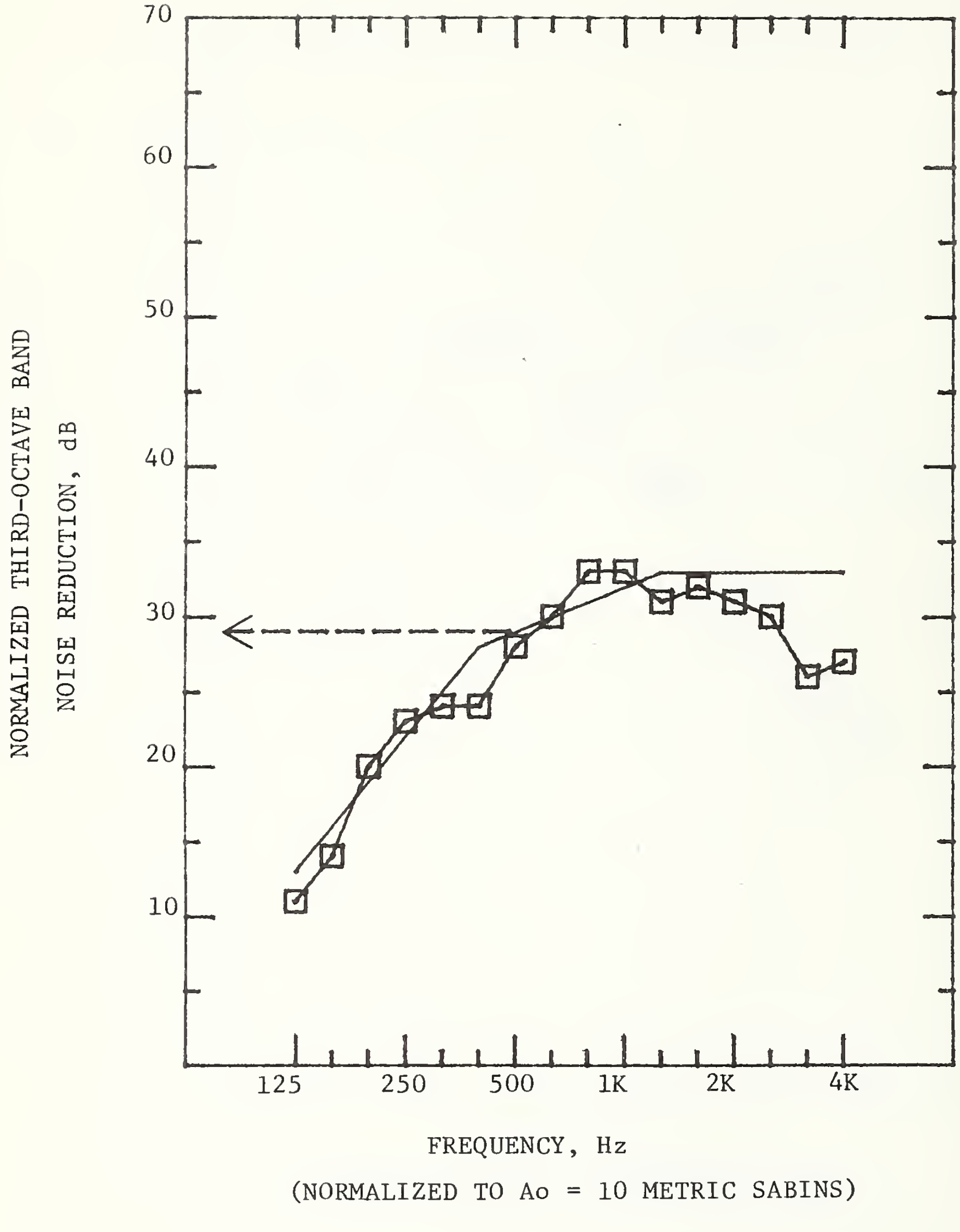

Figure 7. Normalized 1/3-Octave Band Noise Reduction Between a Bathroom and a Back Bedroom Separated by an Intra-Dwelling Wall. Unit 13-SFA/03-14 (NIC - 29).

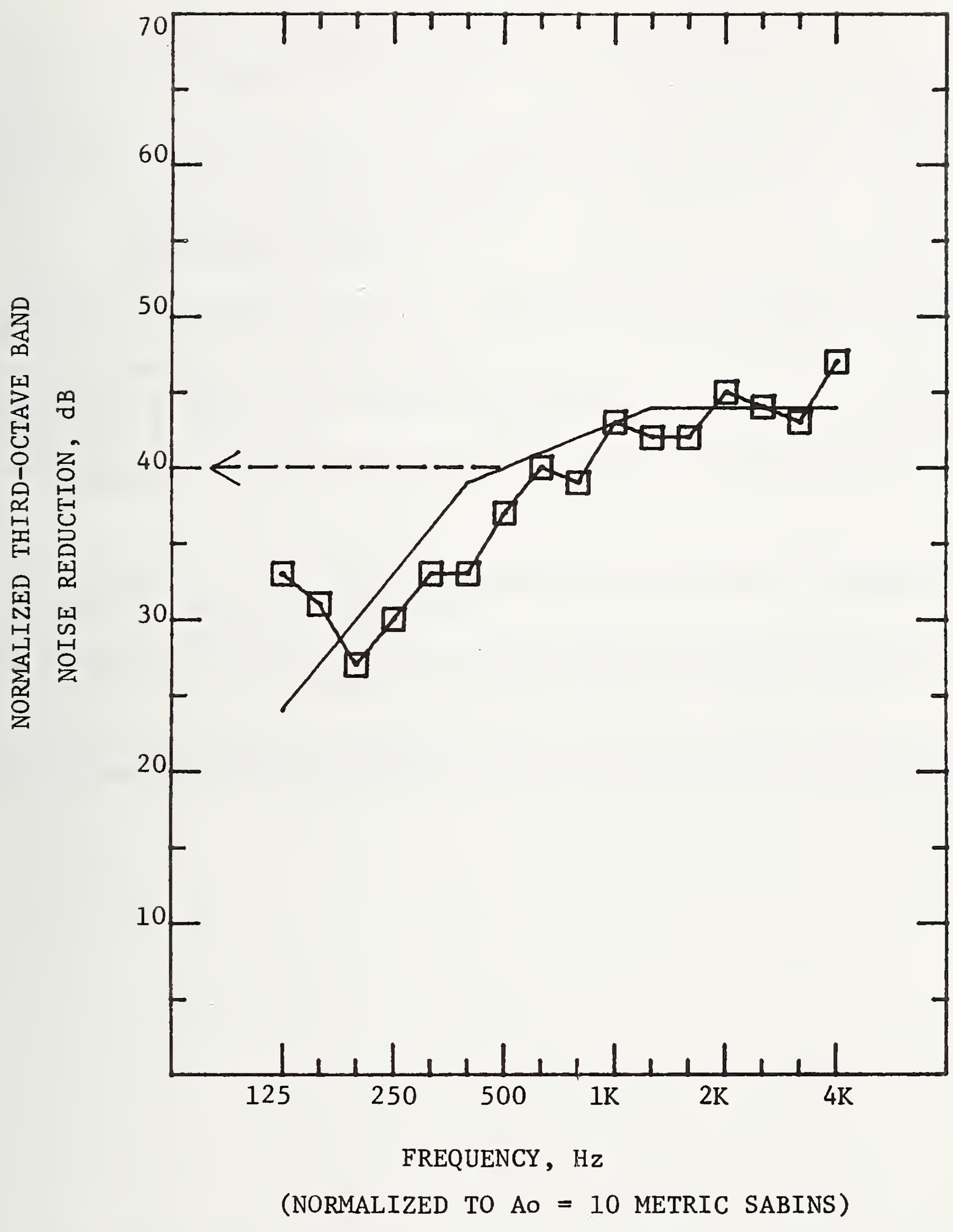

Figure 8. Normalized 1/3-Octave Band Noise Reduction Between a Front Bedroom and a Living Room Separated by an Intra-Dwelling Floor-Ceiling Assembly. Unit 13-SFA/03-14 (NIC - 40).

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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.)

The acoustical performance of a single family attached steel-frame modular housing system was tested on an Operation BREAKTHROUGH prototype site.

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17. KEY WORDS (Alphabetical order, separated by semicolons)

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