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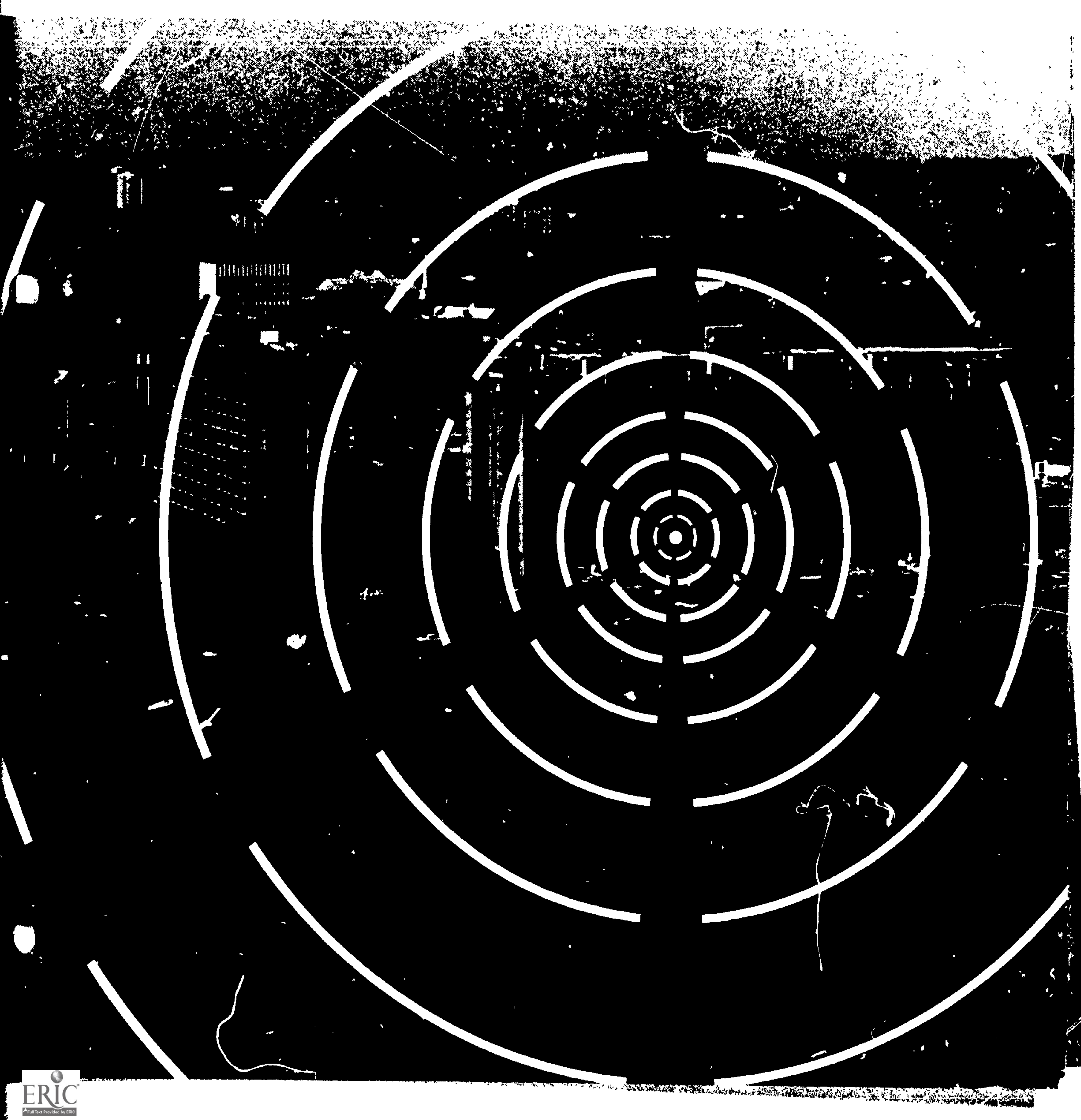
The control of noise on buildings is discussed extensively in this document, incorporating a broad range of criteria appropriate for isolating air borne, impact, and structure-borne noise associated with residential construction. Subject areas include--(1) noise types, sources, and transmission, (2) general principles of noise control, (3) principles for controlling different types of noise, (4) practical solutions to controlling building noise, and (5) development of criteria for evaluating noise control. Special details include a glossary of terminology, international sources of noise control criteria, and sound insulation data for wall and floor-ceiling construction. A bibliography is also included. Numerous drawings, diagrams and charts accompany the report. (MM)

A GUIDE TO

Airborne, Impact, and Structure Borne Noise-

Control in Multifamily Dwellings

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
Washington, D.C. 20410



A GUIDE TO

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FEDERAL HOUSING ADMINISTRATION

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FOREWORD

The Department of Housing and Urban Development is concerned with the livability of residential properties. Increasing concentration of living units in urban areas makes noise control imperative.

Through its Technical Studies Program, the Federal Housing Administration has sponsored research in this area to provide guidance toward achieving a satisfactory measure of control. This guide presents our latest research findings.

PREFACE

Under the sponsorship of the Federal Housing Administration Technical Studies Program, the National Bureau of Standards has developed and prepared this Guide for the benefit of architects, designers contractors, builders, and housing officials to assist them in meeting the growing public demand for control of the building noise problem, particularly in multifamily dwellings.

Surveys have established that the most common complaint among apartment dwellers where noise is involved is its transmission from one apartment to another within the building. Typical noise sources are television, radio, stereo, occupant activity, plumbing fixtures, electro-mechanical equipment, and household appliances. To minimize the annoying disturbance caused by these sources, architects must have a general knowledge of the principles of noise transmission and be able to apply proper design techniques in order to provide effective controls.

With these objectives in mind, this Guide incorporates a broad range of criteria appropriate for isolating airborne, impact, and structure-borne noise associated with residential construction. Sound classifications represented in the most common types of building construction are identified. Also included are summaries of a number of foreign codes now in existence.

This Guide incorporates previous impact noise research performed by Bolt Beranek and Newman and sponsored by FHA. The FHA Minimum Property Standards will reference this NBS Guide.

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TERMINOLOGY

The definitions of some terms used most frequently throughout this guide are assembled here for convenience.

ABSORBER, SOUND. A device, panel, or material specifically designed to absorb sound energy. Such devices are usually constructed of porous materials composed of organic or mineral fibers.

ACOUSTICAL DESIGN. A consideration of all factors bearing on the achievement of a desirable acous 'cal environment, including the selection of building sites, orie tation of buildings, space arrangement within buildings, and proper selection and installation of wall and floor assemblies, building equipment and services.

ACOUSTICAL PRIVACY. The assurance that there is suf .-nt insulation from intruding and disturbing noises.

ACOUSTICAL TREATMENT. The application or use of any sound absorbers, building materials or structures and construction techniques for purposes of controlling noise and improving the acoustical environment.

AIRBORNE NOISE. Noise radiated initially into and transmitted through air.

AMBIENT NOISE. The quiet-state noise level in a room or space, which is a composite of sounds from many external sources both near and far, over which one individually has no control.

ATTENUATION, SOUND. The reduction of the energy or intensity of sound.

AUDIBLE SOUND. Sound which is capable of being heard.

BACKGROUND NOISE. The sound level present in a room or space at any given time above which speech, music, desired signal or sound must be raised in order to be heard or made intelligible.

BAFFLE OR BARRIER, SOUND. A shielding structure or partition used to increase the effective length of a sound transmission path between two locations. Such structures often are constructed or surfaced with sound absorbing materials and are frequently used to seal open plenums above ceilings or below floors.

CAULK. An elastic non-setting material used for sealing cracks, seams and joints to prevent leakage of sound.

DECIBEL (dB). See "SOUND PRESSURE LEVEL".

FLANKING TRANSMISSION. The transmission of sound or noise from one room to another by indirect paths, rather than directly through an intervening partition.

FLEXIBLE COUPLER. A device to prevent or reduce the transmission of vibration, particularly between vibrating equipment and service distribution systems involving ductwork, piping and electrical lines.

FREQUENCY, SOUND. The number of complete to-and-fro vibrations that a source of sound makes in one second. Frequency is measured in Hertz (cycles per second). The pitch of an audible sound depends mostly on its frequency.

IMPACT INSULATION CLASS (IIC). A single-figure rating which provides an estimate of the impact sound insulating performance of a floor-ceiling assembly.

IMPACT NOISE. The noise produced by the impinging or striking of one object with another, e.g. noise caused by footsteps.

INERTIA BLOCK. A massive support used in isolating equipment vibration. The block is usually much heavier than the equipment it supports.

MASKING. The presence of a background noise increases the level to which a sound signal must be raised in order to be heard or distinguished. If the level of background noise is significantly higher than that of the sound signal, for instance a sound transmitted from another room, the transmitted sound signal cannot be heard. This effect is known as masking.

NOISE. Unwanted sound.

PARTY WALL. A wall which separates two adjacent dwelling units within an apartment building.

RESILIENT MOUNTING. A mounting, suspension or attachment system which reduces or restricts the transmission of vibrational energy, e.g. between vibrating elements and building structures.

RESONANCE. The sympathetic vibration, resounding or ringing of enclosures, room surfaces, panels, etc. when excited at their natural frequencies.

REVERBERATION. The persistence of sound within a room or enclosure after a sound source has stopped radiating. This effect is very pronounced in large, relatively empty or partially furnished rooms with hard reflecting walls, ceilings and floor surfaces.

SHORT CIRCUIT. A bypassing connection or transmission path which tends to nullify or reduce the sound insulating performance of a building construction or acoustical device.

SOUND. (1) The sensation of sound. (2) A branch of physics concerned with the propagation of mechanical disturbances in matter and related subjects. In the present context sound is originated by vibrating bodies or aerodynamically, is propagated as an elastic disturbance at least partly in the air, and arrives at the ear or other receiver (microphone, etc.).

SOUND INSULATION, ISOLATION. The use of building materials or constructions which will reduce or resist the transmission of sound.

SOUND LEAK. A hole, crack, or opening which permits the passage of sound.

SOUND PRESSURE. A fluctuation superimposed on the static atmospheric pressure by the passage of sound waves.

SOUND PRESSURE LEVEL (SPL). Expressed in decibels, the SPL is 20 times the logarithm to the base 10 of the ratio of the pressure of sound to the reference pressure 0.0002 dyne per square centimeter.

SOUND TRANSMISSION. The travel or propagation of sound into a room by any path, direct or indirect, from a sound source located outside the room.

SOUND TRANSMISSION CLASS (STC). A single-figure rating which provides an estimate of the airborne sound insulating performance of building partitions.

SOUND TRANSMISSION LOSS (STL). The decrease or attenuation in sound energy (expressed in decibels) of airborne sound as it passes through a building construction. In general, the transmission loss increases with frequency, i.e. the higher the frequency the greater the sound transmission loss.

STRUCTURE-BORNE SOUND. Sound energy imparted directly to and transmitted by solid materials, such as building structures.

A GUIDE TO
AIRBORNE, IMPACT AND STRUCTURE-BORNE NOISE CONTROL
IN MULTIFAMILY DWELLINGS

CHAPTER I

INTRODUCTION

A. BACKGROUND

The accelerated growth and increasing severity of the noise problem in multifamily dwellings has caused considerable concern not only among apartment occupants and owners, but also among investors, real estate interests and governmental agencies.

The current building trend toward lightweight structures, the increasing concentration of dwellings in urban areas, and the increasing noisiness of our environment have led to a growing number of complaints to the FHA of inadequate sound insulation in multifamily dwellings. People have become aware of the noise problem and are more sophisticated in their appreciation of the benefits which careful attention to noise control can provide; therefore, they expect and demand more privacy in their homes and greater freedom from the intrusion of noise from neighboring dwellings.

Although the building industry takes pride in its remarkable achievements, conventional building techniques have produced some of the noisiest buildings in existence.

Major property management firms report that noise transmission is one of the most serious problems facing managers of apartment buildings throughout the country. Managers and owners of apartments readily admit that market resistance is not only increasing as a result of excessive noise transmission, but that lack of both acoustical privacy and noise control are the greatest drawbacks to apartment living.

The basic causes of the noise problem and the major reasons for complaints are due primarily to the following factors:

1. Lightweight Building Structures: For reasons of economy and space-saving, builders are using thinner, lightweight partition walls and floor-ceiling assemblies which provide substantially less sound insulation than their more massive counterparts of the past.

2. Poor Acoustical Design: The selection of a building site, the orientation of the building structure, and the design and/or layout of interior rooms or spaces without regard to noise sources or to separation of noisy areas from those requiring privacy usually result in or intensify noise problems. Although ignorance of noise control principles is the chief cause of the above oversights, the use of good judgment in building design would avert such problems in many cases.

3. Poor Workmanship: Much too frequently the planned sound insulating performance of highly rated wall and floor assemblies is nullified by careless work by the tradesmen or building constructors. Improper sealing of large cracks, holes, and airleaks around wall and floor edges, cabinet and fixture installations, ducts, piping or conduit penetrations constitute serious sound leaks. Such leaks are frequently concealed behind thin cover plates, molding or trim work which unfortunately are

ineffective noise barriers.

4. Mechanization: The increasing use of labor-saving devices and mechanical appliances such as dishwashers, garbage disposals, vacuum cleaners, air conditioners, televisions, and stereo sets has raised the background noise level. Further, the progress in mechanization continues to outrun advances in the technology of machinery noise control.

5. High-Rise Apartments: The current trend toward construction of high-density apartment buildings has resulted in a greater concentration of people in a much smaller area. Increasing family concentration results in greater interfamily friction, unless appropriate countermeasures are taken. High population density was an important factor in the early adoption of noise control requirements in European building codes.

6. Improper Tenant Placement: Failure to place tenants properly often gives rise to noise complaints even in dwellings with adequate sound insulation.

7. Increasing Desire for Privacy: The glamour and convenience of high-rise, town-house apartments are attracting families from suburban areas in growing numbers. Many of these families, who have enjoyed the peace and quiet of living in private homes, now find the noise environment of apartment living intolerable; they expect and demand a degree of peace and privacy comparable to their former environment.

8. Inadequate Education, Training and Research: Inadequate education and research are the underlying causes of the noise problem described above. Although the problem is nationwide and as important to the economy as to the well-being of the citizens, the government has failed to conduct or to support adequate educational or research programs in acoustics and noise control.

The few acoustical laboratories supported by the government are relatively small and of limited use. In some cases they are obsolete by present standards, particularly in the field of architectural acoustics. Although some work in noise control is being conducted by the government, industries and technical universities, the total effort expended and the number of skilled scientists and technicians engaged in this work are too small.

The failure of our technical colleges and universities to provide comprehensive training in acoustics and noise control has resulted in a severe shortage of acoustical engineers. Unless such training is made widely available and required of people engaged in the manufacture of mechanical equipment and appliances, and those associated with the building industry, city planning and transportation systems, progress in overcoming the national noise problem will be very slow indeed.

The most prevalent noise complaints among apartment dwellers involve the transmission of noise originating inside the building. Typical noise sources are television, radio or stereo sets, occupant activity, plumbing fixtures, electro-mechanical equipment and household appliances, as illustrated in Figure 1.1.

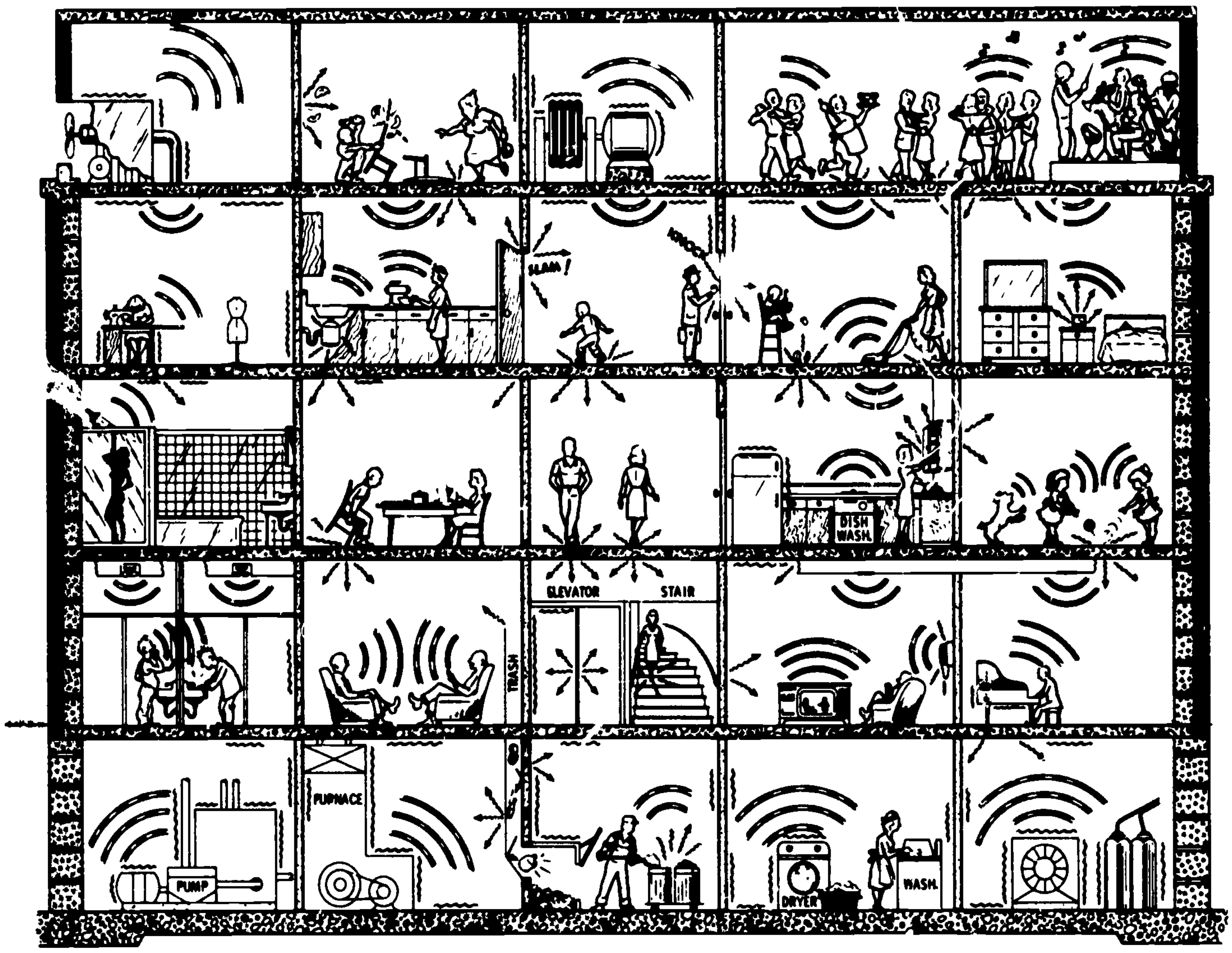


Fig. 1.1. Common Indoor Sources of Noise.

Surprisingly, the frequency of complaints appears to be independent of income bracket in virtually all types of apartment buildings, including high-rise as well as low-story garden-type apartments. Luxury, middle and low income apartments register approximately the same number of complaints because most of the buildings utilize the same type of wall and floor assemblies. This fact clearly demonstrates that builders and architects do not consider privacy and quiet surroundings as necessities, much less luxuries.

The causes of most noise problems in multifamily dwellings originate in the early design stages of the buildings because of the architect's lack of concern about noise problems and his failure to foresee where and under what circumstances noise might be a problem.

Most people will agree that what pleases one's senses enhances one's comfort. Oddly enough, a peaceful and relaxing environment apparently is not recognized as essential to comfort, judging from the fact that it is lacking in a high percentage of buildings. Obviously, we are approaching the time when architects must pay adequate attention to acoustical problems.

B. COST OF SOUND INSULATION

The owner of an apartment development is in a highly competitive market; cost largely determines the amount of sound insulation or noise control that he can install. Unfortunately, there is relatively little reliable information on which to base an estimate of the additional cost involved in constructing buildings with adequate sound insulation. However, some estimates indicate that the additional expenses for the acoustical design and treatment of new buildings might range from 2% to 10% of the total cost of the building, depending on geographic area, labor market and other economic factors.

While many architects and builders might consider such cost much too high, they should recall that their predecessors voiced the same criticism relative to central heating and air conditioning. Despite their high costs, central heating and air conditioning are considered to be necessities not only in office buildings but in homes and indeed automobiles as well. Judging from the increasing public demand for immediate legislation for the adoption and enforcement of anti-noise ordinances and sound insulation criteria, particularly in multifamily dwellings, sound insulated buildings are now regarded as a necessity for which the public is willing to pay a premium.

One point which can not be overemphasized is that a substantial degree of sound insulation can be purchased at relatively little cost through good planning and design, as discussed in Chapter 5. Proper selection of building site, building orientation and equipment, and careful design of space layout contribute substantially toward achieving good sound insulation at little cost.

Although sound insulating construction will add to building costs, the expenses of correcting acoustical mistakes usually are several-fold higher. In some instances, there may be no solution short of major, extensive and prohibitively costly overhaul of the building interior, for example, redesign and installation of heating and air-conditioning systems and/or partition wall and floor assemblies.

Perhaps the highest price that an architect, builder, investor or owner might pay for an acoustically inferior building is expressed in terms of loss of reputation and public confidence and loss of profit for all parties concerned.

C. FHA's CONCERN

Through the development and preparation of this Guide, FHA has taken the initiative in providing architects, designers, contractors, builders and public housing officials with needed assistance in meeting the growing public demand for control of the entire building noise problem, particularly with respect to multifamily dwellings.

The problem is primarily one of noise transmission from one apartment unit to another within the same building, although the problem of intruding noise from outdoor sources such as aircraft and traffic can by no means be dismissed as trivial. If a certain measure of success is to be achieved in reducing the noise transmission in buildings, the problem must be approached methodically. A general knowledge of the principles of noise transmission and methods of control should enable one to deal with most noise problems which come his way.

CHAPTER 2

GENERAL PRINCIPLES OF SOUND TRANSMISSION

Generally speaking, sound is generated by vibrating bodies. More specifically, it is the result of vibration of the particles of some elastic medium or substance, which may be solid or fluid. When the particles are disturbed or displaced by some vibratory force or impulse they collide with the particles adjacent to them, which in turn transmit motion to other particles. Although the individual vibrating particles do not change their average positions of equilibrium, the vibratory displacement of the particles is sufficient to cause contact with surrounding particles. In this manner the disturbance may be propagated rapidly in many directions and over great distances in the medium and adjoining media. A good illustration of this effect is the manner in which the impulse from a cue ball is transmitted through a closely-packed straight line of billiard balls, from one end to the other. Another example is the manner in which the starting jerk of a railroad train progresses successively from the first car to the last.

Vibratory transmission of this type may occur in any elastic medium or substance, whether it is solid such as wood, metal, soil, masonry, or a fluid like air or water. Because such materials possess sufficient elasticity (the property of promptly recovering original dimensions upon unloading) they are prone to vibratory excitation. Most building materials are sufficiently elastic to transmit vibrations readily and therefore are poor insulators of sound. Limp materials like soft putty, lead, leather or fabrics, on the other hand, are poor conductors of vibration because their elasticity is low.

The vibration of a building structure may be caused easily by the operation of equipment producing any one or a combination of the following types of motion.

(a) Rotation; e.g., motors, fans, blowers, gear trains.
(b) Reciprocation; e.g., pumps, agitators, piston engines, compressors.
(c) Expansion and contraction; e.g., heating and plumbing, duct and pipe systems.
(d) Turbulence; e.g., pressure fluctuations or disturbances caused by the flow of air or water in ventilation, heating and plumbing systems.
(e) Oscillation or pulsation; e.g., loudspeakers, musical instruments, vibrators.
(f) Impaction and Detonation; e.g., door slams, falling objects, sonic booms, thunder, furnace ignition.

Frequently, several types of motion may be involved in the generation of noise. For example, in a plumbing system a combination of motor and pump vibration along with water turbulence may excite supporting wall structures into vibration, which in turn radiate noise.

The vibration of the wall or the sound pressure fluctuations in the air can be easily measured, recorded and displayed by sensitive equipment involving microphones, vibration pickups, sound level meters, recorders and oscilloscopes. Observations using such instrumentation are usually described as being objective since they reveal or attempt to measure some physical property or characteristic of the sound or vibration, such as its frequency, amplitude of vibration, intensity and sound pressure.

In addition to a basic understanding of how sound or vibration is propagated in a material, a better knowledge of the other properties of sound and its transmission characteristics, especially in air, is required before one can cope successfully with the problems of noise control. Some of the more important facts to remember are:

1. A sound wave in open air travels radially in all directions at a speed of approximately 1100 feet per second, with a wave front that is usually spherical in shape.
2. The intensity of a sound wave in open air falls off inversely as the square of the distance from a point source, i.e. there is a drop of about 6 dB with each doubling of the distance from the source.
3. In hard-surfaced unfurnished rooms, ordinary sound may build up to annoying levels and may be distorted by excessive reverberation due to the multiple reflections of the sound waves. For this reason, noise from conversation and foot traffic in reverberant hallways is much louder than in open areas outside of the building.
4. Airborne sound penetrates more readily through light porous materials and lightweight structures than through heavy, massive masonry materials or structures.
5. The direction of propagation of a sound wave may by changed by reflection from wall or other building surfaces. This explains why noise is often transmitted great distances in long winding corridors or duct systems.
6. Sound travels easily through small cracks and openings such as those normally found under doors and around windows.
7. Mechanical energy from an impacting body or a vibrating source, which is imparted directly to a solid structure, travels at a higher speed, with less attenuation and generally over a much longer distance than an airborne sound wave of the same initial energy. For example, in water the speed of sound is about 5000 feet per second, while in materials such as wood, metal or stone, the speed of sound may be as high as 12,000 to 20,000 feet per second.
8. The attenuation of sound with distance in solid materials is surprisingly low. In wood, for example, the rate of attenuation may be as low as 1 dB per 100 feet and for certain metals as low as 1 dB per 3,000 feet. Ordinarily, the attenuation of sound in actual building structures is usually much higher because of discontinuities in construction, divergent transmission paths and the mechanical coupling of building materials with different densities, weights, stiffnesses or other physical properties.
9. Generally speaking, for any given type of construction, the heavier or more massive the wall or floor structure, the better its sound insulation.
10. As a rule of thumb, most wall and floor structures are much better sound insulators at the higher frequencies than at the lower frequencies.

Along with a basic knowledge of the principles of sound generation and propagation, the architect and builder should have a general understanding of the subjective or human response to noise. From a psychological point of view, it is most natural for people to feel quite comfortable in an environment with a low level, soothing, steady, unobtrusive sort of ambient noise, which is typical of the natural undisturbed environment. On the other hand, a complete absence of noise, a state approaching the deathlike stillness of a tomb, may be as disturbing, unnerving and oppressive to most people as the shriek of a fire siren, the squeal of brakes or the blare of an automobile horn. Although these limits are rather extreme, the important point is that most people prefer some noise as opposed to not enough noise or too much noise. Hence, the acoustical design objective at which the architect should aim is one which approaches the natural noise environment such as found along secluded beaches, forests or quiet countrysides.

A person's reaction to noise may vary from day to day, depending primarily upon his immediate state of mind, disposition, temperament, health or activities and the type, quality and intensity of the noise. Under normal circumstances most people find that:

(a) high pitched noises are more disturbing than noises of lower pitch; the normal human ear generally responds to sounds in the frequency range from 20 to 20,000 Hz, approximately,
(b) the louder the noise the more likely it is to be disturbing,
(c) intermittent, irregular, impulsive or impact noises are more distracting than a steady-state noise,
(d) the longer the time of one's exposure to a disturbing noise the more irritating it becomes.

Most people will describe changes in sound pressure levels along the following lines:

A 3 dB increase in level is barely perceptible, a 5 dB gain is quite noticeable, whereas a rise of 10 dB is described as being dramatic or about twice as loud.

CHAPTER 3

CLASSIFICATION OF NOISE

Generally speaking, building noise may be classified according to its origin, as either airborne, structure-borne or a combination of both. Under certain circumstances, airborne noise may produce structure-borne noise which in turn may be reradiated again as airborne noise. Both types of noise cause pressure fluctuations in the surrounding air which are perceived by the ear as sound. Other than by positive identification of a sound, e.g. piano playing and speech or the detection of vibrating floors or rattling windows, the ear cannot easily differentiate between noises of airborne and structure-borne origin.

Airborne Noise.

Most of us are quite familiar with airborne noise since we are exposed to it day by day. It is exemplified by the drone of the aircraft flying overhead, the blare of an auto horn, the voices of children or the music from our stereo sets. In short, it is the noise produced by a source which radiates directly into the air. Airborne sound waves are transmitted simply as pressure fluctuations in the open air or along continuous air passages such as corridors and duct systems. If a barrier such as a wall is in the path of the airborne sound wave, the action of the fluctuating sound pressure against one side of the wall causes it to vibrate. Thus the sound is transmitted to the other side of the wall from which it is reradiated as airborne sound waves. Some of the vibrational energy of the wall is transmitted structurally to other parts of the building where it eventually emerges as airborne sound. The wall itself becomes a secondary radiator of airborne sound and a transmitter of structure-borne sound. Although structure-borne sound transmission may be involved in this process, the entire sound transmission sequence would be classified as airborne simply because the initial sound was airborne. The disturbing influences of airborne noise generally are limited to the areas near the source. This is due to the fact that airborne noises usually are of much smaller power and are more easily attenuated than structure-borne noises. For example, the sound from your neighbor's stereo system may cause annoyance in rooms of your apartment which are adjacent to his, but rarely in rooms farther removed unless doors or passage ways are open. Sound absorptive treatment in the form of carpeting, drapery and upholstered furniture in the intervening areas may often provide a significant reduction in the disturbing noise level before it reaches rooms where privacy is desired.

Structure-Borne Noise.

Structure-borne noise occurs when wall, floor or other building elements are set into vibratory motion by direct mechanical contact with vibrating sources such as mechanical equipment or domestic appliances. This mechanical energy is transmitted throughout the building structure to other wall and floor assemblies with large surface areas, which in turn are forced into vibration. These vibrating surfaces, which behave somewhat like the soundboard of a piano, reradiate the vibrational energy as airborne noise into adjacent areas.

The intensity of structure-borne noise generally is much higher than that produced by a wall or floor structure which has been excited by an airborne sound wave. Unlike sound propagated in air, the vibrations are transmitted rapidly with very little attenuation over long distances throughout the building structures. Quite frequently these vibrations are short in duration, as those caused by slamming doors and falling objects. Other vibratory motions may persist for long periods, as those associated with the operation of air conditioners or washing machines. The operation of such mechanical equipment may set wall and floor structures into intense low frequency vibration, which is physically felt or sensed as a pulsating, throbbing or quivering motion. Poorly balanced fans, motors, compressors, disposals or washing machine tumblers frequently give rise to a periodic or vibratory motion of this kind. If the vibration is severe enough it may have adverse effects not only on the occupants of a building but also on the building structure as well. In such instances, occupants may become not only extremely annoyed with walking or standing on vibrating floors but also fearful of damage to or failure of structural components of the building. In less severe cases, the vibration may manifest itself in the rattling of dishes, bric-a-brac, window panes or pictures. Occupants of homes and apartments frequently experience this sort of vibration as large heavily loaded trucks are driven past their dwellings.

It might be well to consider briefly the so-called "sounding board effect", a reinforcement or amplification of sound, which so frequently is involved in the radiation of structure-borne noise. Generally speaking, the efficiency of a sound radiator varies directly with the ratio of its surface area dimensions to the wavelength of sound. A sound source with a small radiating surface, such as a water pipe, produces relatively little airborne sound; but on the other hand, it will radiate higher frequency sounds more efficiently than lower frequency sounds, all other factors being equal. If a small vibrating source, which by itself radiates little airborne noise, is rigidly or mechanically coupled to a large surface such as plywood or gypsum wall panel, the intensity or volume of sound will be substantially reinforced or amplified. A piano provides a better illustration of this effect. If we were to remove the soundboard of a piano, the sound generated by the vibrating strings would be almost inaudible, because of the small radiating surface areas of the strings. The sound produced by the vibrating strings is amplified by virtue of their bearing upon the bridge attached to the soundboard which has a large radiating surface. Thus we see that decoupling vibrating sources from potential soundboards such as wall or floor surfaces, can be quite effective in the control of structure-borne noise.

Combination of Airborne and Structure-Borne Noise.

A third type of noise source to be considered is one which generates both airborne and structure-borne noise simultaneously. This type of noise source is by far the most common, and perhaps the only type of source to be found. Sources, which are usually considered to be strictly airborne noise generators, may generate a substantial amount of structure-borne noise and vibration, if they are mechanically coupled to wall and floor structures. For example, a high-power loudspeaker built into a wall enclosure might cause not only the wall to vibrate but perhaps the rafters as well. Every noise source has vibrating elements which radiate noise. A window air conditioner, for example, suspended in mid-air would produce a substantial amount of airborne noise; however, when the unit is mounted in a conventional manner, a combination of both structure-borne and airborne noise of greater intensity is produced. Occasionally, a noise source may produce vibrations so low in frequency that they can be felt but not heard. In some instances, such a source may induce a wall or floor structure to resonate at its own natural frequency, which may be in the audible range. Thus, the low frequency drone of a passing airplane may cause a wall or window to resonate at a higher frequency than that radiated by the plane itself.

CHAPTER 4

FLANKING TRANSMISSION OF AIRBORNE AND STRUCTURE-BORNE NOISE

The transmission of noise from one completely enclosed room to an adjoining room separated by a continuous intervening partition wall may be either direct transmission through that wall or indirect transmission through other walls, ceilings and floors common to both rooms or through corridors adjacent to such rooms. This noise transmission by indirect paths is known as "flanking transmission". Quite frequently one is faced with a noise transmission problem which involves a combination of both direct and indirect transmission paths, where the latter may be the more serious offender. Such indirect or flanking transmission commonly occurs with structure-borne as well as airborne noise.

Airborne Flanking Noise.

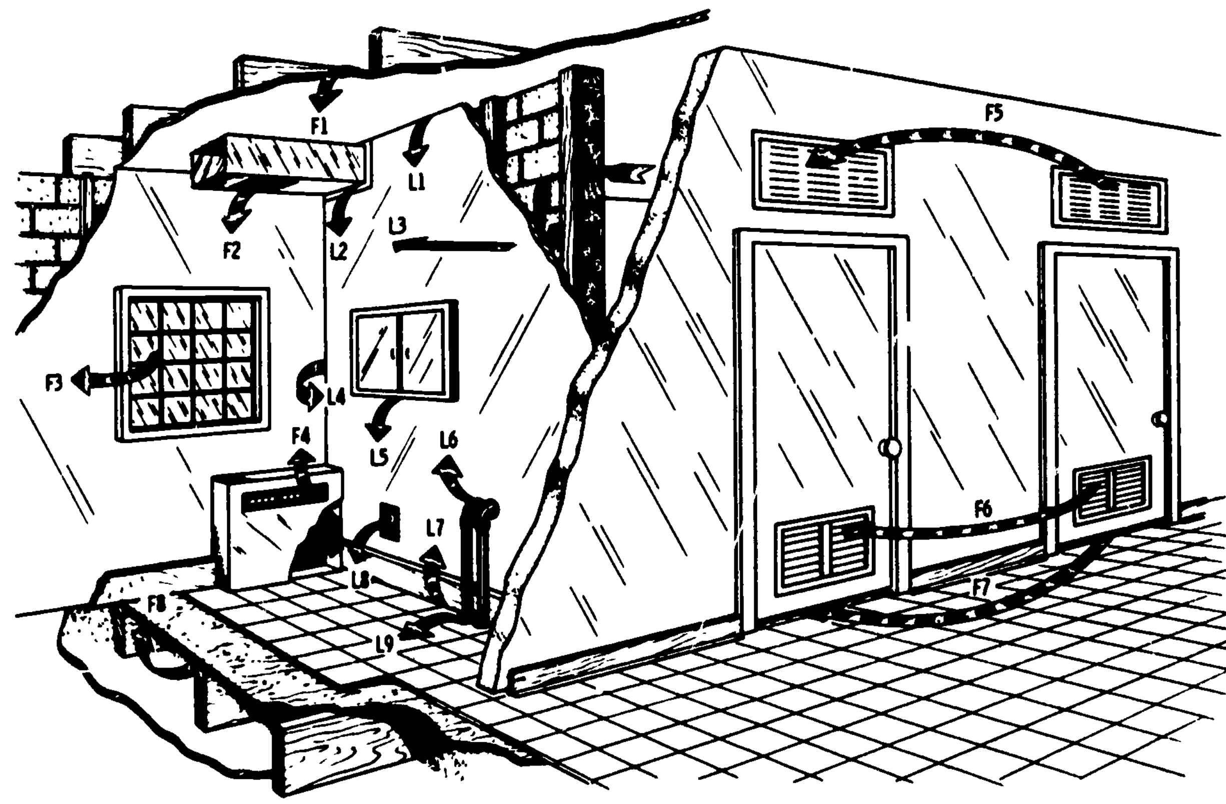
The chief flanking transmission paths of airborne noise between two adjacent rooms usually involve: common corridors, ventilation grilles, duct systems, open ceiling plenums which span both rooms, louvered doors and close spacing of windows between rooms. In addition to the flanking paths, there may be noise leaks particularly along the ceiling, floor and side wall edges of the partition wall. Also, noise leaks may occur frequently around pipe and conduit penetrations, back-to-back installations of cabinets and electrical outlets in the partition wall. Imperfect workmanship may result in serious noise leaks, e.g. poor mortar joints in masonry core-walls which often are concealed behind furred walls, panels or built-in cabinets.

Obviously, it is not economical to select highly efficient sound insulating partition walls and later inadvertently short circuit their efficiency with noise leaks and flanking paths, as illustrated in Figure 4.1. Such noise problems can be prevented by thoughtful planning in the early stage of the building design and close supervision with proper attention to small details during the construction stage.

Structure-Borne Flanking Noise.

Flanking transmission paths of structure-borne noises, as illustrated in Figure 4.2, are far more numerous and much more difficult to trace or detect than those of airborne noises. The detection, cause and correction of structure-borne vibration or noise transmission between adjacent rooms are relatively simple. However, determining the reasons for excessively high noise or vibration levels in rooms far removed from noise sources can be difficult and vexing.

Noise and vibration producing equipment such as fans, compressors, pumps, ventilation and plumbing systems readily communicate their vibrational energy to the building structure if no precautionary measures are taken. The vibration travels quickly over long distances through the skeletal building structure with no appreciable attenuation, especially when the vibrating source or equipment is rigidly attached to the structure by improper mounting of the source or incorrect installation of piping, conduits or associated distribution lines.



FLANKING NOISE PATHS

F1 OPEN PLENUMS OVER WALLS, FALSE CEILINGS
F2 UNBAFFLED DUCT RUNS
F3 OUTDOOR PATH, WINDOW TO WINDOW
F4 CONTINUOUS UNBAFFLED INDUCTOR UNITS
F5 HALL PATH, OPEN VENTS
F6 HALL PATH, LOUVERED DOORS
F7 HALL PATH, OPENINGS UNDER DOORS
F8 OPEN TROUGHS IN FLOOR-CEILING STRUCTURE

NOISE LEAKS

L1 POOR SEAL AT CEILING EDGES
L2 POOR SEAL AROUND DUCT PENETRATIONS
L3 POOR MORTAR JOINTS, POROUS MASONRY BLK
L4 POOR SEAL AT SIDEWALL, FILLER PANEL ETC.
L5 BACK TO BACK CABINETS, POOR WORKMANSHIP
L6 HOLES, GAPS AT WALL PENETRATIONS
L7 POOR SEAL AT FLOOR EDGES
L8 BACK TO BACK ELECTRICAL OUTLETS
L9 HOLES, GAPS AT FLOOR PENETRATIONS

OTHER POINTS TO CONSIDER, RE: LEAKS ARE (A) BATTEN STRIP A/O POST CONNECTIONS OF PREFABRICATED WALLS, (B) UNDER FLOOR PIPE OR SERVICE CHASES, (C) RECESSED, SPANNING LIGHT FIXTURES, (D) CEILING & FLOOR COVER PLATES OF MOVABLE WALLS, (E) UNSUPPORTED A/O UNBACKED WALL BOARD JOINTS (F) EDGES & BACKING OF BUILT-IN CABINETS & APPLIANCES, (G) PREFABRICATED, HOLLOW METAL, EXTERIOR CURTAIN WALLS.

Fig. 4.1. Flanking Transmission of Airborne Noise.

Obviously, the primary flanking path of structure-borne noise or vibration is the skeletal building structure, i.e. the external and load-bearing walls as well as other structural supporting columns. The vibrational energy in the skeletal frame is transmitted to all other wall and floor constructions which in turn become the secondary flanking paths. While this might logically define the overall flanking transmission path, the difficulty in resolving a vibrational problem arises in determining the specific flanking paths and identifying the operating equipment at fault.

Interruption of the flanking path with some form of discontinuous structure or decoupling technique is the only effective way to reduce vibratory transmission. Discontinuous construction of load-bearing walls and structural floors is difficult to achieve in practice, because such structures require support, and as a consequence the discontinuity fails or is short-circuited at the points of support. However, certain construction techniques can be applied which provide an effective degree of discontinuity as well as the required structural support. Such techniques are discussed and illustrated in subsequent chapters.

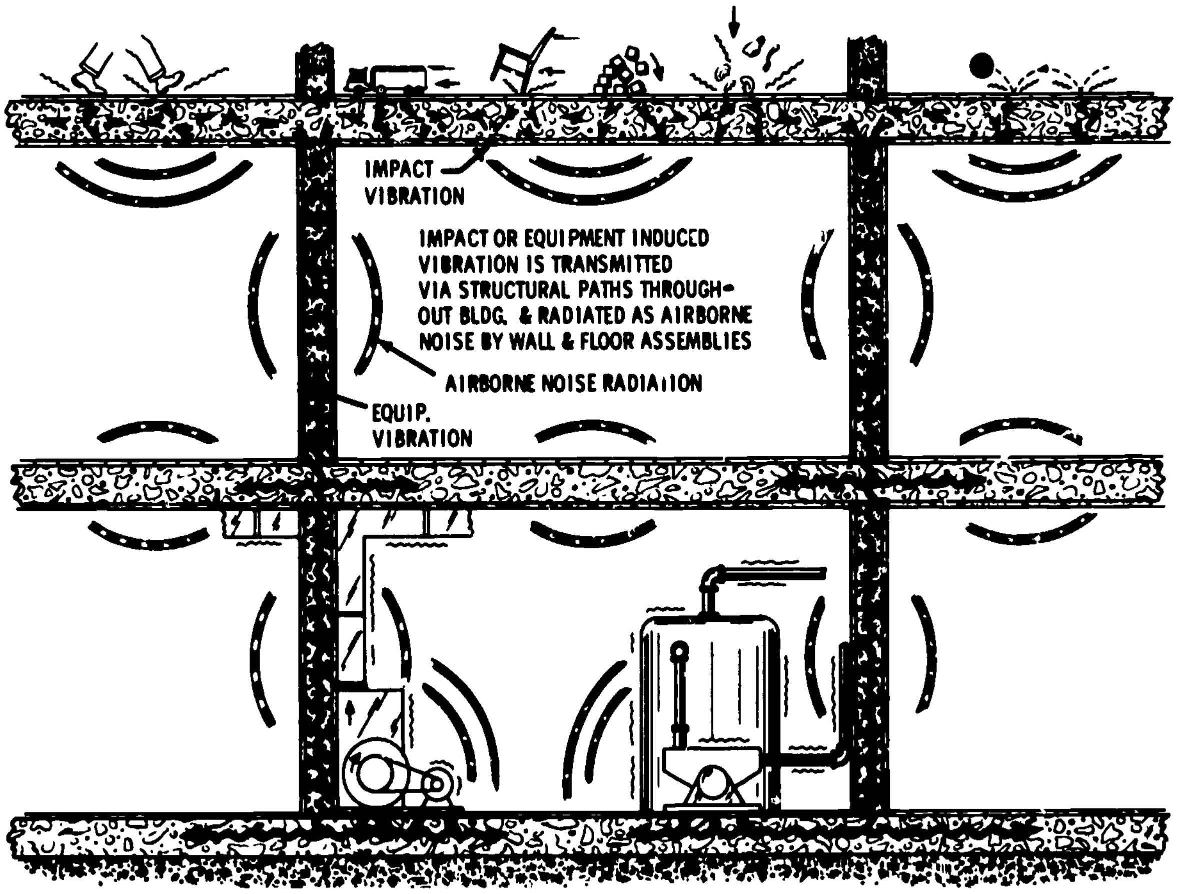


Fig. 4.2. Flanking Transmission of Impact and Structure-Borne Noise.

CHAPTER 5

GENERAL PRINCIPLES OF NOISE CONTROL

The most effective approach to the problem of ensuring that a ilding will have adequate noise control begins with a careful and ethodical consideration of all the acoustical design elements during le early planning stage of the building. The important design elements lat the architect should consider are listed and discussed below. For ovious reasons, the first factors that should be considered are the election of a quiet building site and the proper orientation of the ilding on the site in an attempt to alleviate the problem of outdoor oise disturbance.

A. Selection of Site
B. Orientation of Building on Site
C. Room and Space Arrangement
D. Tenant Placement
E. Building Equipment
F. Control of Noise at the Source
G. Selection of Sound Insulating Structures
H. Sound Absorption
I. Education and Training
J. Supervision
K. Pretesting

. SELECTION OF SITE

1. Zoning and city planning authorities should be consulted for ssurance that the building site has and will retain a residential rating. s a result of future rezoning or other civil planning action, suitable ites are frequently engulfed by industrial park areas, traffic arteries r aircraft flight patterns.

2. A detailed study of the building site should be made, partic- larly with respect to the location of potential sources of noise, such s airfields, industrial plants, railroads and traffic arteries. Noise urveys should be made on the proposed building site located near such oise sources in order to evaluate the noise environment. Sites near arge commercial or military airfields should be avoided completely.

3. Sites which have good natural landscaping, such as rolling errain with a good stand of trees, generally provide more acoustical hielding than sites located in hollows or on flat open ground, as llustrated in Figures 5.1 through 5.4.

4. Avoid selecting a building site which is directly opposite a arge existing or proposed building, especially if an expressway sepa- ates the sites. The reflections of sound waves between opposing build- ngs generally increase the noise levels, as illustrated in Figure 5.5.

5. Building sites near hills or junctions of main traffic arteries re particularly noisy, due to accelerating, decelerating and braking ehicles, as shown in Figures 5.6 and 5.7. If the road happens to be a ain truck route, the noise may become intolerable.

6. If a building must be erected near a busy street or other source f noise, a site which is acoustically shielded by buildings or other arriers is to be preferred. See Figures 5.8 and 5.9.

7. In selecting building sites located near expressways, preference hould be given to those sites on the upwind or windward side of the xpressway as opposed to the leeward side. At a large distance from a oise source the upwind side generally is quieter than the downwind side. See Figure 5.10.

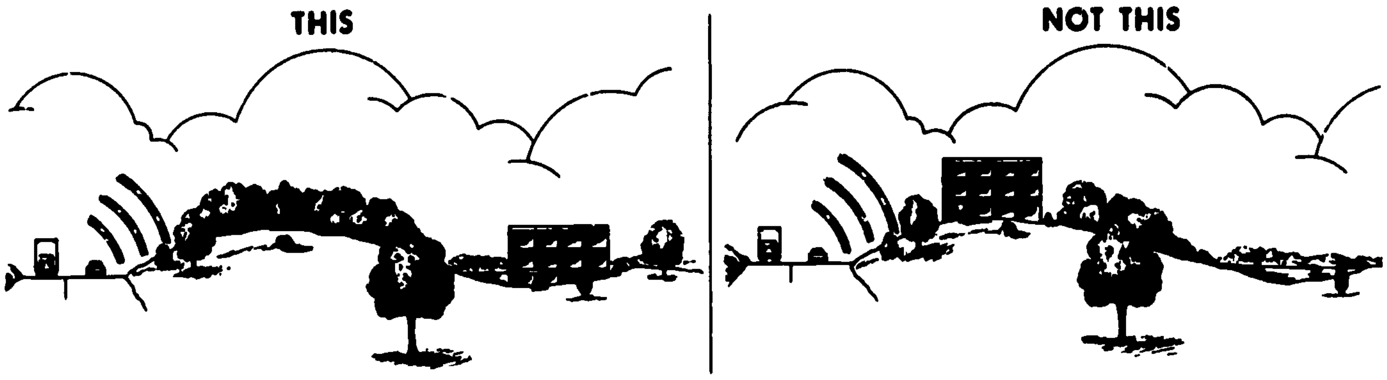


Fig. 5.1. Use of Natural Noise Barriers.

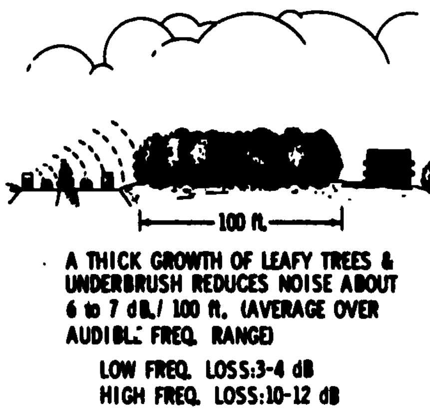


Fig. 5.2. Effectiveness of Wooded Areas as Noise Barriers.

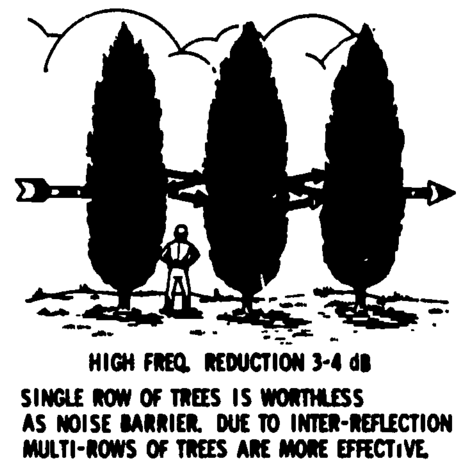


Fig. 5.3. Noise Reduction of Trees.

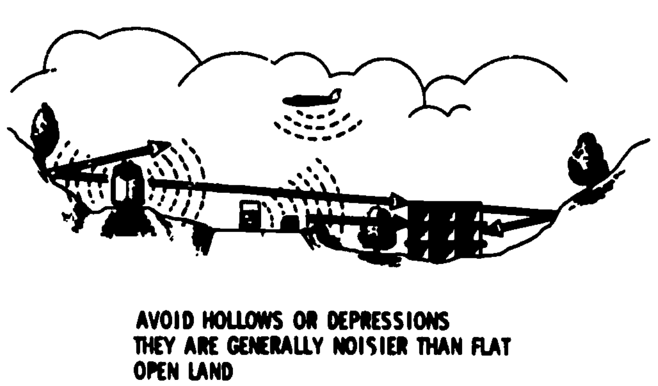


Fig. 5.4. An Example of a Poor Building Site.

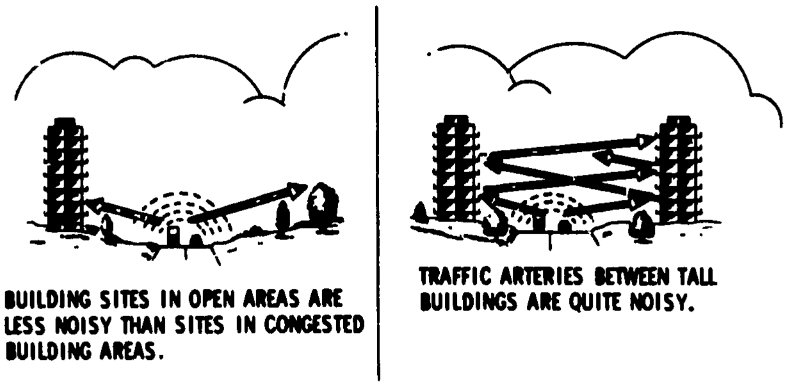


Fig. 5.5. Building Sites near Traffic Arteries and other Buildings.

Fig. 5.6. Building Sites near Traffic Junctions.

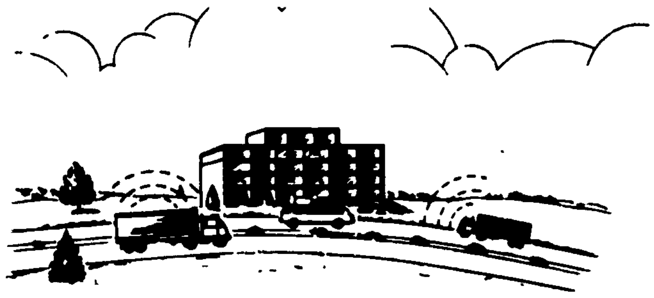


Fig. 5.7. Building Sites near Hilly Traffic Areas.

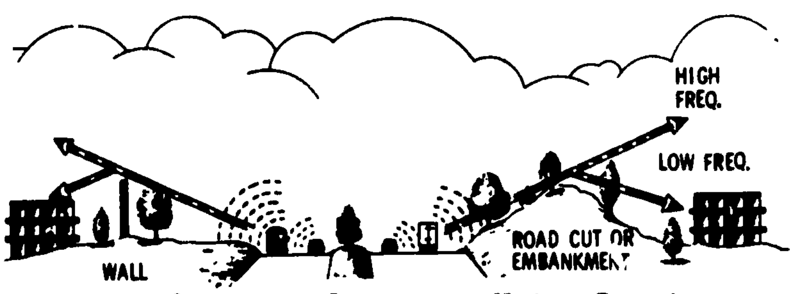


Fig. 5.8. Use of Various Noise Barriers.

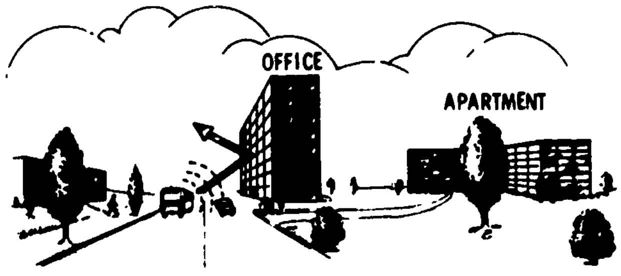


Fig. 5.9. Use of Buildings as Noise Barriers.

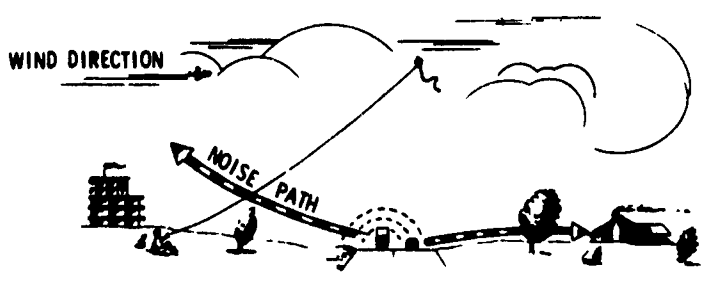


Fig. 5.10. Selection of Building Sites Relative to Wind Direction.

B. ORIENTATION OF BUILDING ON SITE

1. Buildings should be located so as to take full advantage of any acoustical shielding provided by the existing terrain, natural landscaping or wooded areas of the building site.

2. Buildings should be located as far as possible from the source of greatest noise.

3. In large apartment developments, buildings should be arranged so that as many dwelling units as possible are shielded from highway traffic noise or other sources of noise. See Figure 5.11, B and C.

4. On a building site which fronts on an expressway, the building should be oriented so that the long axis of the building is perpendicular to the expressway.

5. If a cluster of buildings is to be erected on a site, a random, splayed or staggered building layout should be adopted, preferably with no buildings parallel to each other. In such instances thoughtful design and layout of curved buildings may be beneficial. See Figure 5.11, C, D and F.

6. In a large apartment development, access roads must be carefully designed and arranged to prevent formation of a main traffic artery through the development.

7. In U shaped buildings, the court areas tend to be quite reverberant and noisy, particularly if they are used as recreation areas or face traffic arteries. Therefore, such buildings should be oriented judiciously, as illustrated in Figure 5.11, A and E.

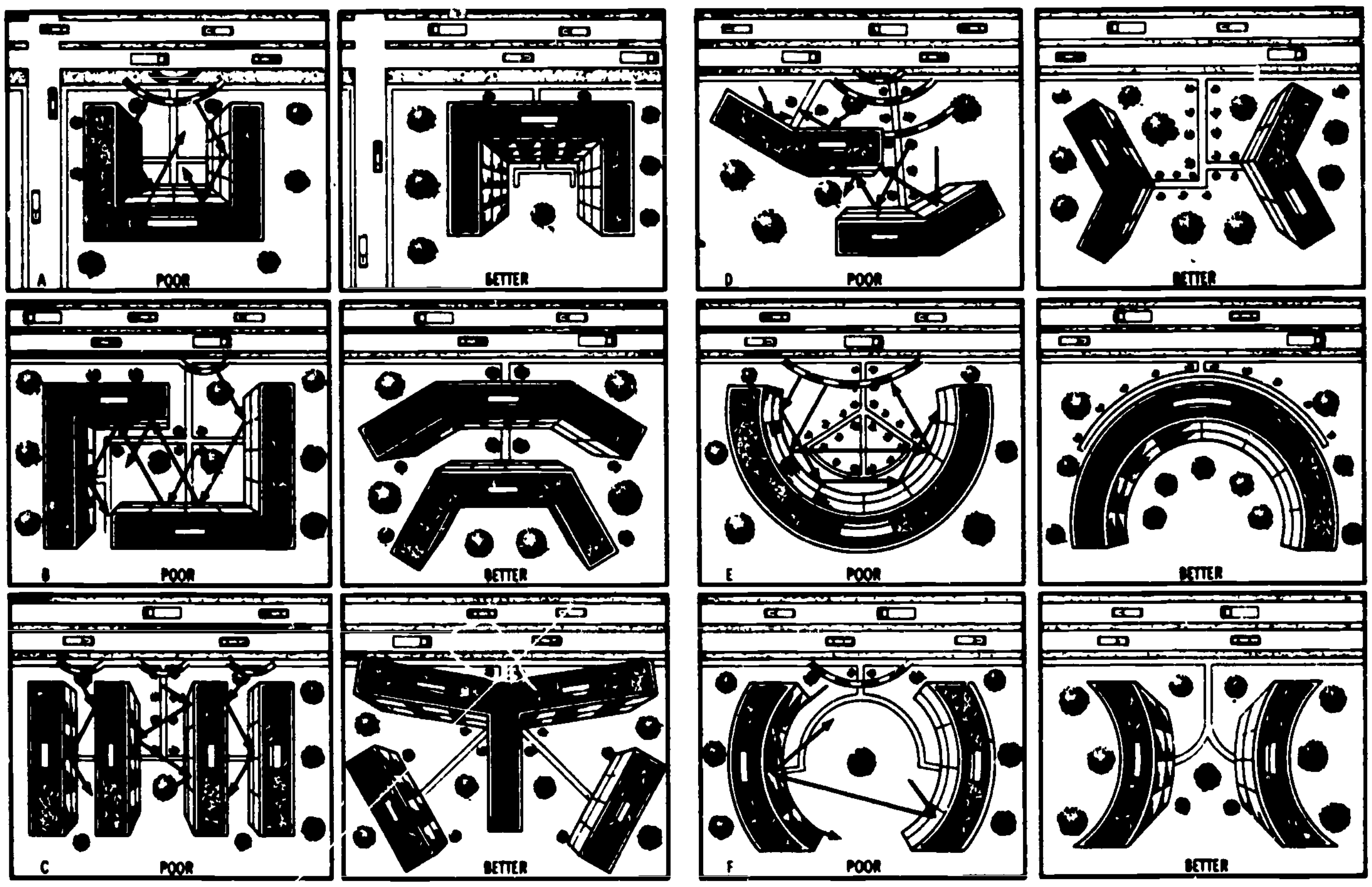


Fig. 5.11. Orientation of Buildings on Sites.

C. ROOM AND SPACE ARRANGEMENT

1. Since most buildings are barriers to external noise they may have a noisy side and a quiet side. Noisy areas such as equipment rooms, recreation rooms and kitchens should be located on the noisy side of the building.

2. Obviously it is good practice to locate noise producing areas such as garages, elevators, equipment and laundry rooms at one end of the building far removed from dwelling areas, rather than in some central location which is often chosen for accessibility.

3. Within individual dwelling units, areas which are likely to be noisy should be as far as possible from those that require quiet.

4. The room layout of adjacent dwelling units should be planned so that the party walls and floors separate similar functional spaces. For example, partition walls and floors between dwelling units should separate the bedrooms of one dwelling from the bedrooms of the other dwelling, rather than separate a bedroom of one dwelling from the living room or recreation room of the adjacent apartment. This may be achieved by using a mirror-image layout on a given floor level and a projected image of the first floor plan on all other floor levels, i.e. rooms of similar use should be stacked one above another in the vertical direction.

5. In the construction of two-story garden-type apartments, it is advantageous to use the town-house or row-house design concept where the bedrooms of each dwelling unit are located on the upper floor. This practice largely circumvents the problem of impact noise transmission through floor structures, which is so commonly found in multistory apartments.

6. In situations requiring the separation of relatively noisy areas from quiet areas, the use of buffer zones such as hallways, dressing rooms and closets with solid-core doors is recommended. The additional air space, enclosing walls and doors of such spaces provide a substantial increase in sound insulation.

Two apartment plans employing the above principles are illustrated in Figure 5.12.

D. TENANT PLACEMENT

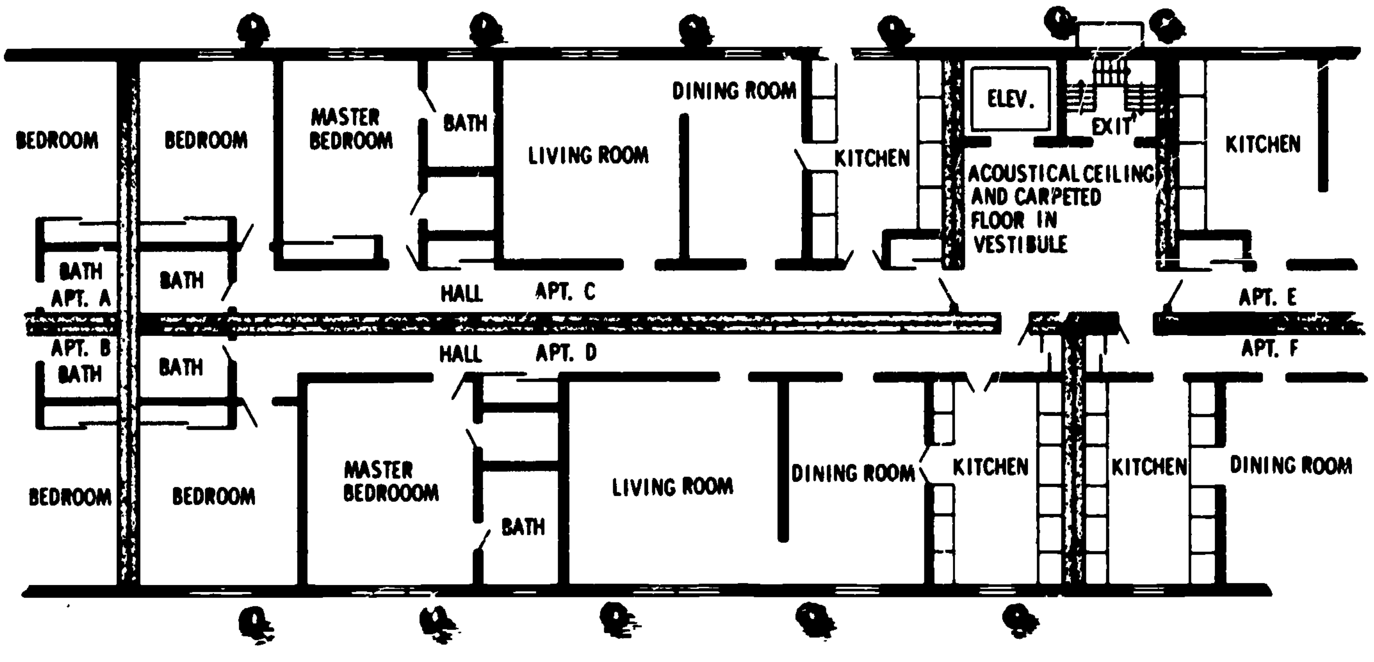
Failure to place tenants properly often gives rise to noise complaints even in dwellings with adequate sound insulation. An intelligent landlord selects and places tenants on the basis of age group, working hours, family size and other similar factors so that tenants with similar living habits are grouped together. Two and three bedroom apartment units should be located adjacent to, or stacked directly above apartment units with the same number of bedrooms. For example, avoid locating a three bedroom unit, which might be occupied by a large family, above a one bedroom unit occupied by a retired couple. This arrangement would be likely to present some noise problems. Consequently, single bedroom units should be located at one end of the building and multiple bedroom units at the other end; or one bedroom units should be located on the upper floors of the building and multiple bedroom units on the lower floors.

E. BUILDING EQUIPMENT

The prevention or reduction of noise transmission from the electromechanical equipment of a building is dependent primarily on all three of the following factors.

1. Proper selection: If there is a choice of several types or models of building equipment which meet the particular service needs or the building requirements, the architect or engineer should select the equipment with the lowest sound power output rating provided by the manufacturers. If such ratings are not available, the architect should make inquiries concerning the noise output of such equipment and, if possible, investigate installations in which such equipment is

operational to evaluate the noise radiation. Sound conditioned equipment is somewhat more expensive, but the acoustical treatment required to correct problems resulting from noisy equipment invariably turns out to be far more costly than an initially quiet installation.



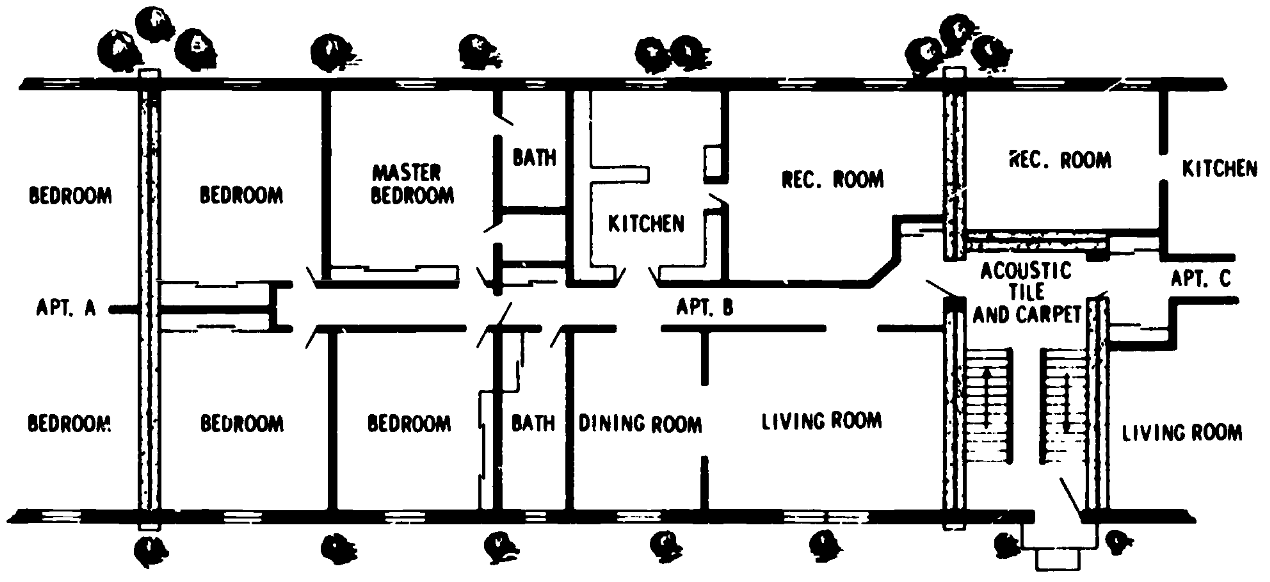


Fig. 5.12. Examples of Well-Planned Buildings in which Quiet Areas are Separated from Noisy Areas.

2. Proper location: Unfortunately, the use of sound conditioned equipment, though necessary, is not sufficient to avert all potential noise transmission problems. Such equipment is still relatively noisy, and depending on the size and number of machines in operation, the resulting noise levels in the equipment room may be excessively high. Thus, equipment rooms should not be located adjacent to or near dwelling units. Instead, they should be located at the lowest building (basement or grade) level and preferably at that end of the building farthest removed from the dwelling areas. It is advantageous to surround equipment rooms with storage areas, hallways, elevator and ventilation shafts which act as buffer zones to provide additional acoustical shielding and sound isolation. Apartment units should not be located above or next to an equipment room, unless extreme precautionary measures are taken, such as the use of specialized discontinuous or double-shell construction of wall, floor and ceiling structures in the equipment room. This is particularly important in high-rise apartments which house equipment of great power. Frequently, it is far more economical to house the large mechanical equipment associated with high-rise apartments in a separate building of masonry and windowless construction, than to resort to the expensive and specialized construction required for in-house location.

3. Proper installation: All the work and effort expended in selecting the proper equipment and its location will be wasted if the equipment and associated service and distribution systems are not installed properly. Indeed, improper installations frequently increase equipment noise output. This phenomenon arises when vibrating equipment and associated systems are mounted directly to building structures which reinforce or amplify the machinery noise to a level above that which the equipment by itself is capable of radiating. The only effective way of coping with this problem is by using resilient separation or vibration isolators in the mounting, support and attachment of all such equipment and distribution systems. The importance of vibration isolation in the control of equipment noise cannot be overemphasized.

F. CONTROL OF NOISE AT THE SOURCE

The first stage of noise control is the control of noise at its source. Obviously, when the noise output of a source is low, there will be less noise radiated and transmitted to other areas of the building; this is especially true in the case of structure-borne noise. If attempts to quiet the source are not completely successful, then corrective measures involving vibration isolation and/or specialized construction techniques should be used as near to the source as is practicable.

The preceding section dealt in part with the control of equipment room noise in a building. There are many other noise sources scattered throughout an apartment building, such as laundry appliances, exhaust fans, roof-mounted ventilation fans, transformer units, household appliances, plumbing fixtures, elevators, garages and trash chutes. Problems associated with such sources can be minimized if the builder selects quiet units and uses vibration isolation mounting techniques to prevent any noise buildup. Defective components should be replaced and loose or rattling parts tightened or braced.

G. SELECTION OF SOUND INSULATING STRUCTURES

After the foregoing design elements have been considered and incorporated as effectively as possible in the building plans, the architect should concentrate on the selection of the sound insulating wall and floor structures which will achieve the desired privacy between dwelling units. Aside from economic factors, the choice of suitable wall or floor assemblies will depend largely on the type of building structure, i.e. masonry, steel or light frame construction. Regardless of the type of construction, the architect should remember that the sound insulating effectiveness of a wall or floor assembly is dependent upon the following factors.

(a) Mass.
(b) Stiffness.
(c) Discontinuity in construction.
(d) Proper installation, particularly with regard to edge and boundary conditions.
(e) Elimination of noise leaks, especially around perimeter edges, joints and penetrations of walls and floors.
(f) Control of flanking noise.
(g) The use of sound absorbent material in the voids or cavities in structures of discontinuous or double-shell construction.

Generally speaking, the greater the mass of a structure, the less likely it will be excited into vibration by incident airborne or structure-borne sound energy; thus, there will be less sound transmission through the structure. Similarly, the greater the degree of discontinuous or resilient type construction, the higher the sound insulating efficiency of the structure. Likewise, effective control of noise leaks and flanking paths will result in better sound insulation. Proper installation of the structure and the judicious use of sound absorbent materials are also important details to remember.

The architect is cautioned again that the use of a good sound insulating structure itself gives no assurance of achieving the desired noise privacy unless the above factors are handled properly.

H. SOUND ABSORPTION

Sound absorbing materials such as acoustical tile, carpets and drapery play an indispensible part in controlling noise generated within a room or in reverberant areas such as lobbies, corridors and staircases. Although such materials are highly effective as sound absorbers, they are relatively poor sound insulators because of their soft, porous and lightweight construction. In short, they transmit noise very easily To illustrate this point, imagine a wall constructed solely of acoustical tile, carpet or drapery material. Such a wall would provide virtually no resistance to the passage of sound through it. Thus, acoustical materials are not a cure for sound insulation. This, of course, is contrary to the building practices and mistaken beliefs which over the years have held that acoustical tile is the panacea for any and all building noise problems. Unfortunately, this sort of thinking still persists in the building industry and is largely responsible for many acoustically inferior and noisy buildings found today.

WARNING! Under no conditions should acoustical materials be used on the surfaces of walls and ceilings for the sole purpose of preventing the transmission of sound through such structures; to do so would result in total failure and a complete waste of money.

Acoustical materials should be used in and near areas of high noise levels. They are beneficial in reducing the reverberation time and the overall noise level in a noisy area. By controlling sound reflection, they tend to limit or localize the noise to the region of its origin and reduce the transmission of the noise along corridors and passage ways to other parts of a building.

When a sound wave strikes an absorbing material, a portion of the energy is converted into heat by the frictional resistance within the pores and the vibrational agitation of the small fibers. Because of the multiple reflections and successive contacts of the sound wave with the absorbing materials during a relatively short period of time, noise level reductions as much as 8 to 10 dB may be achieved. The amount of noise reduction is dependent upon the area or length of sound absorbing treatment. Therefore, in areas such as ducts and corridors, the use of such treatment may produce even greater noise reductions.

Although acoustical tile is used extensively for the control of noise in reverberant areas, other materials and furnishings such as heavily pleated drapery, upholstered furniture and carpeting with felt pad underlayments can be equally effective for the same amount of surface coverage. In buildings or areas with excessive pedestrian traffic, such as schools, office buildings, corridors and staircases, carpets with pads should be used in lieu of, or in conjunction with acoustical tile. In addition to absorbing airborne sound, carpets cushion the force of impacts and thus transmit less noise to rooms below. Because of their softness and resilience, carpets radiate very little of the surface noise caused by the scuffling, thumping and abrasive action of foot traffic. In other words, people generate much less noise walking on carpets than on hard-surfaced floors.

I. EDUCATION AND TRAINING

The degree of success achieved in constructing buildings with adequate sound insulation and noise control hinges not only on the acoustical education and training of the architects but also of the contractors, builders, foremen, work crews and inspectors.

Carpenters, plasterers, masons, plumbers, electricians, equipment installers, and others should be taught, through planned training programs in each of their respective professions, the proper techniques of construction, application and installation of structures, services and utilities to provide sound insulation and noise control. These training programs should include demonstrations which show how effective such methods are, the reasons why they work and how poor workmanship, small variations from design and mistakes might reduce or destroy the acoustical performance of the building.

J. SUPERVISION

Close supervision and strict attention to small details particularly by foreman and inspectors are required during each and every phase of the building construction in order to ensure a high degree of noise control and privacy. It is essential that foremen and inspectors constantly ride "close herd" over the workmen to see that they are doing their work properly, so that serious noise leaks are not overlooked or undetected and then later discovered concealed behind finished wall or floor constructions.

K. PRETESTING

Building inspectors, foremen or supervisors should conduct preliminary tests of the sound insulating effectiveness of apartment walls and floor-ceiling structures shortly after they are installed and prior to painting and final completion. Considerable savings in both cost and time will be realized in correcting any noise leaks or acoustical failures that are detected at this stage. Although a visual examination of an enclosure may detect some potential noise leaks, such as wide gaps or cracks at ceiling, floor or perhaps adjoining wall edges, such tests are usually inadequate since they fail to detect sources of noise leaks hidden from the eye.

A far more effective test is to operate some noisy device like a power drill or a vacuum cleaner, in a closed room and listen near the other side of the partition wall for any noise leakage. The ear is a reasonably good sensing device. However, by using a probe microphone and a sound level meter or even a stethoscope, noise leaks may be located more quickly than by ear. Another useful test, preferably combined with the above test, involves surveying one side of a partition wall at critical points with an intense light source and looking for light leakage in a darkened room on the other side. A small hand mirror is particularly useful in getting into remote corners or otherwise inaccessible places. For greater effectiveness, the man with the light and the observer should simultaneously follow the same survey path. Detection of any light leakage in the darkened room will signify a noise leak.

Detecting the transmission of building equipment noise is somewhat more difficult. With such equipment in operation, one can sometimes locate noise leaks or identify flanking paths by conducting similar hearing tests along with pressing the ear against various room surfaces or using finger tips to sense the vibration of such surfaces. Serious structure-borne noise transmission problems might involve extensive vibrational analyses along the various transmission paths between the equipment room and the room undergoing test.

CHAPTER 6

CONTROL OF AIRBORNE NOISE

The fundamental objectives of noise control are to provide privacy and quiet both indoors and outdoors. Although this guide deals primarily with the control of noise transmission within buildings, some attention must be given to the control of noise from outdoor sources, some of which are illustrated in Figure 6.1.

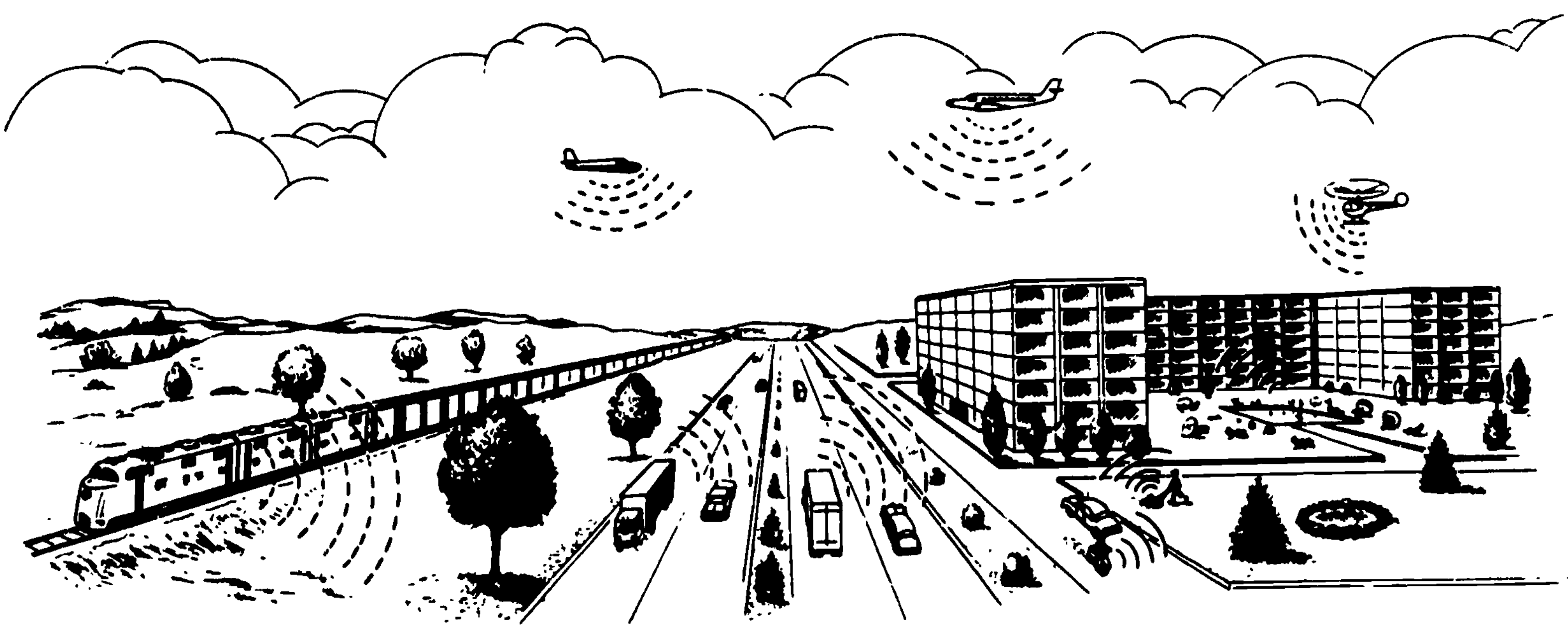


Fig. 6.1. Common Outdoor Noise Sources.

OUTDOOR NOISE:

Among the many outdoor sources of noise, the major offenders are:

(a) Aircraft; e.g., small sport planes as well as large commercial or military planes and helicopters,
(b) Vehicular traffic; e.g., particularly trucks, buses, sport cars, and virtually all types of motorized cycles,
(c) Rail transportation systems; e.g., railroad engines, trains and elevated transit systems,
(d) Industrial plant operation; e.g., manufacturing plants,
(e) Exposed building equipment; e.g., ventilation systems, cooling towers, air-conditioning compressors,
(f) Power garden equipment; e.g., lawn mowers, chain saws, garden tractors, cultivators,
(g) Earth moving and street repair equipment; e.g., tractors, shovels, ditch diggers, air hammers.

The three main courses of action to control outdoor noise are: (1) develop and enforce anti-noise ordinances and zoning regulations, (2) require manufacturers of electrical and mechanical equipment or appliances to provide sound power ratings of their products and (3) educate and encourage city planners and legislators, and transportation system designers to embody noise control principles in the design of their systems.

Although some progress has been made in these fields, much remains to be done. For example, a number of cities and communities throughout the country have adopted rather restrictive anti-noise ordinances relative to industrial areas bordering on residential areas, but have neglected to adopt comparable restrictions regarding traffic noise. An effective over-all anti-noise ordinance should place restrictions on noise generated not only in industrial and commercial areas which border residential areas but also within the residential areas. With such ordinances in effect, manufacturers of various indoor and outdoor equipment and appliances would be forced to market products which would meet the specified noise abatement requirements.

Considerable progress in aircraft noise control has been made primarily through improved flight procedures and design of flight traffic and holding patterns, but very little consideration has been given to control of vehicle or traffic noise, aside from improvements in muffler design and more recently, tire tread design. Although some effort has been made recently in reducing noise levels within passenger automobiles, very little has been done by automobile manufacturers in applying the technology of noise control to silencing the overall noise generated by the vehicle itself.

Likewise, consideration of noise control principles in the design and layout of expressways and traffic arteries has been disregarded. Some reduction of traffic noise has been achieved by high speed interchanges, cloverleaf crossings, depressed road beds and highway cuts which have come chiefly as a surprising and welcome by-product of highway planning based primarily on economic factors and efficient traffic flow. However, expressways frequently are found skirting the edges of otherwise quiet residential or suburban communities in which occupants are exposed to the intermittent and irregular roar of passing trucks that might produce noise levels 15 to 20 dB higher than the noise from other traffic. This unfortunately may occur throughout the night, when peace and quiet are most desired. A significant improvement in the control of traffic noise can be made by proper design and location of interchanges, acceleration and deceleration lanes of expressways and the judicious use of all the acoustical shielding benefits which might be offered by the topography of the land.

The same sort of disregard for noise control prevails among city planners and community builders engaged in city design. In order to contain the growth of the outdoor noise problem, a concerted effort must be made by legislative bodies to formulate and enforce effective community or city wide anti-noise ordinances and noise specifications of mechanical equipment and appliances. Further, some qualification in acoustics or noise control should be required of all responsible individuals engaged in the planning, design and development of our outdoor environment. Until such measures materialize, the architect and builder must resort to two techniques at his disposal to prevent excessive outdoor noise from entering his buildings; that of using natural or artificial barriers on or near the building site to reduce the amount of noise reaching the building and/or utilizing specialized sound insulating construction of roofs, exterior walls and surfaces to minimize the transmission of outdoor noise into the building. Elements of the first technique are described in the foregoing chapter, particularly with respect to "selection of the building sites" and "orientation of buildings on sites".

With regard to the second technique, the ideas and principles developed in the following section for the control of airborne noise transmission within a building can be applied equally well to the problem of excessive outdoor noise transmission through exterior building walls and roofs.

INDOOR NOISE:

The generation of airborne noise in buildings stems from the operation of building equipment, utilities and domestic appliances as well as from occupant behavior and activity. Because of the complexity of sources and activities involved, the composite noise may reach levels of high intensity with an extremely broad frequency spectrum ranging from very low to exceedingly high pitched noises. Since any one or a combination of these sources or activities may give rise to complaints at certain times, it would be a formidable task to reduce all noises to the complete satisfaction of all building occupants.

The logical approach to the problem is to insulate against or control those sources of noise which disturb the greatest percentage of the occupants. The sources of airborne noises which cause the most frequent disturbances are:

(a) Musical instruments; e.g., televisions, radios, stereo sets, pianos and drums,
(b) Adults, children; e.g., loud speech, singing, crying and shouting,
(c) Household appliances; e.g., garbage disposers, dishwashers, vacuum cleaners, clothes washers and dryers,
(d) Plumbing fixtures; e.g., water running, pipes knocking, toilets flushing and refilling.

Among the above, the most disturbing sources, in terms of frequency of occurrence and prolongation, are television, radio and stereo sets. Of these, TV sets rate as the most frequent offenders.

This chapter deals specifically with the types of partitions, construction and installation techniques and various acoustical measures that may be used in the control of airborne noise. For convenience and ease of understanding, the control of airborne noise will be treated primarily as a partition wall problem; although the principles and ideas developed here can be applied equally well to floor-ceiling assemblies. In the consideration of floor-ceiling assemblies, one must cope with the additional problem of controlling impact and structure-borne noise, which is discussed separately in Chapter 7.

The functional objectives of a wall are: to support the structural load of a building, to serve as a space divider or enclosure in the visual sense and to act as a noise barrier.

Load-bearing walls are usually quite massive structures which normally provide an adequate degree of sound insulation. On the other hand, partition walls used solely as space dividers are for economic reasons usually of lightweight, monolithic or rigid construction which afford poor sound insulation. Generally speaking, a wall which will provide adequate sound insulation in a given situation is one which will reduce the transmitted noise to a level below that of the normal background noise. This sound insulating property of a wall or partition is called the "sound transmission loss", which is expressed in terms of decibels. The sound transmission loss, STL, is equal to the number of decibels by which sound energy incident on one side of a partition is reduced in transmission through it. This is illustrated in the first diagram of Figure 6.2, which shows a wall with an STL value of 30 dB reducing an incident noise level of 70 dB to a transmitted level of 40 dB, a 30 dB reduction.

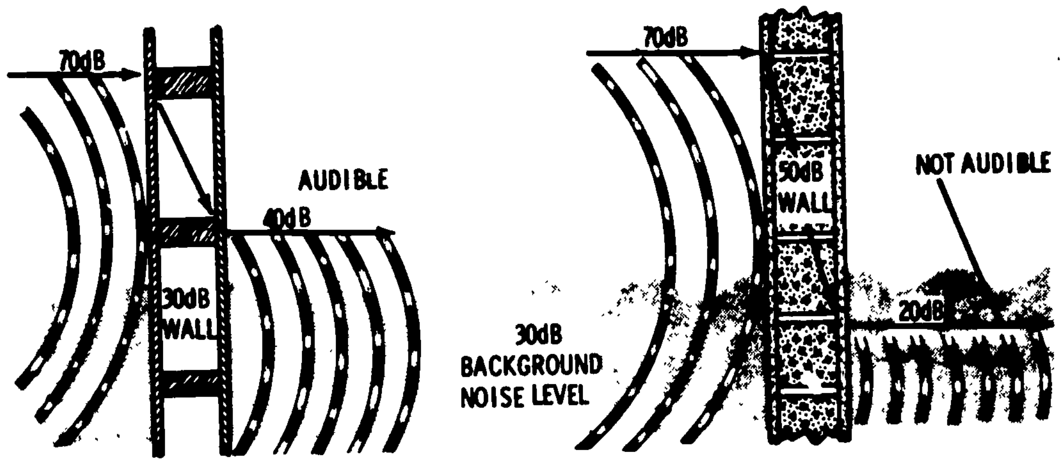


Fig. 6.2. STL of Walls.

In this case, the transmitted noise level is above the background noise and as a result is audible. The second diagram shows a 50 dB wall under the same noise conditions reducing the transmitted noise to an inaudible level, i.e. below that of the background noise. In this instance, the background noise is said to mask the transmitted noise. In the first example, the wall would not provide satisfactory sound insulation whereas in the second case, adequate insulation would be achieved under these conditions.

Thus, the satisfactory performance of the wall in a given situation hinges primarily on three factors: (1) the sound level on the source or noisy side; (2) the sound transmission loss of the wall; and (3) the background noise level on the receiving or quiet side.

BACKGROUND AND MASKING NOISE:

From the foregoing example, one might reason that for a given case, the higher the background noise level the lower the wall STL value required for adequate sound insulation. Generally speaking, this is true up to the point at which the background noise level itself becomes as disturbing as the noise transmitted through the partition wall, as might well happen if one should use nearby heavy downtown street or expressway traffic noise for masking purposes. Under certain conditions, background noise or even artificially induced masking noise may be considered in selecting a partition wall which will perform satisfactorily, providing that the background or masking noise is not too disturbing and is smooth, continuous and preferably nondirectional in character. This rules out noise sources which are either cyclic or intermittent in operation such as furnace/air conditioner blowers and compressors, or the continuous hum of automobile traffic which is interrupted at frequent intervals by the roar of trucks.

The interior background noise level on the side of a building facing a noisy area may be considerably higher than that on the shielded side.

Use of this higher background noise level to "trade off" or compensate for the selection of a partition wall with a comparably less STL value would be a mistake. Only the occupants on the noisy side of the building would find the sound insulating performance of the wall satisfactory because of the masking benefit. Since noise travels through a wall with equal ease in both directions, the occupants on the quiet side of the building, deprived of the masking effect, would find their neighbor's noise quite disturbing.

On the other hand, if too much masking noise is introduced equally in both apartments to compensate for an acoustically poor party wall, both occupants might raise the volume of their TV sets or voices, thus negating the benefit of the masking effect. The net result is that the ratio of the disturbing TV level to masking noise level, i.e. the ratio of signal to noise level, remains the same. As a rule of thumb, the upper limit for use of masking noise should be no higher than 10 dB but more conservatively about 5 dB above the normal background noise level, if the masking noise itself is not to be disturbing.

Artificially induced masking noise such as produced by electronic devices and continuous operation of fans can be more effectively used in the acoustical design of office buildings where the sound insulation requirements and the need for a comfortably quiet environment are generally not as demanding as in dwellings. Perhaps the greatest value of such masking noise, if properly shaped and controlled, is in its utilization as an expedient, inexpensive, fairly effective method for relieving noise transmission problems in existing buildings; or in masking intermittent disturbing background noise, such as accelerating or braking vehicles, cyclic or periodic equipment noise, chirping birds, crickets, barking dogs, children's laughter or other equally disturbing noises.

The common economic practice of selecting somewhat noisy and cheaper air-conditioning/heating equipment for purposes of using the masking effect to compensate for the installation of cheaper and poorer sound insulating partitions between dwellings usually ends up in disappointment. Generally speaking, the noise produced by such installations is usually excessive and the cause of complaints. The architect or builder is now in an awkward position. To reduce the noise output by lowering the compressor or fan speed of the equipment, at the expense of its heating and cooling efficiency, is guaranteed to bring on more complaints from this direction. Even if the efficiency of the heating and cooling system is preserved, the now obvious lack of privacy between dwellings becomes a source of complaints. In serious cases, the architect or builder may be required to modify the heating and cooling system and improve the acoustical performance of the walls, which is a very costly and time-consuming process for the architect and purchaser. Even if such corrective measures are carefully designed by competent acoustical consultants, rarely are the desired results achieved in practice, owing to either poor workmanship, unforeseen problems or difficulties stemming from the initial building construction. In short, masking noise in multifamily dwellings may be of some use in dealing with intermittent outdoor noise, but it is not a substitute for good sound insulating partitions.

Before selecting the appropriate type of partition wall the architect should observe the following.

1. Establish acceptable interior background criteria as a design objective. See Chapter 10 for suggested criteria.

2. Arrange for a detailed noise survey of the proposed building site to determine the existing outside noise levels for purposes of estimating the interior background noise levels within the dwellings and what measures are necessary to reach the design objective. Estimates of future noise levels also should be considered. If buildings of similar construction are near the proposed site, a noise survey within such buildings will simplify the task of estimating the interior background noise of the new constructions. It is important that such surveys be made on the quiet side of the building in order to obtain minimum background noise levels. As a precaution, the maximum design requirements of the partition wall should always be based on the lowest measured background noise levels.

3. As a design objective, assume a level of 75 to 80 dB for average peak household noise generated by occupant activity. For successful performance of the partition wall, its design requirements must be based on the expected highest or peak average noise levels rather than on the lower average steady state levels.

4. Based on the foregoing background and household noise considerations, select a wall with an appropriate sound insulating capacity. See Chapter 11 for a listing of various types of wall construction and sound transmission class ratings.

The basic types of wall structures and the construction and installation techniques used in the control of airborne noise are illustrated and discussed below. Although this discussion deals specifically with interior walls, the ideas can be applied to exterior walls and floor-ceiling structures as well.

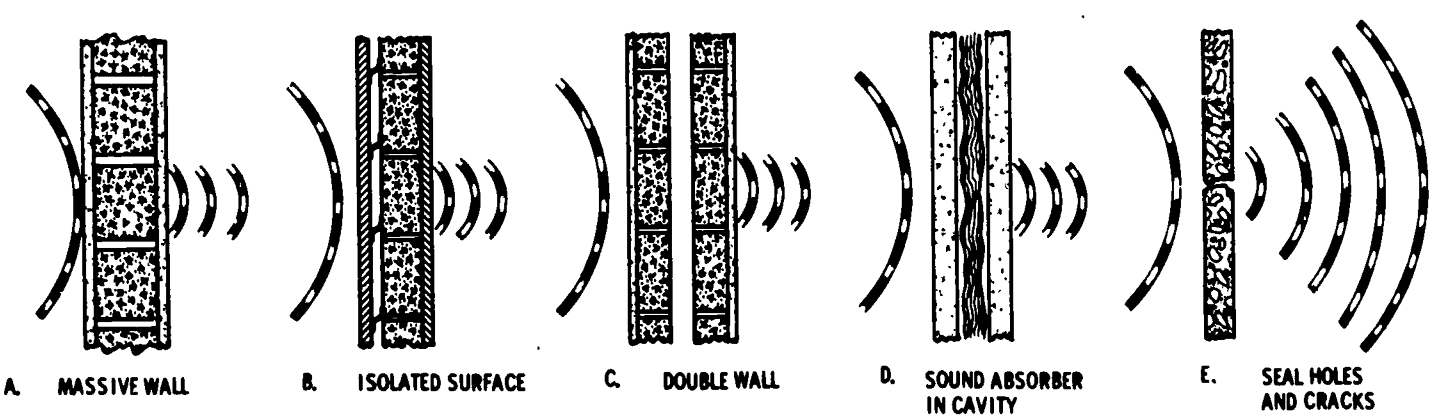


Fig. 6.3. Basic Sound Insulating Wall Constructions.

MASSIVE OR HEAVY WALLS: (See Figure 6.3 A)

The airborne sound insulation effectiveness of solid homogeneous walls of concrete, masonry, brick or solid gypsum construction improves with increasing mass or weight, providing the constructions are either non-porous or their surfaces are coated with a pore-sealing substance such as plaster, grouting mix or heavy masonry paint. The average sound transmission loss of such walls, which are said to be "mass controlled", increases only about 5 to 6 dB for each doubling of weight. As a consequence, single walls of such construction become impractical where a high degree of sound insulation is required. In terms of economic and practical usefulness, a solid wall thickness of 8 to 10 inches approaches the upper limit of sound insulation effectiveness.

WALLS WITH ISOLATED SURFACES: (See Figure 6.3 B)

Walls of this type represent a form of discontinuous construction which provides improved sound insulation performance at the expense of little added weight. The construction involves the use of resilient materials such as fiber boards, felt or cork strips, or resilient elements like spring clips or channels between outer wall surfaces and the inner core wall.

The isolated wall surfaces may be fastened to either one or both sides of the core wall. The resilient material or element acts as a decoupler or vibration isolator which dissipates the vibrational energy. Such isolated wall surfaces may be used in the same manner in rigid stud constructions.

DOUBLE WALLS: (See Figure 6.3 C)

Double walls have substantially greater sound insulation than a single wall of the same weight. Care should be exercised to avoid short circuiting of the two walls by accumulated debris, wire ties or excessive coupling at the perimeter edges. If high performance is to be achieved, there should be a complete separation of at least 2 inches and preferably 4 inches between the walls.

Double walls of wood frame construction include slit stud, staggered stud and double stud walls, listed in order of increasing effectiveness. In such constructions the air, by virtue of its compressibility, acts as the spring element or vibration isolator. A wider air space provides a softer spring action which results in greater sound insulation.

WALLS WITH SOUND ABSORBENT LINERS: (See Figure 6.3 D)

The use of sound absorbing materials such as mineral wool blankets in the airspaces of double walls or walls employing resilient elements or staggered studding may improve the sound insulation of the wall from 3 to 8 dB, depending on the thickness of the blanket and type of wall construction. Sound absorbing materials usually are more effective in light frame than in heavy masonry construction. Such materials tend to minimize the sound energy buildup in the hollow reverberant wall cavities, particularly at the higher frequencies. However, they are only marginally effective at low frequencies.

Unfortunately, the use of sound absorbing blankets in voids or airspaces of conventional stud walls contribute little or nothing toward improved sound insulation. Owing to the rigid ties of the stud framing to the wall surfaces, the entire wall behaves like a diaphragm under vibrational excitation and transmits the sound readily; thus the effectiveness of the sound absorbing blanket is "short circuited".

PROPERLY SEALED WALLS: (See Figure 6.3 E)

In order to obtain the highest sound insulation performance, a partition wall must be of airtight construction. Care must be exercised to seal all openings, gaps, holes, joints, penetrations of piping and conduits. Even hairline cracks which might occur, particularly at the adjoining wall, floor and ceiling edges, during the drying out period or building settlement should be sealed. A substantially greater amount of sound energy is transmitted through a crack than would normally be expected on the basis of its area.

Both sides of the walls, particularly those of brick, concrete or masonry block construction, should be surface coated with a plaster or cement mix to seal surface pores, mortar joints, cracks, etc. In the case of double masonry walls, the inner face of one wall should be back plastered. These precautions also should be observed relative to surfaces of masonry corewalls which may support furred-out gypsum board or plaster faces.

PROPER INSTALLATION OF WALLS:

Success in achieving adequate sound insulation between dwellings depends not only on the selection of the appropriate wall, but also on the proper installation of the wall. In addition to the airtight construction requirements discussed above, proper installation of the wall should keep coupling or rigid ties to other structural assemblies at an absolute minimum. Techniques for achieving this involve using gasketing materials above and below head and base plates and at points of intersection with adjoining walls. The purpose of decoupling the wall is to break up or minimize the flanking paths for structure-borne noise transmitted from other areas. In addition, the flanking paths for airborne noise via open ceiling plenums, corridors, etc., must be eliminated. See Chapter 8 for additional discussion and illustrative examples relative to proper installation of walls.

CONTROL JOINTS:

One of the problems associated with high-rise buildings is extensive cracking and separation of party walls from adjoining wall and floor constructions, which often results in serious loss of acoustical privacy. Walls, particularly of non-load bearing construction, frequently fail under the stresses induced by floor slab deflection and movement of the building's structural frame. The causes of such structural movement may be differential expansion or contraction of exposed supporting columns, wind and gravitational forces and differential settlement of the foundation or footings. Such wall failures may be minimized through the use of control joints properly designed to accommodate building movement while preserving good sound insulating performance. The control joints, which may be constructed of metal channels containing resilient gasket material, should be used along the peripheral edges of the partition walls, as illustrated in Figure 8.72.

OTHER PRECAUTIONS:

1. Avoid Short Circuits: Much too often the effectiveness of a good sound insulating wall is inadvertently impaired by builders or construction workers as a result of on-the-job changes, which might be trivial for all other practical purposes but serious relative to noise control. For example, a last-minute alteration of a kitchen cabinet layout might result in mounting wall cabinets on party walls of resilient spring construction. The cabinets must be rigidly and

securely fastened to a sturdy stud-framework or perhaps an inner masonry core wall in order to carry the heavy loads. Thereby, the advantages of the resilient construction are lost and the sound insulating performance of the wall is reduced to that provided by a single homogeneous wall of the same weight. In a similar vein, pipe runs through walls of resilient construction or double walls will seriously reduce the high performance of such walls if the pipes bridge across and make rigid contact with the exterior wall surfaces by means of clamps or cover plates. The overemphasis on structural rigidity, particularly with respect to non-load bearing walls, is a frequent cause of poor acoustical performance. For example, a common practice of construction workers is to use excessive nailing, cross-bracing, and wire tying of resilient elements to gain an "extra measure" of structural strength or rigidity simply "to be on the safe side".

Building foremen and inspectors should caution construction workers that such seemingly insignificant practices may nullify the benefits of good sound insulating construction.

2. Wall Mounting of Equipment or Appliances: A good rule of thumb is to avoid mounting of motor-gear driven appliances, telephones, exhaust fans and paper dispensers on party walls, or butting kitchen cabinets with built-in appliances tightly against such walls. Unless special mounting precautions are taken, the operation of such devices may be the cause of serious noise complaints.

3. Walls with Windows or Doors: In the foregoing discussion, the fact that partition walls may have windows and doors has been largely ignored. Even though well sealed, a window or a door in a wall usually represents the "weakest link" in the sound insulating performance of the composite wall assembly. In other words, a window or a door in a wall usually transmits more sound than the rest of the wall.

While it is generally true that little will be gained by improving the sound insulation of the wall as long as the window or door remains, it is false to reason that the insulation of the wall need be no better than that of the door. The total amount of sound transmitted through a composite wall-door assembly depends on the surface area and the sound transmission loss of each of the component parts. In general, if a composite wall is constructed of two panels of equal areas but quite different STL ratings, the average sound transmission loss of the composite wall will be only slightly higher than that of the poorer panel. If on the other hand, the area of the panel with the higher STL rating is much greater, e.g. 10 times greater than the area of the poorer panel, the sound transmission loss of the composite wall will be substantially higher than that of the poorer panel.

To illustrate this, consider a wall with an average STL of 50 dB and an area of 220 square feet. Installed in this wall is a door with an average STL of 20 dB and an area of 20 square feet. The net wall area (less door) is 200 square feet, i.e. 10 times greater than the door area. Using expressions (1) and (2) and the following table the average sound transmission loss of the composite wall structure can be computed.

$$STL_{\text{single wall}} = 10 \log_{10} \frac{1}{\tau} \text{ dB} \qquad (1)$$

where τ is the transmission coefficient.

$$STL_{composite\ wall} = 10 \log_{10} \frac{S}{(\tau_1 s_1 + \tau_2 s_2)} \text{ dB} \quad (2)$$

where τ_1 and τ_2 are the transmission coefficients of the wall and door respectively, s_1 and s_2 are their corresponding surface areas and S is the sum of these surface areas.

Partition	Area, ft^2	STL, dB	τ	τs
Wall	200	50	.00001	.00200
Door	20	20	.01	.20
TOTALS	220			.202

$$STL_{composite\ wall} = 10 \log_{10} \frac{220}{.202} = 10 \log_{10} 1089.1 = 10(3.04) = 30.4 \text{ dB.}$$

This shows that the 30 dB average STL of the above wall-door combination is substantially better than that of the 20 dB door. However, this wall-door assembly would not provide adequate sound insulation. The obvious solution would be to use a door with an STL rating of 30 dB or better which opens into a vestibule or foyer, rather than directly into a living room. In this way, one would preserve the integrity of the 50 dB wall.

NOISE CONTROL WITHIN THE APARTMENT UNIT:

In addition to the disturbing intrusion of noises from other parts of the building, the apartment tenant has little respite from noises generated within his own dwelling. It is difficult for him to escape from the clatter of the garbage disposal, the rumbling of the dishwasher, the boisterous laughter of his children or the irritation of his wife's favorite TV or radio program. Even though a person's tolerance of noise produced by his own activity is quite high and he can control the noise by curtailing his own or family's activities, the fact remains that domestic noises generated within a typical apartment are much more disturbing than need be. This is due primarily to three factors:

(a) the operation of excessively noisy appliances, bathroom or plumbing facilities and TV, radio or stereo sets,

(b) the open space design, particularly with respect to layout of kitchen, dining room and living room, which provides no separation of noisy areas from sensitive areas, and

(c) the poor sound insulation provided by partition walls and doors, especially in bedroom and bathroom areas.

Although the techniques discussed throughout this guide deal primarily with the control of noise transmission between apartment units, they can be applied equally well to the problem of controlling noise within a dwelling unit. At the risk of being repetitious, the control measures involve:

(a) using a well designed floor plan which separates noisy areas from quiet areas by means of buffer zones and/or designing each room as a self-enclosed area,

(b) vibration isolating plumbing systems, fixtures and built-in appliances from wall and floor structures and cabinets,

(c) installing walls and doors with adequate sound insulation in all sensitive areas, such as bedrooms and bathrooms, and

(d) installing carpeting and/or acoustical tile in most areas, particularly in hallways, which separate living areas from bedroom areas.

CHAPTER 7

CONTROL OF STRUCTURE-BORNE NOISE

The most serious noise problems in multifamily dwellings involve the transmission of structure-borne noise. Because of the increasing severity and wide diversity of the overall problem, its solutions are of much greater importance and considerably more difficult to achieve than those associated with the control of airborne noise.

Buildings obviously must be supported by loadbearing walls, columns and beams, as well as structural floors, which must be joined to form a structural framework of great strength and rigidity. Since these members are highly efficient transmitters of vibration, the structural frame of the building becomes a network of vibrational transmission paths which subdivide and engulf the entire building enclosure. To complicate the picture further, the installation of utility systems, partition walls and equipment adds a multitude of new transmission paths, some of which invariably become hidden from view in the completed building. Thus, the problem of controlling structure-borne noise might be vexing and difficult to resolve, if precautionary measures are not incorporated in the early design stage of the building.

Unfortunately, the simple solution of forbidding the installation of vibration sources within a building is impracticable. Instead, one should limit the length of continuous transmission paths by introducing joints, changes in materials or dimensions, isolators, or other attenuating or decoupling devices as close to the source and as repeatedly as possible.

Although structure-borne noise is frequently transmitted by way of wall assemblies, the problem is more severe with floor-ceiling structures which, due to their wide spans, are particularly susceptible to impact and vibratory excitation. Such excitation causes diaphragmatic movement of the entire floor-ceiling structure which results in noise radiation from the ceiling surface into the room below. Unlike the case of airborne noise, increasing the mass of the floor structure is not very effective, nor is the use of buffer zones between floors practicable. As a consequence, structure-borne noise transmitted from the apartment above is usually more disturbing than the airborne noise transmitted from the apartment next door.

SOURCES OF STRUCTURE-BORNE NOISE AND METHODS OF CONTROL

The major sources of structure-borne noise are impacts, plumbing systems, heating and air-conditioning systems, mechanical equipment or appliances and low frequency vibration from external sources.

A. IMPACT NOISE:

This section will deal with impact noise and its prevention. Impact noise is caused by an object striking against or sliding on a wall or floor structure, such as that produced by walking, falling objects, moving furniture or slamming doors. In such cases, the floor (or wall) is set into vibration by direct impact and sound is radiated from both sides. As will be shown later, the amount of noise generated by impact on a floor is highly dependent upon the type of surface covering.

IMPACT NOISE THROUGH WALLS:

Although most impact noise is transmitted through floor-ceiling structures, problems of impact noise transmission through party walls may appear, particularly in one-room efficiency apartments in which the single room serves the multipurpose functions of living room, bedroom and kitchen. The major causes of impact and structure-borne noise transmission through party walls are:

(a) wall-mounted kitchen cabinets; where the impacts are caused by placing dishes or canned foods on the shelves, as well as the slamming of cabinet doors,
(b) wall-mounted appliances; such as knife sharpeners, can openers and ice crushers,
(c) built-in dishwashers and garbage disposals as well as countertop blenders and mixers; where the vibration is transmitted to the party walls by way of the abutting cabinetry,
(d) built-in-wall units such as chests, closets and fold-in-wall beds; where the noise is caused by the sliding of drawers and doors, clothes hangers impacting against the wall and the opening and closing of fold-in-wall beds.

Obviously in certain cases, particularly those involving one-room efficiency apartments, measures must be taken to ensure adequate impact noise insulation of the party walls separating dwelling units. Observance of the following rules of thumb will avoid most of such problems.

1. Refrain from mounting any noisy appliances, devices or kitchen cabinets on or against party walls; party walls should be free or clear of any appliances, cabinetry or household furniture.

2. If party walls must be used for such purposes, it is recommended that they be of reasonably massive double-wall construction, e.g. double brick or masonry block walls devoid of wall ties. Further, vibration isolation mounting must be used in the installation of all appliances whether on walls or in built-in cabinets.

3. Cabinets, which house appliances such as dishwashers or disposers, should also be isolated from party walls and indeed all walls by means of strips of resilient gasketing.

4. As a precautionary measure, walls using resilient channel or spring clip construction should not be used as party walls, if wall-type kitchen cabinets are to be mounted on them. The resiliently mounted surfaces of such walls are not capable of supporting heavy loads. If the cabinets are bolted to the inner rigid framework of such walls, the spring action of the resilient element is short-circuited which results in serious reduction of both the airborne and impact sound insulating merits of the party wall.

Although not recommended, it is possible to mount cabinets on party walls of resilient construction if specialized vibration isolating mounting techniques are used, similar to those illustrated in Figure 8.69. Other sources of impact noise disturbances are slamming doors and sliding of furniture against party walls. In some cases the noise may be controlled at the source; for example, door slams may be eliminated by the use of door closers or rubber bumpers. Where the source of noise is difficult to control, such as sliding of furniture against party walls, the use of discontinuous or double wall construction may prevent the transmission of such noise to adjacent apartments.

The actual techniques used in controlling impact noise transmission through floor structures differ somewhat from those associated with party walls, but they are based essentially on the same principle of using a form of resilient or discontinuous construction.

IMPACT NOISE THROUGH FLOORS:

Impact noises usually constitute a serious problem because such noises generally are of high intensity and transient or impulsive in character. The problem is particularly acute in floors of light frame construction. Because of their flexibility and lightweight, such floors are easily set into vibration by impact excitation. Under heavy foot traffic such floors will generally produce a thumping or booming noise which tenants find most irritating. Whereas the high frequency components of impact noise can be attenuated quite easily by various resilient types of floor surface coverings such as carpeting, cork or rubber tile, the attenuation of low frequency impact noise requires the modification of the basic structural floor with some form of discontinuous construction. The basic types of discontinuous structures and construction techniques used in the control of impact and structure-borne noise are illustrated in Figure 7.1.

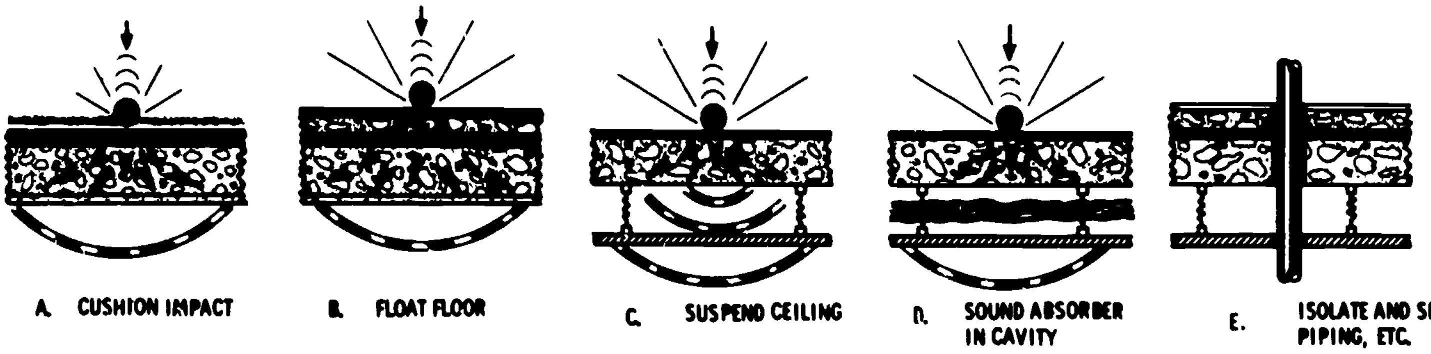


Fig. 7.1. Basic Sound Insulating Floor Constructions.

1. Cushion the Impact: (See Figure 7.1 A)

The most logical approach to the control of impact noise is to cushion the impact by means of soft resilient surfacing materials. Such materials dissipate a substantial amount of the impact energy and thus reduce the energy which may be transmitted to the supporting structural floor. The effectiveness of the impact insulation depends not only on the thickness and resilient characteristics of the surface material but also on the construction of the basic floor structure. For example, a given carpet and pad combination on a floor of wood frame construction would not necessarily provide the same degree of impact noise insulation as when placed on a concrete floor. Floors surfaced with soft resilient materials are also effective in reducing noise produced by abrasive actions such as sliding of furniture, vacuum sweeping and scuffling foot traffic. Unfortunately, no appreciable gain in airborne sound insulation is obtained by using carpets, pads or other resilient floor surface materials.

2. Float the Floor: (See Figure 7.1 B)

Floating floor constructions isolated from the supporting structural floor by means of resilient materials or spring elements represent a type of discontinuous construction which can be highly effective in reducing the transmission of impact noise. The resilient material or element might be in a form of rubber pads, mineral wool blankets or spring metal sleepers which support nailing strips or subflooring. Floating floors may be used on structural floors of masonry, wood or steel frame construction.

The effectiveness of a floating floor structure is dependent primarily on three factors:

(a) the compliance of the underlayment or the resilient element,
(b) the mass of the floating floor assembly, and,
(c) the degree of decoupling of the floating floor from adjoining walls and structures. In this regard the joint between the floating assembly and the adjoining walls should be not only flexible but airtight, so that the additional airborne sound insulation provided by the floating floor is not wasted.

As a general rule of thumb, the greater the compliance of the resilient material, the mass of the floating floor and its decoupling from adjoining walls, the better the airborne and impact sound insulation of the structure. Using carpets and pads or other resilient materials on the floating floor will generally provide additional impact noise insulation.

The following precautions must be observed in the construction of a floating floor, particularly of the type illustrated above, wherein a resilient mat or pad is sandwiched between a structural floor and a floating concrete floor.

(a) The characteristics of the pad must be such as to resist breakdown or excessive deformation under long periods of loading.
(b) The pad must be covered with a protective layer of some strong impermeable vinyl or other plastic material with overlapping edges to prevent concrete from leaking into the pad during the pouring of the floated slab. In fact, it is recommended that thin sheets of plywood or hard boards be used on top of the plastic membrane to prevent its accidental rupture during the pouring operation.
(c) The mass of the floating floor should be large compared to any loads it will support in order to achieve a more uniform load distribution on the resilient underlayment or pad.

3. Suspend the Ceiling: (See Figure 7.1 C)

Ceilings which are isolated from floor structures by resilient channels, hangers or separate ceiling joists usually are efficient airborne noise insulators. However, in actual buildings such ceilings are quite often ineffectual against impact noise unless precautionary measures are taken. The reason for their poor performance is that any impact or vibrational energy imparted to the floor-ceiling assembly is transmitted to adjoining loadbearing walls or other structures and is reradiated as noise elsewhere. In effect, these structural flanking paths by-pass the isolated ceiling. In laboratory installations where flanking transmission is virtually eliminated, floors with resiliently suspended ceilings perform remarkably well, as shown in Chapter 11. The architect is cautioned that such results may be achieved in actual buildings only when the floor-ceiling structure is vibrationally decoupled from supporting walls or the interior wall surfaces of the room below are resiliently mounted. In the latter case, resilient gaskets should be laid under the base plates of these walls to minimize transfer of vibrational energy to the floor of the room. In short, the shell-within-shell design should be used for effective control of impact noise transmission.

4. Sound Absorber in Cavity: (See Figure 7.1 D)

As in the case of double walls, the insertion of sound absorbing materials in the cavities of the floor-ceiling structure improves its sound insulation providing that the structure has a floating floor and/or a resiliently hung ceiling. In conventional floor-ceiling assemblies, wherein the flooring and ceiling surfaces both are rigidly coupled to the structural floor, sound absorbing materials within the cavities are relatively ineffectual.

Sound absorbing materials improve both the airborne and impact sound insulating performance of most floor structures incorporating resiliently mounted surfaces. However, such materials usually are more effective when used in suspended ceilings rather than in floating floor structures, and as a rule provide more insulation against airborne noise than impact noise.

5. Isolate and Seal Pipes: (See Figure 7.1 E)

In order to obtain a high degree of sound insulation, the floor-ceiling structure must be of airtight construction. All openings or gaps, particularly at the peripheral edges of the structure and around pipe or conduit penetrations, should be sealed with a waterproof, non-setting caulking compound.

6. Proper Installation of Floors:

The installation of floor-ceiling assemblies should be designed to keep coupling or rigid ties to other supporting structures at an absolute minimum. Installation techniques which meet the structural support requirements and yet provide adequate decoupling involve the use of cork plates between the floor and supporting structures, as illustrated in Chapter 8.

In order to minimize the transmission of impact noise between neighboring apartment units, avoid the practice of laying a continuous subfloor throughout the building, particularly at the points where party walls are to be installed. The common practice of rigidly tying non-loadbearing walls to floor-ceiling structures should be avoided, since this provides a flanking transmission path for impact noises and frequently is a cause of poor acoustical performance. The acoustical performance of various floor structures is illustrated in Figure 7.2.

7. Avoid Short Circuits:

In floating floor constructions, a clearance must be maintained between the entire perimeter edge of the floor and adjoining walls, base boards and toe molds. This is especially important to prevent short circuiting the isolation provided by the floating floor. The perimeter clearance should be filled with resilient gasket material or sealed with

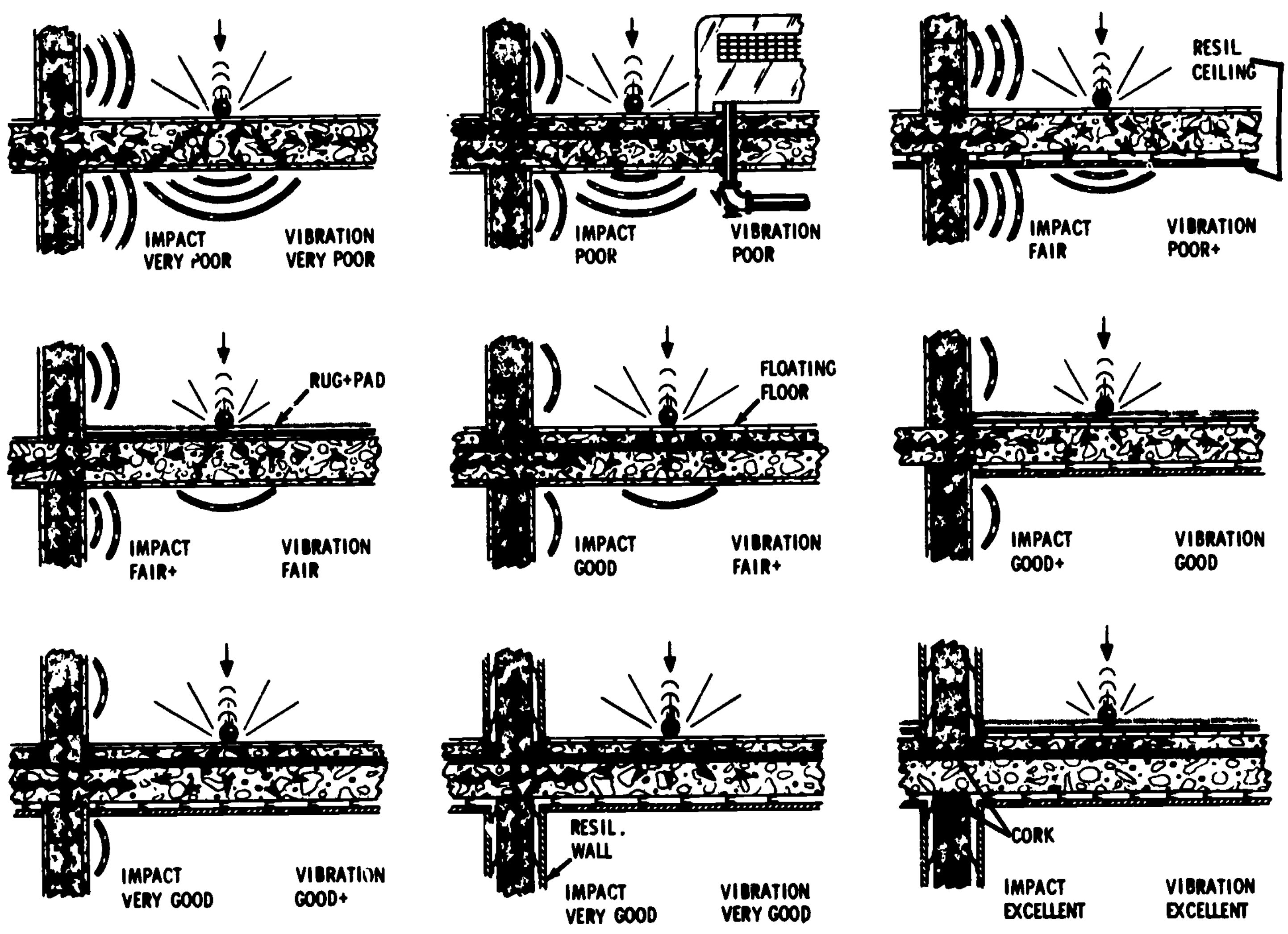


Fig 7.2. Insulation Effectiveness of Various Constructions,
Re: Impact Noise and Equipment Vibration.

a waterproof non-setting caulking compound. In like manner, a clearance must be maintained between a floating floor and any pipe or service chase installed between the structural support floor and the floated floor.

Pipes or conduits penetrating floor structures with floating floors or resiliently hung ceilings must be isolated with rubber or neoprene sleeves to avoid rigid coupling of the floating elements to the structural floor.

With regard to resiliently hung ceilings, flexible connectors must be used in the installation of ductwork and electrical fixtures to prevent short circuiting of the suspended ceiling. A clearance must be maintained between the perimeter edge of the ceiling and adjoining wall surfaces. The edge clearance should be filled with resilient gasket material or non-setting caulk which can be properly finished. Failure to do this usually causes short circuiting of the ceiling suspension system which results in poor impact noise insulation.

Resiliently mounted wall surfaces should be used in conjunction with resiliently suspended ceilings and special care be taken not to restrain the action of either resilient system at the ceiling-wall junction. Similar precautions should be observed with respect to the wall-floor junction.

8. Floor Mounting of Appliances and Electro-Mechanical Equipment:

Household appliances such as refrigerators, washing machines and clothes dryers should be vibration isolated from the floor by means of rubber mounts. If such appliances are installed in kitchen cabinets, they should be vibration isolated from both the floor and the cabinets, or the cabinets must be isolated from the floor by rubber or resilient gaskets. If such installation techniques are ignored, equipment noise and vibration will be transmitted to the floor structure which may amplify tne noise to disturbing levels.

Large heavy equipment such as boilers and central heating plants should be installed in basemen' or slab-on-grade locations. The equipment should be mounted on massive inertia blocks which are supported on vibration isolators. If such installation techniques are not used, the section of the floor slab directly under the equipment must be separated and isolated from the main floor slab by means of expansion joints. All pipes, conduits or service distribution systems must be vibration isolated from such equipment by means of flexible connectors to prevent transmission of vibrational energy to the main floor slab or building walls. For further discussion and illustrations relative to floor structures refer to Chapter 8.

SQUEAKING FLOORS

I Causes:

On occasions, the problem of floor squeaking is more serious than that of impact noise, because generally both families separated by the defective floor will register their complaints. Although the problem commonly is found in buildings of light frame construction, it may appear in buildings with concrete floors surfaced with wood block or strip flooring.

In general, floor squeaks are caused by the rubbing or sliding of one floor layer over another or the movement between adjacent blocks, strips or sections of subflooring or finish floor. Such movement may be due to any one or a combination of the following factors.

(a) Excessive deflection of the structural floor:

Although a floor joist system may be adequately designed in terms of structural and load requirements, it may deflect sufficiently under foot traffic to permit movement of the surface flooring; this generally occurs when either the depth of the joist is too shallow or the spacing between joists is too wide for a given floor span.

(b) Excessive moisture or humidity:

The installation of dry flooring in damp areas often results in squeaking floors because the absorption of moisture by the flooring causes it to swell, crush and buckle. On the other hand, flooring materials which inadvertently have been exposed for extended periods to wet or damp surroundings should be redried before installation; otherwise, the excess moisture absorbed by the material will eventually dry out causing the floor to shrink and show cracks.

(c) Poor quality flooring material:

Poorly manufactured strip or wood block flooring in which tongues do not fit tightly in the grooves may lead to squeaks. Another cause of squeaking is flooring or joists which permit strips, blocks or sheathing to rock under foot.

(d) Poor nailing:

The most frequent cause of floor squeaking is poor nailing which may result from improper spacing of nails, poor workmanship and the use of undersize nails.

II Methods of Controlling Floor Squeaking:

The most effective means of eliminating the squeaking floor problem involve:

(a) using straight, true, good quality flooring materials and joists,
(b) building a rigid well-constructed floor system,
(c) controlling proper moisture content of flooring prior to installation.
(d) inserting building paper or felt between finish and subfloor layers to eliminate rubbing or sliding contact,
(e) employing good nailing techniques.

If squeaks occur in a finished floor, the cause must be determined before corrective measures can be taken. However, some squeaks can be eliminated by lubricating the tongues of wood blocks or strips with mineral oil introduced sparingly into the openings between adjacent boards. With the exception of floating floors, loose finish flooring may be securely fastened to subflooring by surface nailing into the subfloor and preferably the joist. Ring type nails or sawtooth staples, properly spaced, should be used in nailing finish flooring to subflooring. In an exposed joist structure, where finish flooring is warped, driving screws up through the subfloor and into the finish floor will be effective in drawing the floor layers tightly together to reduce the movement.

Prior to installation of ceilings, spaces between warped joists and subfloor should be shimmed and wedged to reduce deflection of the flooring. Excessive deflection of the structural floor due to lightweight or widely spaced joists may be corrected by the insertion of a few extra joists, if the under surface of the floor is exposed. However, if there is a finished ceiling below the floor, cross-beaming with support columns may be the most expedient corrective measure.

For typical residential floor installations, it is suggested that the deflection of the floor should not exceed 1/8 inch under a uniform dead-load distribution of 40 lb/sq ft. This amounts to approximately one fourth of the conventional deflection limitations which are based on 1/360 of the floor span.

Although the above discussion dealt primarily with conventional floors of wood construction, all except one of the techniques for controlling floor squeaking are applicable to floating floor systems. The one exception is that a floating floor should never be surface-nailed through the resilient elements into the subfloor or joists of the structural floor. To do so would short circuit the impact sound insulating action of the floating system. For further discussion of the squeaking problem associated with floating floors, refer to Chapter 8.

For a more thorough and comprehensive discussion concerning proper installation of wood flooring, refer to Agriculture Handbook No. 204, entitled, "Wood Floors for Dwellings", U.S. Department of Agriculture, Forest Service.

B. PLUMBING NOISE:

Most apartment occupants readily admit that noise arising from the use of plumbing services, whether within their own dwelling unit or those located elsewhere in the building, can be heard almost anywhere in their apartment and in many cases throughout the building. In short, it is difficult to escape from the plumbing noise nuisance. Though plumbing noise is seldom very loud, it can be most annoying, particularly during hours of relaxation, and quite frequently is the cause of embarrassment, especially when bathroom facilities are used. Although never discussed publicly and only rarely among close friends and acquaintances, the noise generated by bathroom facilities is the cause of more embarrassment, discomfort and complete invasion of one's privacy than perhaps any other household noise. It is for these reasons that plumbing noise problems are at least as serious as those of impact noise. Unless effective counter measures are taken the present problems will become worse, due to the poor design and installation of plumbing fixtures and the current trend toward the use of high pressure systems, thin-wall piping and lightweight building construction. Solutions to these problems are not very simple because of the numerous types of noise sources and transmission paths involved.

I Causes or Sources:

A basic understanding of the causes or sources of plumbing noise should be helpful in devising methods for its reduction and control. The causes of plumbing noise are one or a combination of the following.

(a) Turbulent flow:

High water pressures with resultant high flow velocities cause turbulence particularly around bends, valves, taps and connectors which usually contain many sharp edges and constrictions. The familiar hissing noise, occurring frequently at partially opened taps, is associated with turbulence. It has been suggested that this noise is due to the combined action of eddies and collapsing water vapor bubbles.

(b) Cavitation:

Although turbulent flow is considered to be the chief cause of plumbing noise, the onset of cavitation in a plumbing system will result in much higher noise levels. Both conditions may exist simultaneously, especially around restrictions in high pressure systems. Cavitation is associated with the collapse of vapor bubbles, which are formed at some restriction by a critical combination of high velocity and low pressure.

(c) Water hammer:

The noisy hammering of a plumbing system is usually caused by the sudden interruption of water flow; for example, by a quick-closing tap. The sharp pressure build up at the point of interruption forms a shock wave which reflects back and forth in the system. The multiple reflections produce a series of hammer-like noises which gradually decrease in loudness as the energy of the shock wave is dissipated. The sudden release of pressure by a quick-opening valve which discharges into a section of piping with a narrow restriction, elbow or tee connector also may cause hammering of the plumbing system.

(d) Pump Noise:

Noise in plumbing systems is frequently caused by motor driven pumps which, by virtue of rigid mechanical coupling, transfer the vibrational energy of the motor, or the pump to the piping system.

Noises due to such sources are easily recognized, since they consist mostly of pure tones associated with the rotational speed of the pumps or motors. The current trend toward using miniaturized, high-speed, shaft-coupled motor pumps has intensified this problem.

(e) Defective parts or fittings:

Defective, loose or worn valve stems give rise to intense chattering of the plumbing system. The defective device frequently can be pinpointed without difficulty, since immediate use of the device causes the vibration which generally occurs at some low flow velocity setting and diminishes or disappears at a higher flow setting. For example, if vibration occurs when a particular faucet or tap is opened partially and diminishes when fully opened, the faucet more than likely has some loose or defective parts.

(f) Expansion and contraction of piping:

The expansion and contraction of pipes produce a staccato-like series of creaking, squeaking and snapping noises which are caused by the sliding or binding of the pipes against studding or other supports.

(g) Drains:

The draining of water from bath tubs, basins and toilets produces gurgling noises which frequently are more annoying than those associated with the filling of such units. The noise problem is intensified when vertical drain systems do not run directly to the basement, but branch off into horizontal pipe runs which usually are supported from floor joists. Falling water striking the horizontal piping sets the drain system into vibration which in turn is transmitted to the building structure.

(h) Running water:

The singing or whistling of pipes or the splashing of water, such as that associated with filling a bath tub or running a shower, is irritating primarily because the noise persists for extended periods of time.

(i) Entrapped air in plumbing system:

A relatively common noise problem generally confined to newly constructed buildings is that caused by entrapped pockets of air in the plumbing systems. The combined action of water pressure and compression of the air pockets may produce intense noise and vibration disturbances which are characterized by explosive bursts, spewing and spitting of water and air from open faucets or taps and hammering or knocking of the piping system. Such problems seldom are a source of complaints, unless they persist for extended periods. Generally speaking, the problem eventually corrects itself by gradual release of the entrapped air through continued use of the plumbing services.

II Methods of Controlling Plumbing Noise:

Water pipes and fixtures are rather inefficient noise radiators because of their small radiating surface areas. The major problem arises when such sources or their support systems are rigidly coupled to large efficient noise radiating surfaces such as wall, ceiling and floor structures. Such surfaces, acting as sounding boards, reradiate the noise at more intense levels.

Some of the most common techniques used for the control and reduction of plumbing noise are given below. They are listed in order and should be combined for greatest effectiveness.

(a) Isolation of plumbing system:

All effort expended for the proper design of a quiet plumbing system is wasted if the system is not properly installed. Since large efficient noise-radiating surfaces such as walls, ceilings and floors pose the chief problem, efforts should be made to isolate the plumbing system from these structures.

Bands or collars of resilient material such as rubber, neoprene, felt or mineral wool should be placed around pipes at points of support, e.g. pipe clamps, straps or hangers and penetrations through wall and floor structures. In addition, when possible attach all pipe clamps or supports to the most massive structural elements, such as masonry walls. Avoid hanging pipes from floor joists or attaching them to lightweight wall surfaces. The above precautions also should be observed when a large number of pipe runs are to be cradled in a rack, or the rack itself should be vibration isolated from the wall by means of rubber grommets.

Bath tubs, toilets and shower stalls should be set on underlayments of cork, rubber, neoprene or other resilient materials or installed on floating floors to reduce the transmission of noise due to falling water. Likewise, the fixtures should be vibration isolated from supporting walls by means of resilient gaskets. Such mounting precautions should be observed with respect to installation of wash basins and faucet fixtures as well.

(b) Use of quiet fixtures:

Siphon-jet toilet and flush tank fixtures with adjustable flow valves are considerably less noisy than conventional models. Taps and faucets using full-ported nozzles and equipped with anti-splash or aeration devices produce little noise.

(c) Reduction of water pressure:

High-pressure plumbing systems are inherently noisy, due to the resultant turbulent flow generated within such systems. The static pressure of main water-supply lines of buildings with three stories or less should be regulated so that it will not exceed 50 psi. The water pressure in branch lines serving individual apartment units should not exceed 35 psi. In high-rise structures where high-pressure main supply lines are required, pressure reducers or regulators should be used in supply branches at various floors to maintain water pressure within the above limits.

(d) Reduction of water velocity:

High velocity flow in a plumbing system, due chiefly to undersized piping, gives rise to turbulence which frequently generates excessive noise A noticeable reduction in noise level may be obtained by using proper size piping to lower the water velocity. Flow velocities of the order of 6 ft/sec or less in domestic systems have been found to be quite acceptable. Specified flow capacity requirements can be met and a substantial reduction in noise can be obtained by using both pressure regulators and larger diameter piping in the plumbing system.

(e) Use of flexible connectors and air chambers:

Flexible connectors should be used in coupling supply and drain pipes to vibrating appliances such as pumps, garbage disposers, clothes and dishwashers. Since such appliances frequently have electrically operated shut-off valves, air chambers or other shock absorbing devices should be installed in supply and drain lines to prevent water hammering of the plumbing system. The air pockets, rubber inserts or spring elements in such devices act as shock-absorbing cushions.

(f) Use simple plumbing layout:

A well designed plumbing system with a minimum of fittings and bends is substantially less noisy than a complicated layout. Proper size fittings and large-radius elbows or bends should be used for improved performance.

(g) Location of supply and drain pipes away from quiet areas:

In order to prevent the transmission of noise into bedroom areas, supply and drain pipes should not be installed in walls common to bathrooms and bedrooms. Piping should be installed in partition walls which separate adjacent bathroom or kitchen areas. Supply and drain pipes must be isolated from internal studding or wall surfaces.

(h) Sealing around pipe penetrations:

To prevent noise leaks, seal all openings around pipe penetrations through wall and floor structures with a non-setting waterproof caulking compound. Party walls between bathrooms should be completely finished to floor level on both sides, particularly in back-to-back tub and/or shower installations. Failure to surface the walls behind tubs results in serious noise transmission problems. Likewise, both subflooring and finish flooring in bathroom areas should be completely finished before tubs and shower stalls are installed. Solid core doors with gaskets and drop-closures should be used in bathroom areas to ensure much needed privacy.

(i) Pipe enclosures:

Large diameter supply and drain pipes, particularly in high pressure systems, frequently radiate considerable noise. Such pipes should be boxed in gypsum board enclosures, preferably lined with acoustical material. An alternate, though somewhat less effective, technique is to enclose the pipes in thick glass fiber jackets with heavy impervious outer coverings of plastic or leaded-vinyl materials. It has been suggested that the glass fiber jackets should have a density of about 6 lb/cu ft and a thickness of at least 3 inches. The impervious covering should weigh at least 1 lb/sq ft.

Most of the above techniques used for the control and reduction of plumbing noise are illustrated in the following chapter.

C. HEATING AND AIR-CONDITIONING SYSTEM NOISE

The increasing severity of the noise problem associated with heating, ventilating and air-conditioning systems is due primarily to the current trend toward installation of the following types of systems:

(1) small, individual, apartment-size units in medium rise, garden-type or townhouse buildings. Such units feature small-diameter, high-speed, motor-coupled blowers and simplified supply ducts with open corridors serving as centralized returns, and

(2) high-pressure, high-velocity, large centralized systems with complex distribution networks in multistory or high-rise buildings.

I. Closet Installation of Heating and Air-Conditioning Equipment:

The conventional apartment-size heating and air-conditioning installations are notoriously noisy. Tenants complain vehemently that their sleep is seriously disturbed due to the excessive operational noise of the system. The noisy equipment is a constant source of irritation and annoyance even during their leisure hours. Tenants must tolerate the racket or else suffer the discomforts of a poorly heated or air-conditioned apartment when the equipment is turned off.

An examination of a typical installation shows that the noise problem is due to the following factors.

(a) Location of unit.

For economic reasons, the unit is generally installed at a central location in the apartment. As a consequence, the disturbing noise is radiated in all directions throughout the apartment with equal facility. The unit should be installed outside the apartment or in a kitchen or laundry area which is far removed from noise sensitive areas.

(b) Closet enclosure:

The central hall closet, in which units normally are installed, is generally of wood stud and gypsum board construction with louvered doors. As a consequence, the furnace or air-conditioner noise radiates with virtually undiminished intensity from this acoustically weak enclosure. For adequate sound insulation, the closet walls should be of double stud or resilient element construction surfaced with double layers of gypsum board. Single masonry walls sealed with masonry paint or plaster also would provide adequate sound insulation. The closet should be closed with a solid core door equipped with a perimeter rubber gasket seal and drop closure. A small fan housed in a lined duct could be used for forced ventilation of the closet enclosure, if necessary.

(c) Blower:

Most apartment-size heating and air-conditioning units come equipped with high-speed motor-coupled blowers which are frequently the chief source of noise. Large diameter, low-speed belt-driven blowers are substantially less noisy, all other factors being equal.

(d) Central return duct:

The installation of the central return of a typical individual apartment size heating and air-conditioning system has two serious shortcomings. The central return usually is coupled to the blower by a short-length, unlined duct with a relatively large cross-sectional area. As a result of the short transmission path and the lack of acoustical lining, the return duct transmits and radiates the motor-blower noise with undiminished intensity. Since there are no return ducts in individual rooms, entrance doors are undercut approximately one inch at the bottom to provide passage of the air and thus complete the circulation system. Unfortunately, the large air gaps under the doors are extremely efficient flanking noise paths which effectively nullify the sound insulation of intervening partition walls between adjoining rooms.

A practical solution to these problems involves:

(1) installing a flexible boot at the blower end of the return duct,

(2) lining all interior surfaces of the return duct with sound absorbing material,
(3) installing solid-core doors equipped with threshold seals in noise sensitive areas such as bedrooms and bathrooms,
(4) installing in each room an air return which consists of both an acoustically lined cavity within the wall and two grille openings vertically staggered about six feet, similar to that shown in Figure 8.34,
(5) installing approximately 5 lineal feet of acoustical lining in supply ducts, preferably at the grille or discharge end. This would provide a substantial reduction in noise from these outlets.

(e) Installation:

In most central-closet installations, the heating and air-conditioning equipment is mounted directly on the floor with all ducts coupled directly to wall structures. As a consequence, the wall and floor structures are set into vibration and reradiate the noise with increased intensity. Placing vibration isolators under the equipment and using flexible boot connectors on supply and return ducts should reduce the noise output significantly.

Most of the control measures given above are illustrated in Figures 8.32 through 8.36.

II. <u>Central Building Installation of Large Heating and Air-Conditioning Systems</u>:

The high-pressure heating and air-conditioning installations in large multistory buildings frequently are very noisy and give rise to numerous complaints from the occupants.

Causes or Sources of Noise:

Owing to the complexities of such installations, noise may be generated in a number of ways. The principle sources of noise are:

(a) Turbulent air flow:

Turbulence in a duct system may be caused by high velocity air flow, pulses created by blower blades, or the flow of air around sharp bends or ragged edges.

(b) Resonance, pulsation, flexing, and drumming of duct walls:

Most air distribution systems with thin-wall sheet metal ducts can be easily excited into resonance by the flow of air impinging on the duct walls and fan or motor vibration. Because of the thin-wall construction and the lack of bracing or stiffeners, duct walls will pulsate under the impact of the turbulent air. Direct coupling of fans or motors to a duct system frequently causes the system to vibrate or drum at frequencies associated with the fan or motor speeds. The rattling or buzzing of a duct system often is caused by loose connections which permit ducts to vibrate against each other or their supports.

(c) Mechanical noise and vibration:

Mechanical noise generated by the operation of motors, compressors, pumps, fans or blowers is transmitted along the air stream within the duct system. The main sources of mechanical noise are ball and roller bearings, motor commutators and brushes, belts and pulleys and fan or blower blades. The air pulses from blower blades usually generate pure tone at frequencies associated with the number of blades passing a fixed point per second.

Mechanical vibration in a heating and air-conditioning system usually is caused by improper dynamic balance or alignment of rotating units such as fans, blowers, pulleys and motors. Defective ball or roller bearings and bent shafts or axles may also be sources of vibration.

Methods for the Control of Heating and Air-Conditioning System Noise.

If noise problems associated with heating and air-conditioning equipment are to be avoided, careful consideration must be given to the proper design and installation of the three major integral parts of the system; namely:
(a) the mechanical equipment, which includes furnaces, blowers, fans, motors, compressors and pumps, (b) the air distribution or duct systems which include main supply and return ducts as well as branch networks, and (c) the terminal units, which include induction units, diffusers and grilles.

To ensure a proper installation, the architect should consider each part separately in the order listed, since this represents the means by which noise is transmitted from the source to the receiver, the building occupant. The following noise control measures should be observed.

Heating and Cooling Equipment

(a) Selection of equipment:

Equipment should be selected on the basis of low noise output. The more progressive manufacturers provide sound power ratings of most types and sizes of equipment they market. Such ratings, which frequently contain sound power levels in various frequency bands under different load conditions, are useful for acoustical design purposes. A few salient points worth remembering are:

1. It is less expensive to install quiet equipment than to reduce the noise output of a cheaper unit by costly acoustical treatment or construction.
2. Centrifugal fans are less noisy than vaneaxial fans, all other factors being equal.
3. For a given flow capacity, large-diameter, slow-speed, belt-driven blowers are substantially less noisy than small-diameter, high-speed motor-coupled blowers.
4. For purposes of noise control, it is more advantageous to install equipment with output capacities which are greater than required instead of installing smaller units which must labor continuously at maximum speed in order to meet the building's minimal heating or cooling requirements.

(b) Location of equipment:

Basement or slab-on-grade locations, far removed from living quarters, are preferred for medium-sized heating and cooling installations. Roof top or intermediate floor-level locations should be avoided, particularly in multistory buildings of light frame construction. Such locations usually give rise to serious noise and vibration problems, which often are difficult and expensive to correct.

Extremely large or heavy duty equipment associated with high-rise buildings should be installed either in sub-basement areas or in separate buildings of windowless masonry construction, located a minimum of 200 feet from the nearest apartment bedroom area. In many instances, housing such equipment in separate buildings is considerably cheaper than the expensive sound insulating constructions required for in-house operation.

(c) Acoustical construction of equipment rooms:

Noise levels in equipment rooms which house heavy duty heating and air-conditioning equipment frequently exceed 90 dB. If such rooms are near noise sensitive areas, a high degree of acoustical separation or isolation between the areas will be required to prevent serious noise complaints. Either double wall construction or the use of closets, corridors or storage areas as buffer zones is essential, in both horizontal and vertical directions.

Double doors of solid core construction or heavy, thick refrigerator type doors should be used in the equipment room. Since such rooms generally are quite reverberant, thick sound absorbing material should be applied to the ceiling and 50% of the wall area. All penetrations through wall and floor ceiling structures must be carefully sealed to prevent noise leakage. All ducts must be of heavy, double wall construction with innermost surfaces lined with acoustical material. Refer to Figures 8.44 through 8.47.

(d) Installation of equipment:

1. Vibration isolation of equipment:

Very large and heavy blowers, motors, compressors, pumps and calming chambers should be mounted on concrete inertia blocks or bases which weigh at least three and preferably five times the combined weight of the supported equipment. The inertia block should then be isolated from the structural floor slab by means of vibration isolators. The architect should engage the services of vibration engineers in designing the installation of large, heavy-duty equipment.

In installations of lighter or smaller units, it might be sufficient to mount the equipment on a heavy plywood base which rests on a resilient underlayment. Such equipment may be mounted directly on the basement or on-grade floor slab providing that part of the slab directly under the equipment is structurally isolated from the main building slab by perimeter expansion joints.

All rotating and reciprocating equipment should be dynamically balanced to minimize vibrational resonance of fan blades, structural frames, metal panels or component parts. Proper alignment between motor and belt-driven or shaft-coupled units such as blowers, circulating pumps and compressors is essential for quiet operation. All pipe and electrical lines should be connected to the equipment with flexible connectors.

2. Vibration isolation of ducts from equipment.

In most vibration isolated heating and air-conditioning installations, one of the greatest and most frequent mistakes is made at the discharge end of the blower. In a typical installation the discharge port of the blower is connected by means of a flexible boot to a short-length header duct of approximately the same cross sectional area. This header duct generally feeds into a vertical riser of the main supply duct system which is rigidly supported from the ceiling slab by tie rods.

The point that invariably is overlooked in such installations is that the flexi le boot cannot isolate the ductwork from the vibration of the blower housing. The intense air-flow turbulence, which is generated by the blower blades, is carried beyond the flexible boot with undiminished intensity and causes flexing and pulsation of the duct walls and severe vibration of the header and riser ducts. As a consequence, not only is the flexible boot rendered useless, but the effectiveness of all acoustical lining or sound silencers within such ducts is short circuited, since they are component parts of the vibrating source.

The vibration due to turbulence in a typical installation is many times greater than that due to mechanical vibration of the motor-blower unit. Of course, if one eliminated the turbulence by reducing the blower speed or removing the blower blades, the flexible boot would be most effective in isolating the ductwork from the mechanical vibration of the motor-blower unit. Unfortunately in most cases, this cannot be done without seriously reducing the efficiency of the heating or cooling operation.

The practicable solution to the problem of reducing turbulence in and near the blower region involves the combined use of large-diameter, slow-speed blowers and a plenum or calming chamber on the discharge side of the blower.

3. Plenum or calming chambers:

The plenum chamber is a large volume enclosure designed to reduce air flow turbulence. It should be constructed of heavy metal or rigidly braced walls with flexible boots fitted to flared intake and exhaust ports.

The design of a plenum chamber should be based on the anticipated air flow velocity and the cross-sectional dimensions of the blower discharge port. A conservative design of a plenum chamber, which should be taken only as a guide, might have a cross-sectional area approximately ten times that of the discharge port and a length about 5 times the largest port dimension. Streamlining the chamber and inserting splitters would simplify the problem of reducing air turbulence. Lining the inside surfaces of the plenum chamber with sound absorbing materials would reduce the noise level build-up due to reverberation and hence the amount of noise transmitted along the duct passages. Refer to Figure 8.45.

<u>Ducts</u>

Because ducts are extremely efficient transmission paths of airborne and structure-borne noise and vibration, considerable attention must be given to the proper design, construction and installation of duct networks. Noise problems most common to ducts usually involve:

(a) Equipment noise:

Airborne noises from equipment are easily transmitted through the duct passages. The installation of sound absorbing lining or prefabricated sound silencers in the ductwork will substantially reduce the noise transmission.

(b) Cross talk:

Noise from one room to another is easily transmitted through an unlined duct serving both rooms. For example, this frequently occurs in a common return duct in back-to-back bathroom installations; or in common ducts in which the grille openings serving separate apartment units are too closely spaced. Such problems also arise in exposed, thin-wall main ducts which span across adjacent apartment units, even though such ducts might not have any grille openings. Domestic noises may penetrate the thin walls of the ducts in one apartment, travel through the short duct passage in the party wall and emerge through the thin-wall duct of the adjoining apartment. Noise transmission from one apartment unit to another may also occur by way of openings and holes around poorly sealed duct penetrations through wall and floor structures.

The above noise transmission paths short-circuit the sound insulating effectiveness of the intervening party walls and floor structures. The following corrective procedures should be used to eliminate the cross talk problem.

1. Separate grille openings as widely as possible and line the intervening duct run with acoustical material or install sound silencers or baffles, preferably at the party wall junction. Avoid back-to-back grille openings at all costs.
2. Where common ducts are to be exposed in the apartments, heavy-wall duct construction is essential. Double-wall acoustically-lined ducts are mandatory between high noise and sensitive areas. An alternative to such construction would involve enclosing thin-wall duct runs in gypsum board.
3. Isolate ducts from wall and floor structures at points of penetration with collars or sleeves of rubber, neoprene or other resilient material; and use a non-setting, waterproof caulk at such points to ensure an airtight seal.

(c) Duct vibration:

The turbulent air flow generated by the blower blades is the chief cause of duct vibration. In order to prevent the transfer of this vibrational energy to the building structure, the following steps should be taken:
(1) reduce the turbulence by using a properly designed blower and a large plenum chamber with flexible boots at intake and exhaust ports; (2) use resilient hangers and duct supports; (3) isolate ducts from wall and floor structures with resilient sleeves or collars at points of penetration or termination; and (4) construct ducts of heavy gage metal or use braces and stiffeners to prevent flexing and pulsation of the duct walls.

(d) Turning vanes:

Turning vanes frequently are installed at sharp bends in ducts in order to reduce the turbulence and thus minimize the noise output. Because such vanes frequently are constructed of light gage, loose fitting parts which resonate and rattle, they tend to intensify rather than alleviate the noise problem. Such problems may be avoided by using streamlined vanes constructed of heavy gage metal coated with a thick layer of vibration damping mastic. Prefabricated turning vanes made of sound absorbing materials are also efficient and quiet in operation. Loose play or back-lash in the vane mounting should be avoided to prevent rattling.

(e) Turbulence in branch ducts:

Noise from turbulence often occurs at "tee" or "ell" junctions of branch ducts and at grilles, diffusers or induction units. When the turbulence occurs very close to the discharge terminals of unlined ducts, the generated noise may be excessively high in level.

Any acoustical treatment installed in the main ducts to attenuate equipment noise cannot possibly alleviate noise problems which originate near the discharge ends of the branch ducts. The following steps should be taken to prevent the occurrence of such problems:
(1) avoid sharp edges and corners by using flared or streamline-contoured "ell" and "tee" connectors; (2) use branch ducts with sufficiently large cross-section areas or install damper plates to reduce the air flow velocity; and (3) install a minimum of 5 lineal feet of acoustical lining at the grille end of all supply and return branch ducts.

(f) Flow velocities:

High velocity air flow generates noise not only within the ducts but at the face of the outlet grille or diffuser as well. The intensity of aerodynamic noise is strongly velocity dependent and increases approximately at the rate of the velocity raised to the fifth power, in typical ventilation duct installations. Thus, for a given duct area, a doubling of the flow velocity may increase the output noise level as much as 15 to 24 dB. Conversely, for a given mass or volume flow, doubling the area of the duct effectively reduces the flow velocity about one half and may lower the output noise by 15 to 24 dB.

In discharge ducts, air flow velocities of about 15 feet per second are quite acceptable in most apartment areas. However, to be on the safe side, flow velocities in noise sensitive areas should be lowered to about 8 or 9 feet per second.

(g) Noise radiated from duct walls:

The problem of noise radiation from ductwork generally is associated with large exposed ducts constructed of light gage metal. Such noise may result from thermal expansion and contraction of the ducts or pulsation of duct walls due to air movement.

The duct systems should be designed so that a minimum number of ducts are contained within occupied areas. Large ducts which are unavoidably exposed in occupied areas should be boxed-in with gypsum board enclosures. Where large ducts cannot be enclosed, vibration damping material should be applied to the surfaces of the duct walls. Acoustical lining applied internally often serves the two fold purpose of attenuating airborne noise from equipment and acting as a vibration damper. If noise radiation from the duct system is excessive, the duct walls should be encased in a heavy plaster jacket or wrapped in a thick mineral wool blanket with an impervious plastic outer cover.

Grilles

Noises generated within induction units or at the faces of outlet grilles or diffusers give rise to numerous complaints from tenants. The intensity and characteristics of such noise are dependent upon the airflow velocity and the size and design of the outlet units. For example, high velocity air striking the face of an outlet grille often generates a high-pitch whistling noise.

Removal of the grille is a simple expedient test to determine the cause of noise. If there is no appreciable reduction in the noise output without the grille, the noise may be due to turbulence within the discharge duct or some other source farther back in the duct system. If there is a marked reduction in the noise output without the grille, it is evident that the grille was at fault and therefore should be replaced with one of better design, or the air speed should be reduced if practicable.

(a) Selection of outlet grilles and diffusers:

The following points are worth remembering when choosing outlet grilles and diffusers for quiet operation.

(1) Grilles or diffusers which radiate little noise are made of heavy-gage metal with widely-spaced streamlined deflectors devoid of any sharp corners or edges.

(2) A wide-angle diffuser which gives a large spread of air will generate substantially more noise than a small spread unit, all other factors being equal.

(3) Grilles constructed of wire mesh or perforated metal facings with large gap ratios are less noisy than those with tightly woven or small gap ratios which restrict or obstruct the air flow.

(4) For a given flow velocity, doubling the number of outlet grilles or the area of each grille increases the noise output approximately 3 dB. Conversely, if the volume of air or mass flow delivered by the grille is held constant, doubling the area of the grille will effectively reduce the flow velocity about 50%, which will lower the output noise about 15 to 24 dB.

(b) Grille location:

Care must be taken to avoid locating grilles near or in corners. The surfaces near such locations act as sound reflectors and can increase grille noise levels about 6 to 8 dB. The most favorable grille location is near the center of the ceiling. A grille installed in a wall should be at least 6 feet from a corner and as low as practicable from the ceiling edge.

D. MECHANICAL EQUIPMENT AND APPLIANCE NOISE:

The foregoing discussion concerned the noise problems associated with heating, air-conditioning and plumbing systems. In many cases, the noise from other building equipment gives rise to complaints from occupants. Examples of such noise sources are as follows.

(a) <u>Cooling Towers</u>:

Because such units usually are located on roof tops or in court yards, they often cause complaints from occupants in neighboring buildings as well as from tenants of the apartment building serviced by the units. This is particularly true when nearby apartment units are located at the same height or above the cooling tower. Generally speaking, fan noise constitutes the greatest disturbance. However, serious vibration problems frequently occur in top-floor apartment areas, due to faulty roof-top installations.

Such problems may be avoided by using equipment with large-diameter, slow-speed fans, sound absorbing baffles and vibration isolation mounts, as illustrated in Figure 8.65. Ground level installations of such equipment should be made at locations far removed from noise sensitive areas. Roof-top installations should be made on the roof of the tallest wing or section of the building, preferably above a non-occupied area.

(b) Electrical Circuit Equipment:

Automatically controlled electrical circuit equipment consisting of circuit breakers, relays, micro-switches, timing units and solenoid operated devices frequently generates humming, buzzing and clicking noises which often reach disturbing levels and are most irritating because of their impulsive and intermittent characteristics. Such equipment often is housed in large switch boxes which act as sounding boards. Flush or recessed mounting of switch boxes in wall partitions usually weakens the sound insulating performance of the wall which results in serious noise transmission problems. Such equipment should be housed in vibration isolated boxes which are surface-mounted on heavy masonry exterior walls. See Figure 8.69.

(c) Elevator Hoist Equipment:

Heavy duty motors, hoists and drive mechanisms associated with freight or service elevators should be vibration isolated to avoid serious noise problems. Elevator shafts should be surrounded with storage areas which act as buffer zones to isolate dwelling units from elevator equipment noise. See Figure 8.14.

(d) Garage doors:

During the raising and lowering operations, electrically operated overhead garage doors generate considerable impact noise and vibration in apartment units located directly above the garages. Since the impact noise is produced primarily by the overhead doors jolting against backstops and dropping onto the garage floor slab, rubber bumpers should be installed at the backstops and the base of the doors to absorb the impact energy. A further reduction of impact noise and vibration may be achieved by isolating the guide tracks and motor-driven hoist mechanism from the building structure by means of resilient mountings.

(e) Pressure Reducing Valves:

Large heavy duty reducing valves are capable of generating extremely disturbing high-pitch hissing noises. In order to isolate such noises, pressure reducing valves should be located in basement equipment rooms or in areas far removed from occupied areas. The valve should be resiliently mounted on a massive exterior wall. Under no conditions should the device be mounted on party walls, regardless of wall construction.

(f) Swimming Pool Equipment:

In roof-top swimming pool installations, tenants often complain about the noise and vibration from circulating pumps, filtration systems, shower baths and diving boards. Special precautions must be taken to vibration isolate the entire installation including the swimming pool, water supply and drain systems, mechanical equipment and all associated auxiliary or accessory equipment such as diving boards and slides. The recommendations given in both this chapter and Chapter 8 relative to the installation of plumbing systems, fixtures and related equipment should be observed whenever possible.

(g) Ventilation and Exhaust Systems:

Likewise, roof-top installations of ventilation systems, including exhaust fans and exposed duct runs, give rise to numerous complaints about fan noise, vibration and aircraft noise. Such installations must be isolated from the roof and building structures by means of resilient mounts and flexible connectors. Exposed ductwork must be of double wall construction and either lined with acoustical treatment or provided with prefabricated sound silencers or baffles. Such measures are used both to prevent transmission of aircraft noise into the duct system and to attenuate any noise within the system before it reaches occupied areas. Refer to Figure 8.63 for proper installation of roof-top ventilation equipment.

(h) Transformers:

Transformer installations in multistory buildings may be sources of objectionable low frequency humming noise and vibration, which usually are caused by vibrational resonance of cores, coils and housing. Because such noise has low frequency components which are difficult to isolate, transformers should be installed in non-sensitive areas such as basement equipment rooms or in closets surrounded by storage areas. If such locations are not available, it is recommended that transformers be installed in masonry enclosures, as illustrated by Figure 8.70. A considerable reduction in noise level may be obtained by vibration isolating the transformer from the floor and building structure. Transformers with low noise ratings are available and should be used whenever possible. Such units feature vibration mounts, good steel-core construction, single stacked lamination and varnish-impregnated cores and coils.

(i) Appliances:

Although most household appliances are noisy devices, the major noise problems are caused primarily by the faulty installation of built-in appliances, such as room air conditioners, dishwashers, clothes washers, dryers and garbage disposers. The investment of properly installing higher-priced quiet units is well repaid by fewer rental vacancies or the savings in costly acoustical treatment required to isolate noisy appliances. Some of the more common appliances which frequently cause noise problems are as follows:

1. Air conditioners: In conventional room air conditioners, the high-speed blowers radiate disturbing high frequency airborne noises, while the motors and compressors generate low frequency vibration. Such problems can be avoided by using air conditioners which feature streamlined air passages, large-diameter slow-speed blowers and vibration mounted motors and compressors. The problem can be simplified further if sound absorbing baffles and vibration damping materials are installed inside the cabinets. It is essential that the air conditioner be completely isolated from the building structure by means of a resilient collar or perimeter gasket, as illustrated in Figure 8.1.

2. Dishwashers, disposals, clothes washers and dryers: Dishwashers, disposals and laundry appliances frequently are built into kitchen cabinets, which abut or are installed along party walls. The high noise levels produced by such appliances are further magnified by the resonance and vibration of the hollow lightweight cabinets, which in turn set party walls into vibration. Solutions to this noise problem require the use of quiet appliances and, more importantly, proper location and installation of the units. Dishwashers and garbage disposals should be installed in cabinets along exterior walls. Measures should be taken to isolate the appliances from both the cabinets and the floor by means of

resilient gaskets and vibration mounts, as illustrated in Figures 8.1 and 8.2. Flexible connectors and air chambers should be installed in all water lines feeding such units. The application of sound absorbing materials inside of cabinets and dishwasher housings will improve the noise reduction.

3. Exhaust fans: Small high-speed exhaust fans commonly found in kitchen, bathroom and laundry room areas generate excessive noise and vibration. To lessen the noise problem, squirrel cage or centrifugal fans should be used whenever possible in lieu of vaneaxial fans. Fans should be isolated from exhaust ducts with rubber mounts, as illustrated in Figure 8.3. The use of sound absorbing material in the exhaust duct should provide a noticeable reduction in noise output.

4. Sewing machines: Sewing machines have become virtually household necessities among large families and the cause of increasing noise complaints from occupants. As a matter of convenience, housewives usually locate and use the machines in bedroom areas, which of course disturbs the neighbors in bedrooms adjacent and below. One method of alleviating this problem is to caution occupants about locating their sewing machines against party walls and recommend that they place rubber mounts under the legs of the machine cabinet. Such mounts should be provided by the apartment management in order to gain better co-operation from the occupants.

5. Small appliances: Small household appliances such as electric can openers, knife sharpeners, mixers, ice crushers, blenders and pencil sharpeners, are troublesome sources of noise and vibration, especially when such devices are mounted on lightweight walls or are used on counter tops. The only effective way of dealing with this noise problem is to restrict tenants from mounting such appliances on walls and to provide them with small sponge rubber pads on which to place their appliances.

6. Televisions, radios, stereo sets, pianos: Although these devices are primarily sources of airborne noise, they are capable of generating a considerable amount of low frequency noise and vibration. This is especially true of the large, multispeaker, high fidelity units. When musical scores or orchestrations rich in bass are played, the vibrations of the loudspeaker are transmitted through the cabinet enclosure and legs to the supporting wall or floor structures, which in turn are excited into vibration. Such problems may be avoided by placing suitably designed rubber mounts under the legs of the cabinets or pianos. A rubber pad with a top plate of steel or hardboard should be used to provide a uniform distribution of the load. Such mounts are effective vibrational isolators if they retain their compliance under load. In the case of built-in-wall sets, the cabinets should be encased in rubber gaskets to prevent mechanical contact with the wall structure.

7. Central vacuum cleaner systems: Where such a system is installed, tenants frequently complain about the high pitch noise generated by the turbine-type blower and the hissing noise produced by the high velocity air rushing through the thin-wall plastic tube network. In most installations, the large tank-type cleaner is located in a basement area where it is mounted on an exterior wall, which is vented to discharge the fine dust particles. By virtue of this direct coupling, the wall transmits and radiates the noise and vibration from the motor and blower. The

plastic tube network is rigidly coupled to the inner framework or wall and floor structures, which in turn radiate the noise generated by the high-velocity, turbulent air flow.

A considerable reduction in noise output may be obtained by: (a) using rubber sleeves around the tubing to isolate it from the wall and floor structures, (b) isolating the tank unit from the wall by means of resilient mounts, (c) installing flexible connectors between tubing and wall outlets, tank unit and discharge vent, (d) enclosing tank unit in outer metal jacket with mineral wool lining and (e) installing a muffler on discharge vent.

8. Electronic air filters: Tenants of luxury apartments occasionally complain about the loud, sharp, snapping noises produced by the electronic air filter unit installed in the heating and air-conditioning system. Dust particles passing through the ionizing cell of the filter are given an intense electrical charge and are collected by highly-charged electrical plates. Abnormally large dust particles occasionally short across the electrical plates and cause arcing, which produces the objectionable snapping noise. This condition is most prevalent in newly constructed buildings in which a considerable amount of airborne dust may be present in the duct system and room areas. The problem eventually corrects itself as the air is filtered free of the larger dust particles through normal usage of the heating/air-conditioning system. However, the installation of acoustical lining in supply and return ducts for the purpose of attenuating mechanical equipment noise will alleviate the electronic filter noise problem as well.

E. LOW FREQUENCY VIBRATION FROM EXTERNAL SOURCES:

Low frequency vibrations from industrial or commercial operations, railroad, subway and truck traffic may give rise to complaints from occupants of buildings erected near such sources. Since it is difficult to prevent the transmission of low frequency vibrations into a building, the most effective way of avoiding this problem is to erect the building at a distance of at least several hundred feet from the source of vibration.

Some of the following techniques have been used with varying degrees of success to insulate buildings from externally induced low frequency vibration.

(a) Base Plates:

Buildings have been erected upon thick base plates of lead, asbestos, cork or bituminous materials which were sandwiched between the superstructure and the supporting footings, foundations, piers and columns.

(b) Cork Jackets:

In buildings of steel frame and masonry construction, cork jackets have been wrapped around steel girders to prevent vibratory transmission between the exterior masonry walls and the structural frame of the building.

(c) Trenches:

The effectiveness of trenches cut into the ground between the building and the source of vibration is highly dependent on the nature and properties of the ground and the foundation bed on which the building is erected. If the building rests on a foundation bed of firm dry gravel and the ground above is hard packed clay or sand, a trench which is cut down to the gravel bed and filled with loose gravel may attenuate low frequency vibration before it reaches the building. Rock, clay, chalk and sand are considered to be relatively good transmitters of vibration, whereas gravel is a rather poor conductor.

(d) Gravel Backfill:

Foundation walls are particularly susceptible to low frequency vibration, due to their exposures of large surface areas. As a precautionary measure to minimize the transmission of low frequency vibration. gravel should be used as a backfill against such walls, especially on that side of the building which faces the source of vibration.

(e) Smooth Street Pavement:

The problem of vibration from heavy street traffic can be eased considerably if streets or roads are paved with thick smooth-surface asphalt. In cases of concrete roads, care should be exercised to make the joints between concrete slabs as small as possible and to ensure that the slabs are flush and level, particularly at the joints.

CHAPTER 8

PRACTICAL SOLUTIONS TO CONTROL BUILDING NOISE

Although proper planning, selection and good acoustical design relative to building sites, space arrangement, wall and floor structures, and building equipment and services are essential for the overall successful control of building noise, careful supervision must be exercised during the "crucial stage" of actual construction or the costs and efforts previously expended for this purpose might be wasted. As a consequence, there is provided below and throughout this chapter a series of warnings, precautions and suggestions in the form of a check list and more importantly an extensive collection of detailed architectural drawings which illustrate acoustically important building construction and installation techniques. In these drawings, emphasis is placed primarily on the recommended techniques and methods of construction and installation and not necessarily on the types of wall and floor structures illustrated.

These drawings should not be considered as representing the only possible solutions to the control of the overall building noise problems; they are offered as examples of the techniques that might be used for this purpose. Various types of wall and floor structures and indeed different installation techniques, other than those illustrated, may be used provided that they are based on similar or equivalent noise control principles.

ACOUSTICAL CHECK LIST WITH ARCHITECTURAL ILLUSTRATIONS

APPLIANCES — See Figures 8.1, 8.2 and 8.3.

Cabinet-installed or built-in appliances such as dish washers, clothes washers and dryers, garbage disposals and exhaust fans should be provided with vibration isolators and flexible connectors, and the cabinets in which they are installed should be offset from the back wall with strip gasketing of such material as felt and cork. Window air conditioners should be completely vibration isolated from surrounding window frame or building structure.

BALLOON FRAMING — Avoid using balloon framing in wood frame construction. The open troughs between studs and joists are efficient sound transmission paths.

BUFFER ZONES — Hallways, storage areas, closets with closed unlouvered doors may be used quite effectively as buffer zones to gain additional sound insulation between dwelling units; or between such units and somewhat noisier areas, such as elevator shafts and laundry rooms.

CARPETS — Use carpets and pads particularly in heavy pedestrian traffic areas such as corridors and lobbies to reduce footstep and impact noise and provide additional sound absorption.

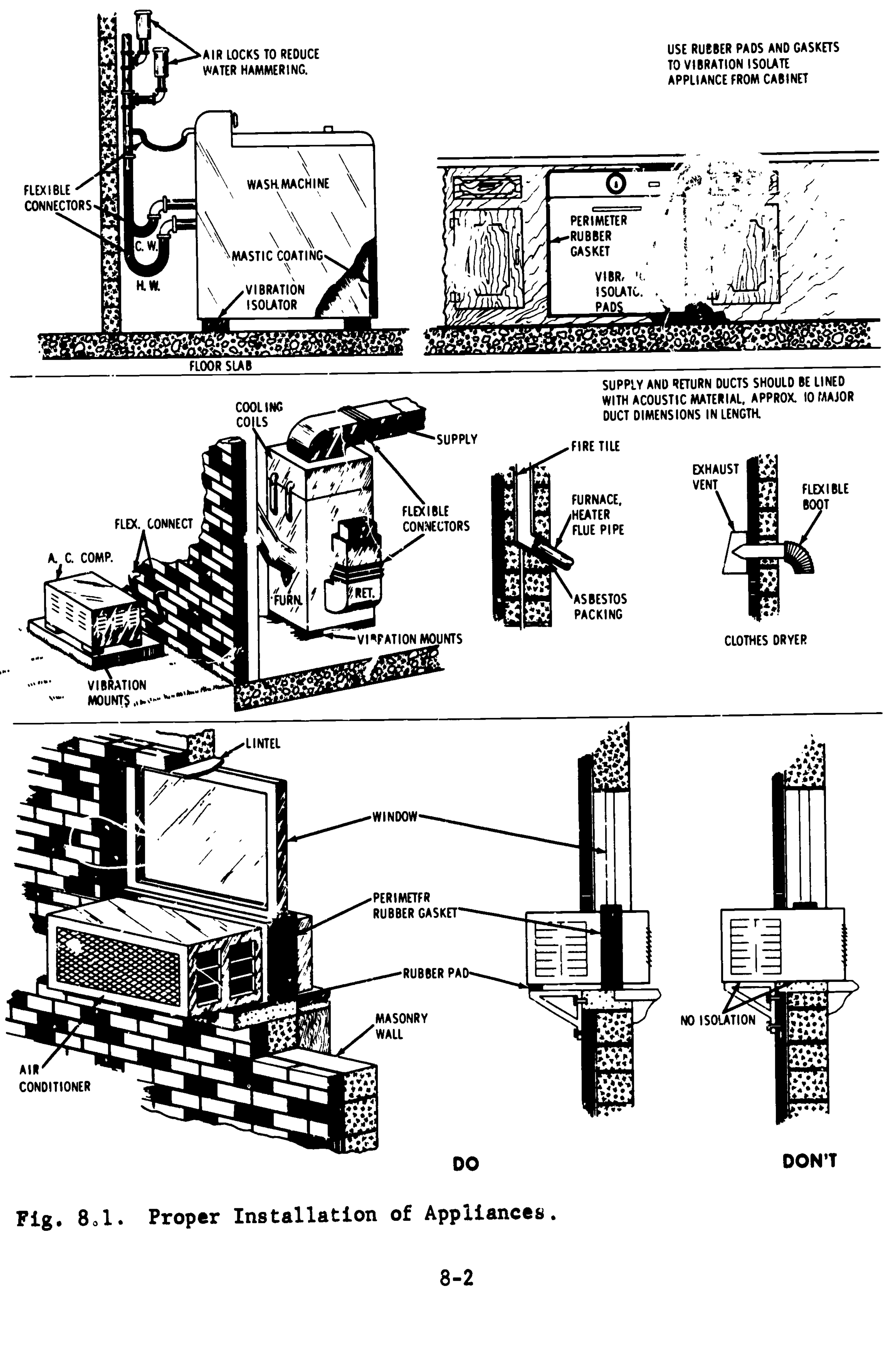


Fig. 8.1. Proper Installation of Appliances.

CEILINGS

Ceilings suspended on resilient hangers provide effective airborne and impact sound insulation. However, avoid running a continuous suspended ceiling throughout building. Installation of ductwork, grilles, recessed lights, etc. require special noise control techniques.

CINDER BLOCK

As a precautionary measure, coat exposed surfaces of cinder, masonry and concrete block walls with plaster, grouting mix or masonry paint to seal pores, poor mortar joints and other possible noise leaks, even if furred-out surfaces of gypsum board or plaster are applied later.

CORRIDORS

Because of their reverberant characteristics, corridors and hallways usually are excessively noisy. Use carpeting and/or acoustical ceilings in these areas to reduce noise build-up.

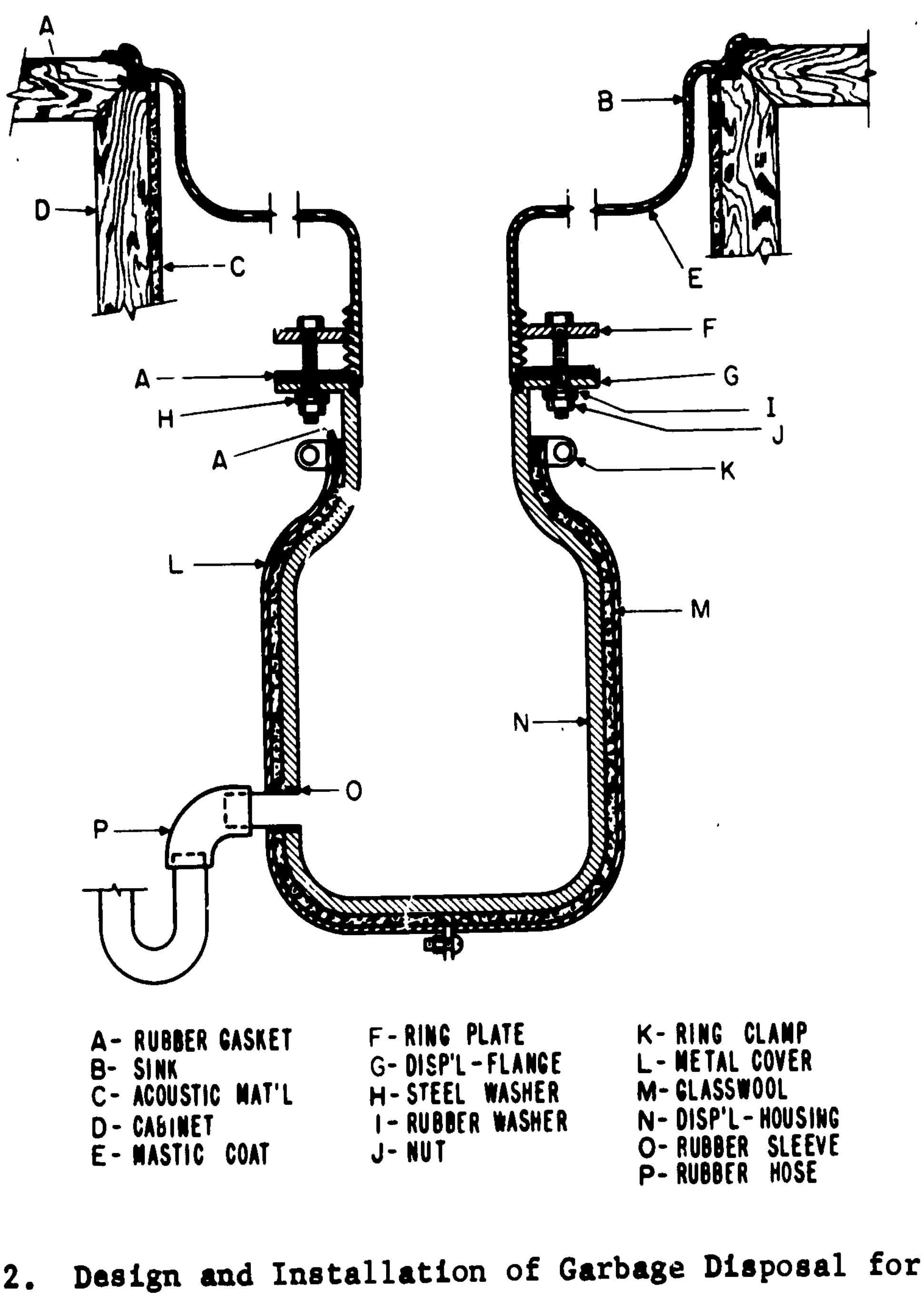


Fig. 8.2. Design and Installation of Garbage Disposal for Quiet Operation.

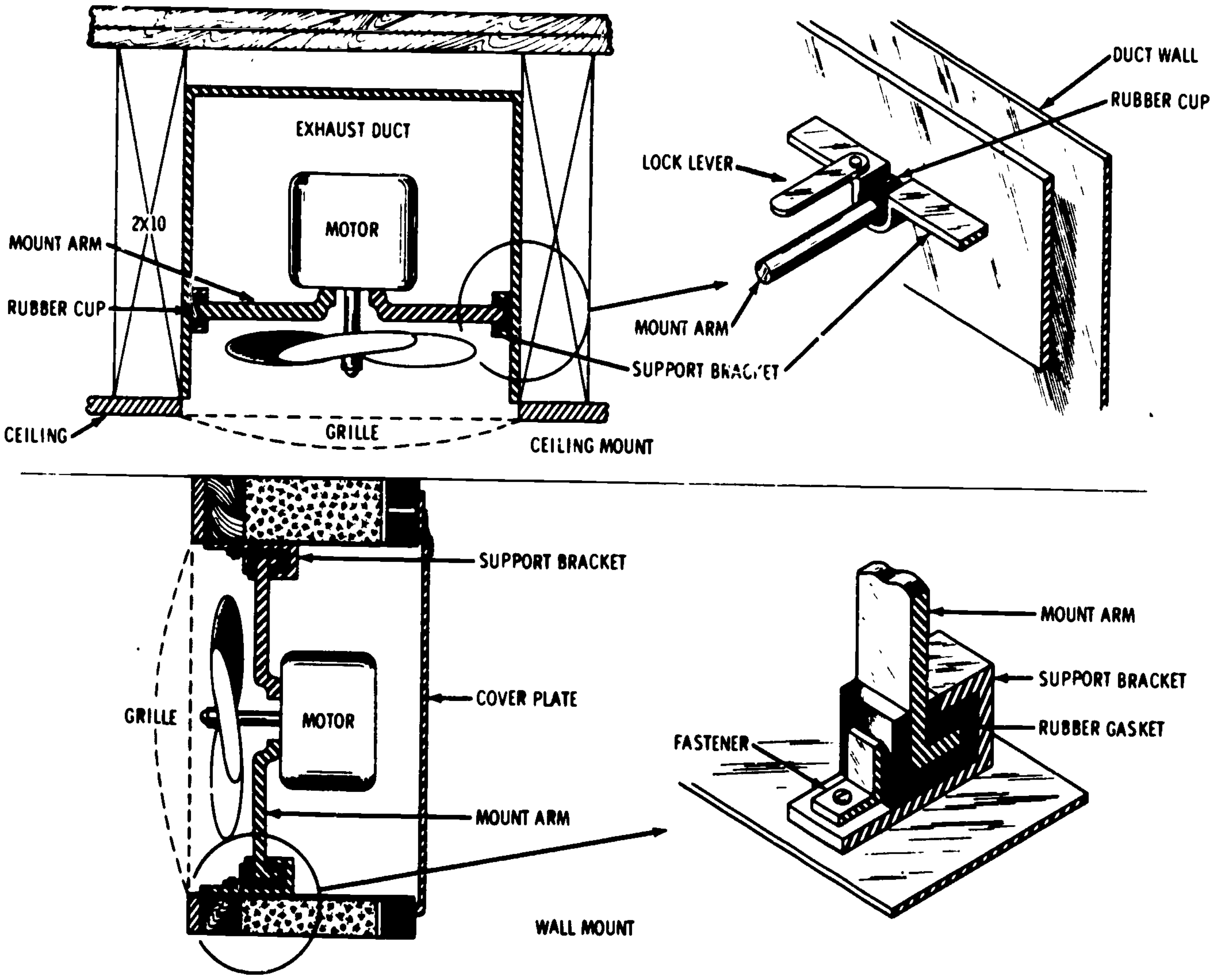


Fig. 8.3. Proper Installation of Exhaust Fan.

DOORS

See Figures 8.4, 8.5, 8.6 and 8.7.

Exterior, apartment entrance, bedroom and bathroom doors should be of solid core construction. Door closers should be installed on exterior and entrance doors to eliminate door slam noise. Entrance doors should be staggered. Gaskets and drop closures should be installed on bedroom and bathroom doors. Sliding or folding closet doors should be installed in tracks which are vibration isolated from adjoining walls or ceilings.

Door knockers are noisy nuisances which could well be eliminated in multifamily dwellings without inconvenience to the occupant. Door chimes should be used in lieu of door knockers. When installed on non-party walls inside dwelling units, door chimes are less apt to disturb the neighbors. If door knockers are to be used, vibration isolating mounting is required.

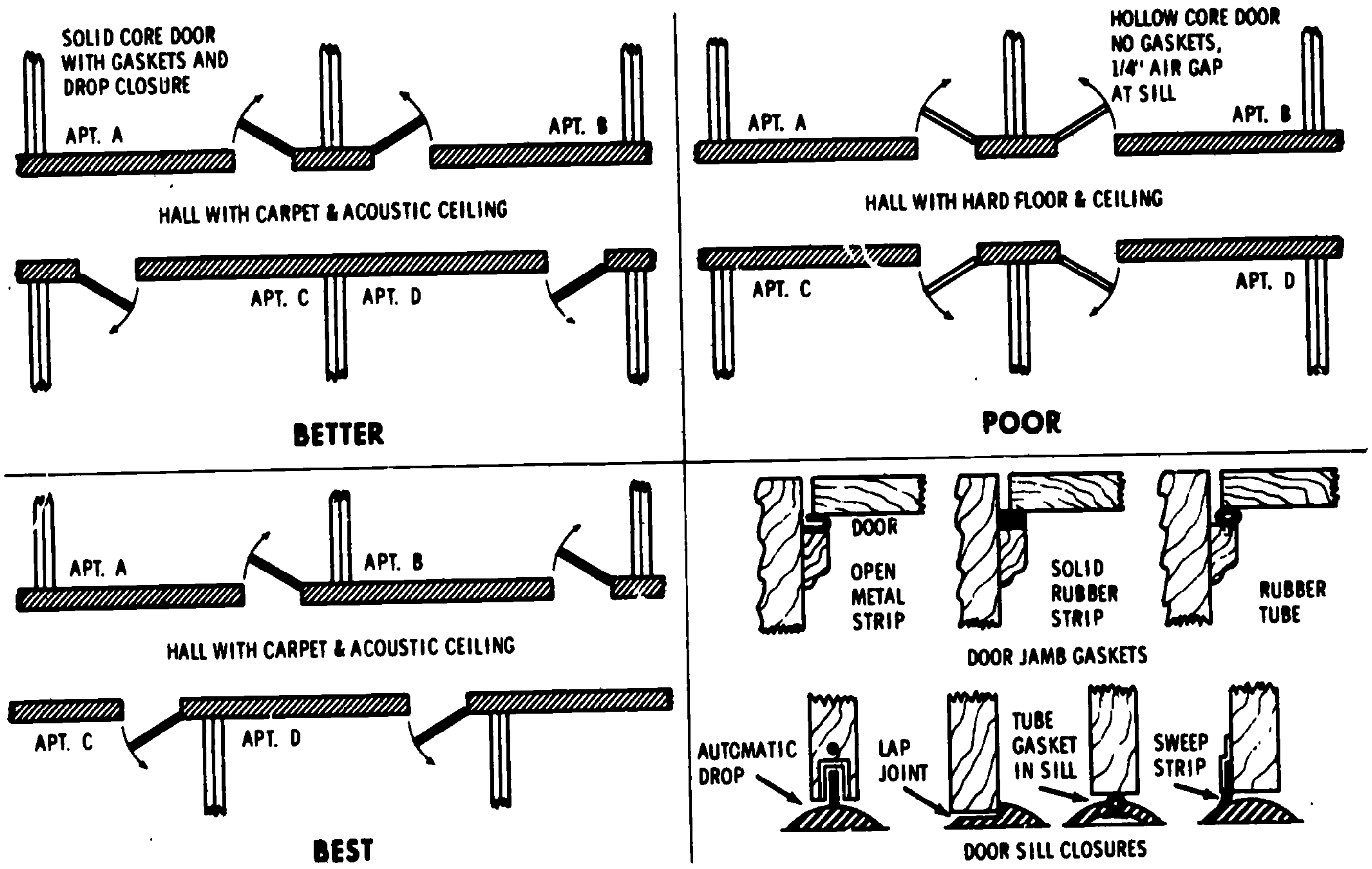


Fig. 8.4. Acceptable Locations and Gasketing of Doors.

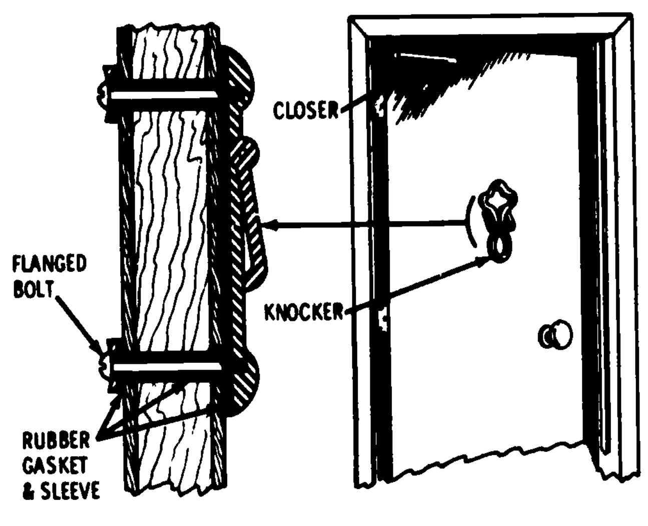
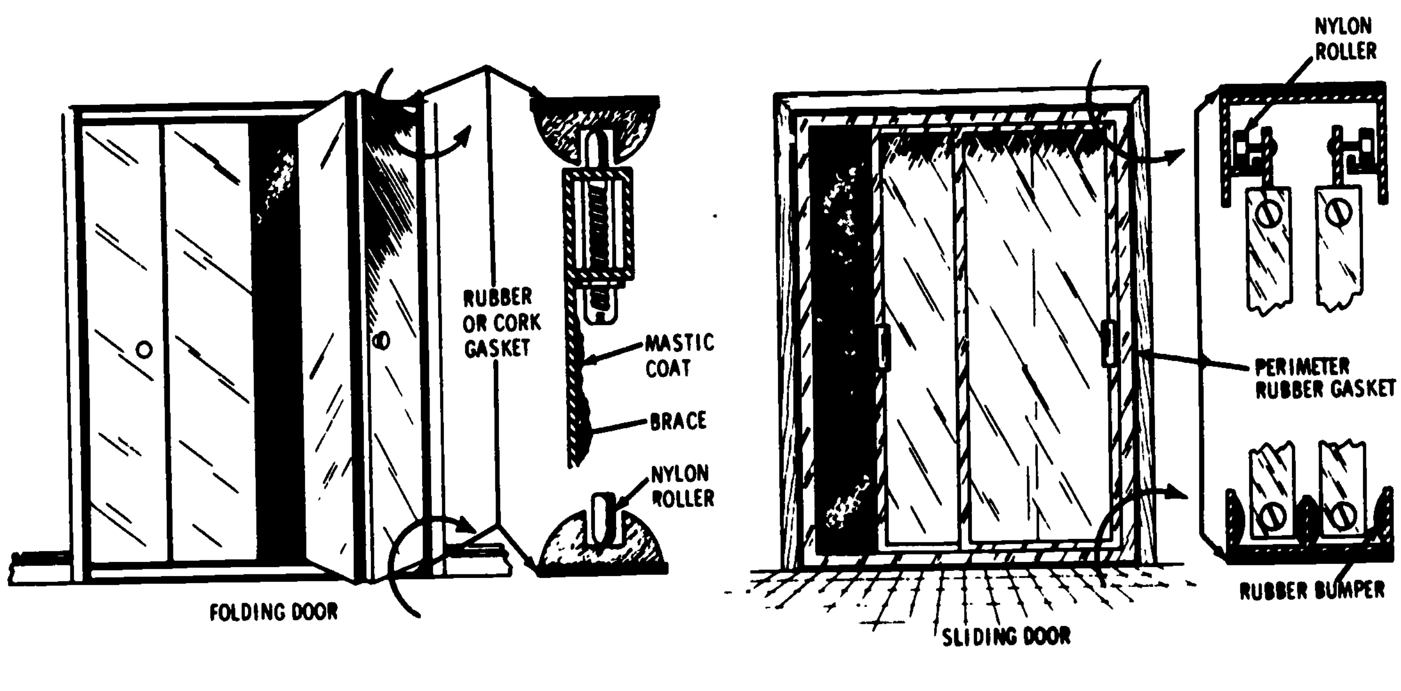
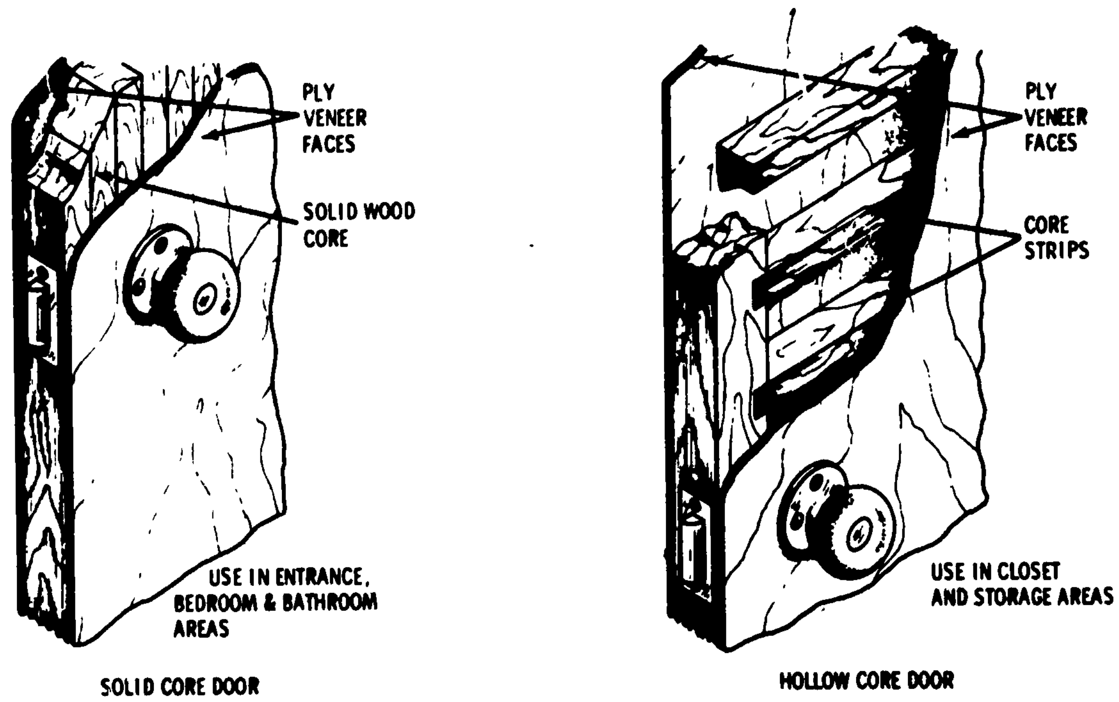


Fig. 8.5. (On the Left)
Mounting of Door Knockers.

Fig. 8.6. (Below)
Proper Installation of
Folding and Sliding Doors.





-·-·- 1 3/4" solid wood core door with gaskets and drop closure

—— 1 3/4" hollow wood core door with gaskets and drop closure

- — — Same hollow door, no gaskets or closure, 1/4" airgap at sill

········· Louvered door, 25-30% open area

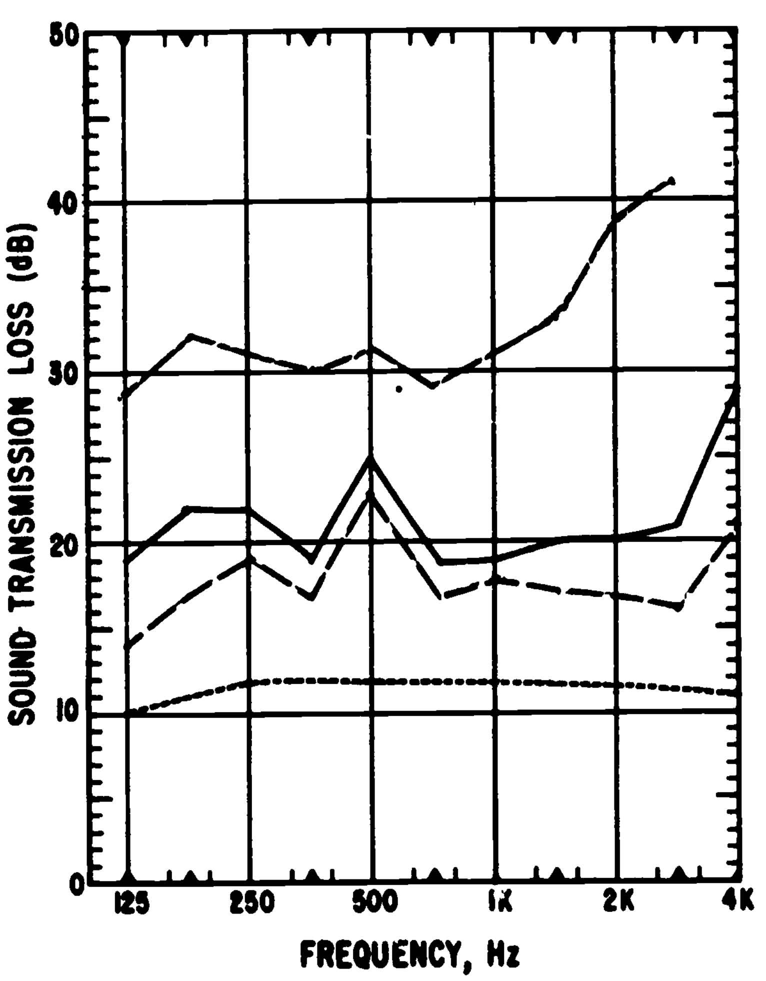


Fig. 8.7. Sound Transmission Loss of Doors.

DUCTS

See Figures 8.8, 8.9, 8.10, 8.11 and 8.12

Since ducts are extremely efficient sound transmission paths, considerable precaution must be taken to avoid cross-talk, ventilation, combustion and equipment noise. Avoid running ducts as a common supply or return between dwelling units, unless such systems are properly baffled and lined with sound absorbing material. The common practice, in wood frame structures, of using troughs between joists as a common return duct between dwellings results in very serious noise transmission problems. Caulk or seal around ducts at all points of penetrations through partitions. Use double-wall ducts, acoustical lining, flexible boots and resilient hangers where required. Dwelling units should be serviced by separate supply and return ducts which branch off a main duct system.

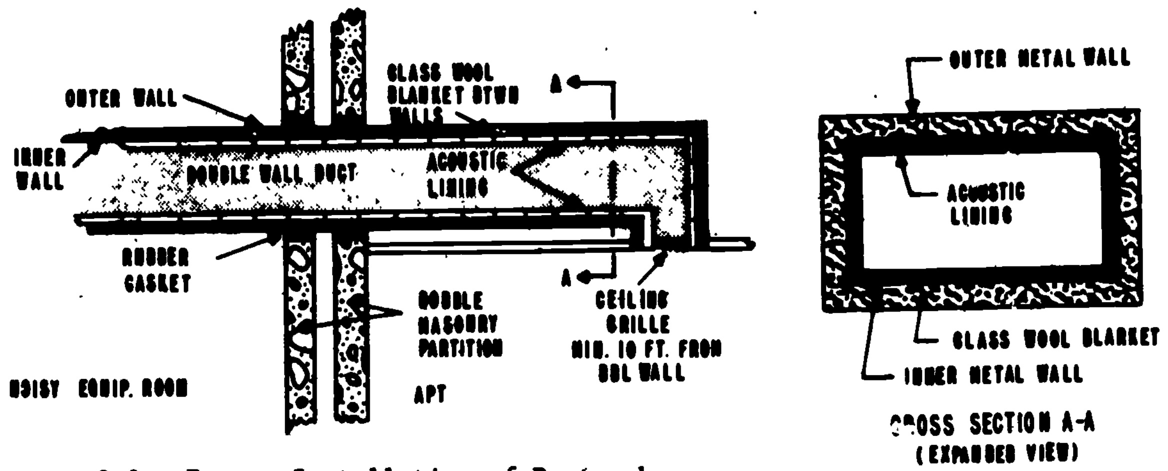


Fig. 8.8. Proper Installation of Ductwork.

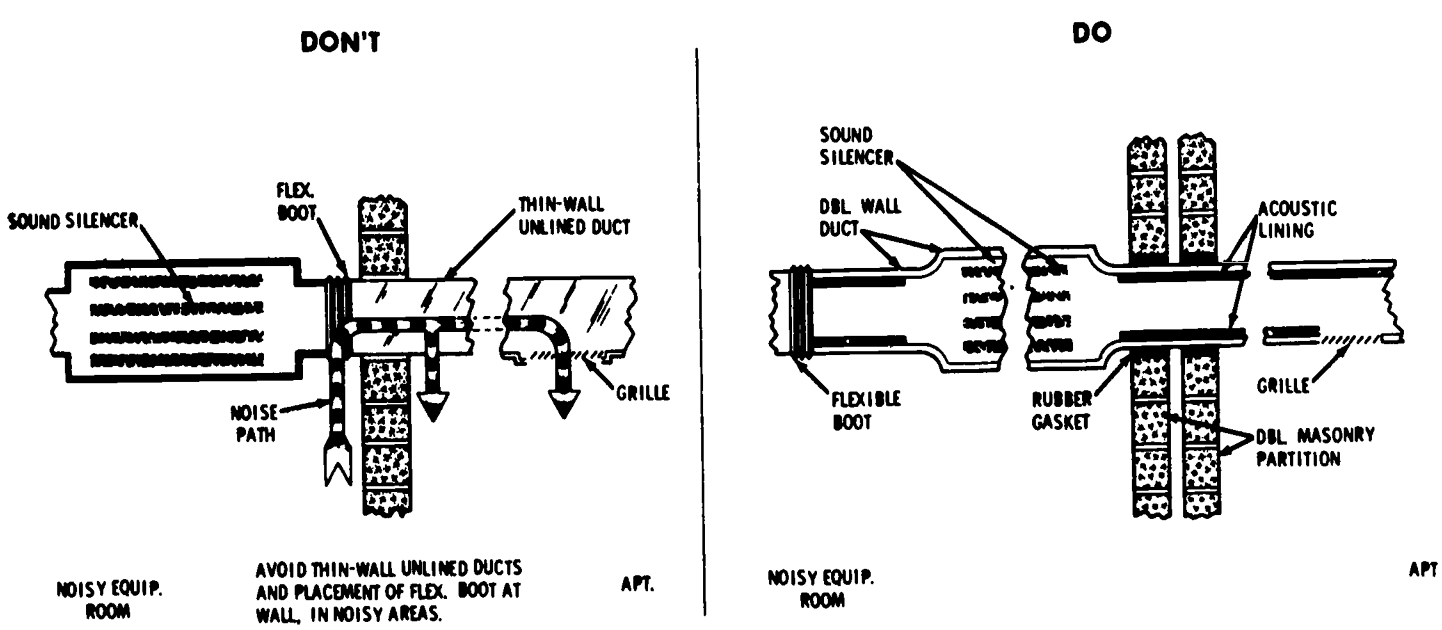


Fig. 8.9. Installation of Ductwork through Equipment Room Wall.

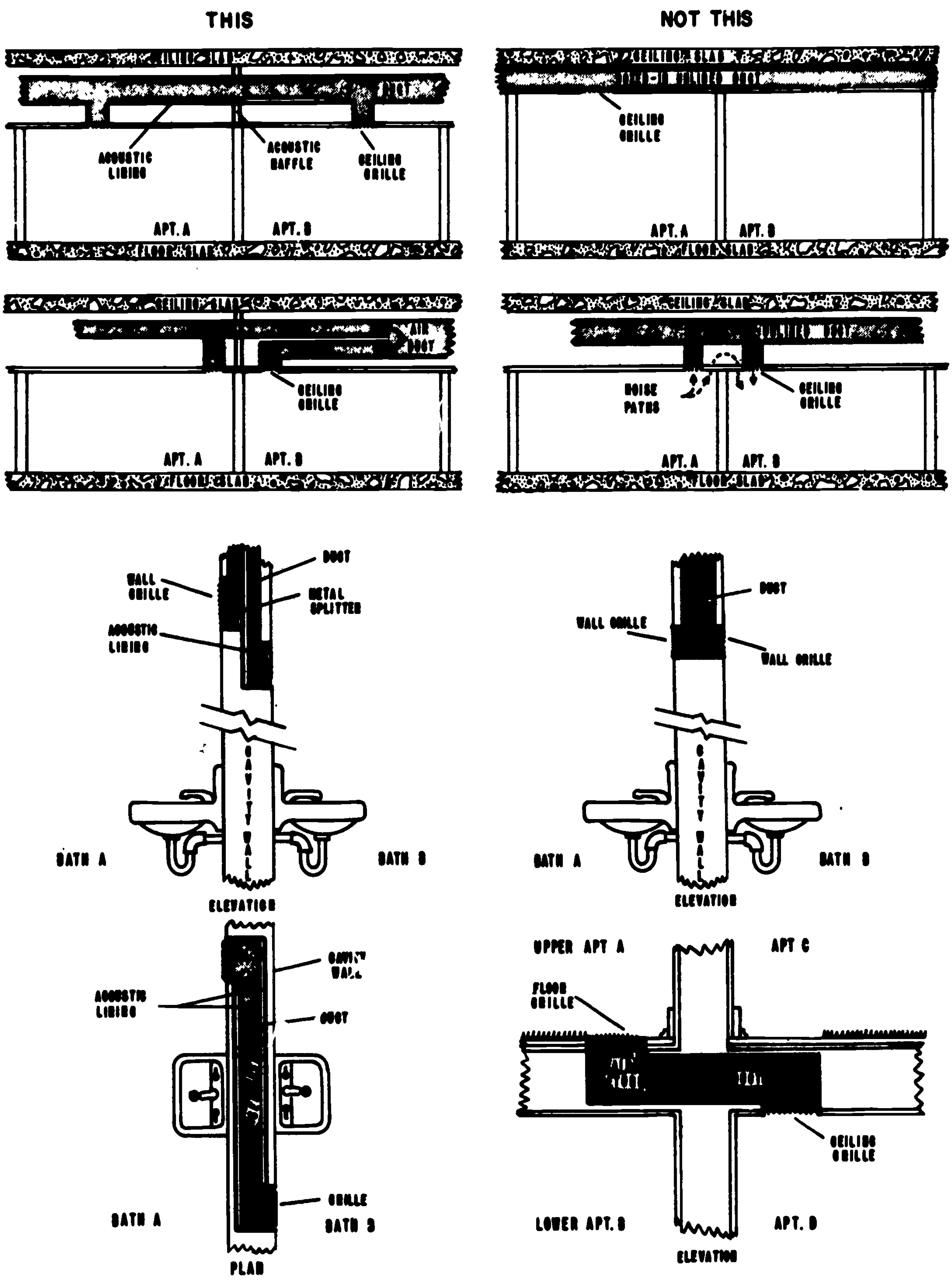
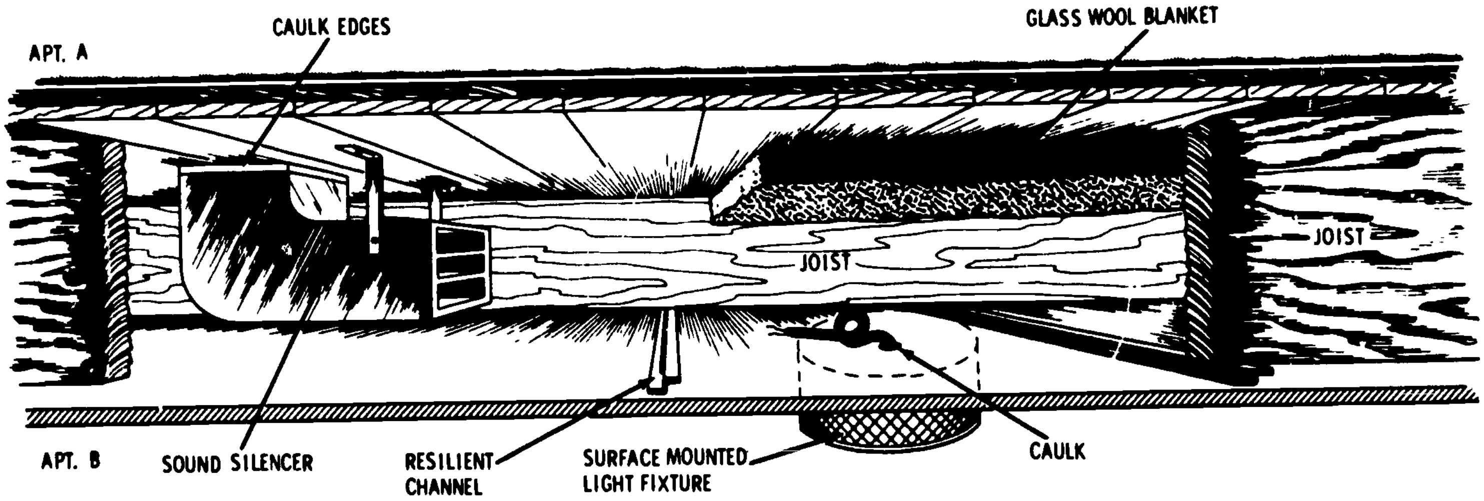


Fig. 8.10. Proper Installation of Ductwork.

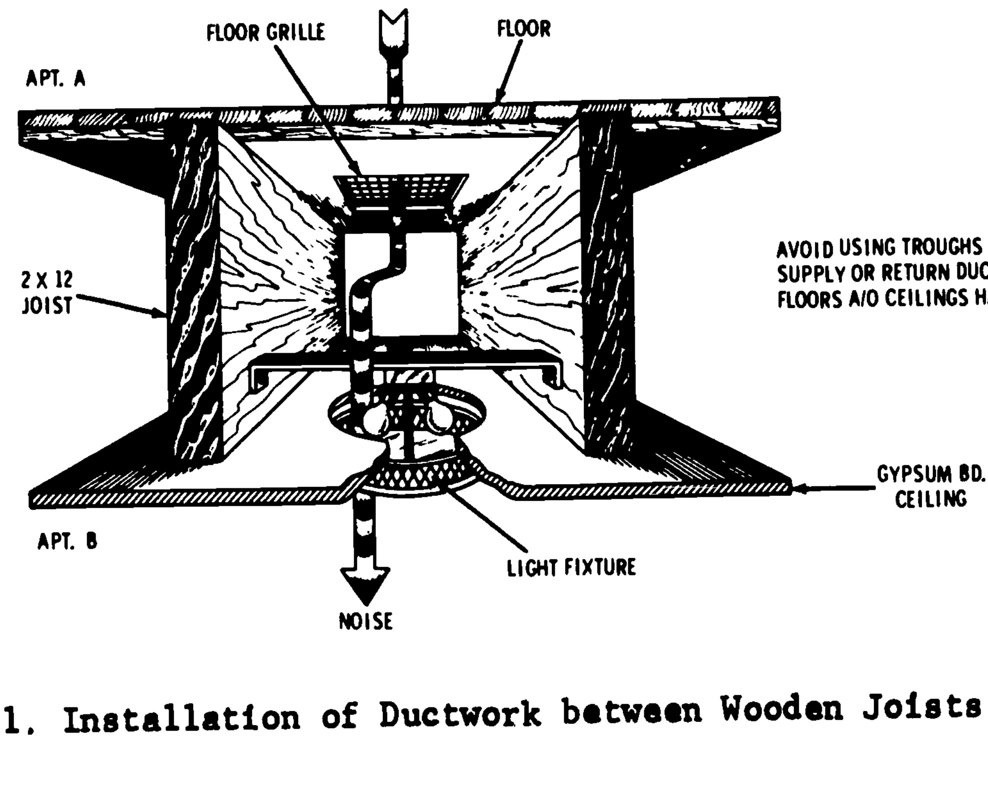
DO



WHEN TROUGHS BTWN. JOISTS ARE USED AS RETURN DUCTS, INSTALL SOUND SILENCERS IN ALL VENT OPENINGS, MINIMIZE AND CAULK OR SEAL PENETRATIONS AND USE SOUND ABSORBING LINING OR BLANKETS.

The above installation generally is not recommended in design of new buildings, but may be used to some degree as a corrective measure in existing buildings with the type of noise problem illustrated below.

DON'T



AVOID USING TROUGHS BTWN. JOISTS AS SUPPLY OR RETURN DUCTS, ESPECIALLY WHEN FLOORS A/O CEILINGS HAVE FIXTURE OPENINGS.

Fig. 8.11. Installation of Ductwork between Wooden Joists.

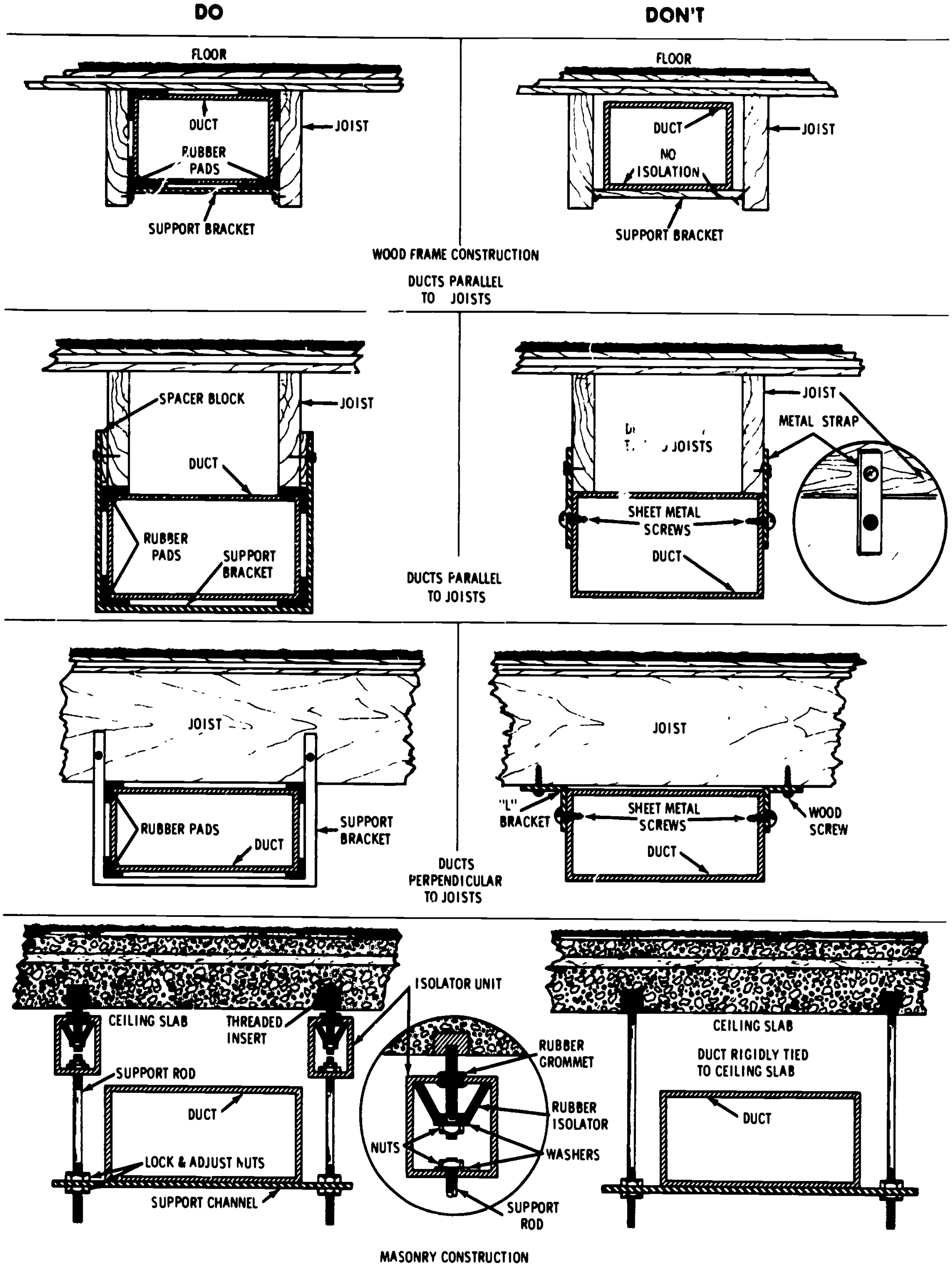


Fig. 8.12. Installation of Duct Hangers and Supports.

ELECTRICAL FIXTURES

See Figure 8.13.

Avoid back-to-back installation of electrical outlets in party walls. Avoid short-circuiting of double walls or walls with resilient type construction by careless installation of conduits. Back-plaster or box-in recessed fixtures in ceilings as well as walls.

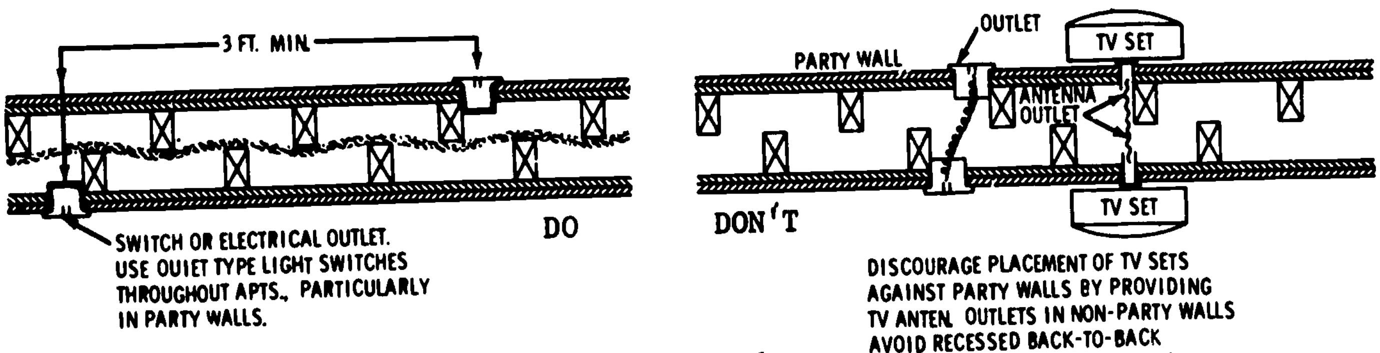


Fig. 8.13. Installation of Electrical Outlets.

ELEVATORS

See Figure 8.14.

Avoid locating elevator shafts next to quiet dwellings areas. Select quiet units. Vibration isolate hoist equipment, buzzers or bells, and other vibrating devices.

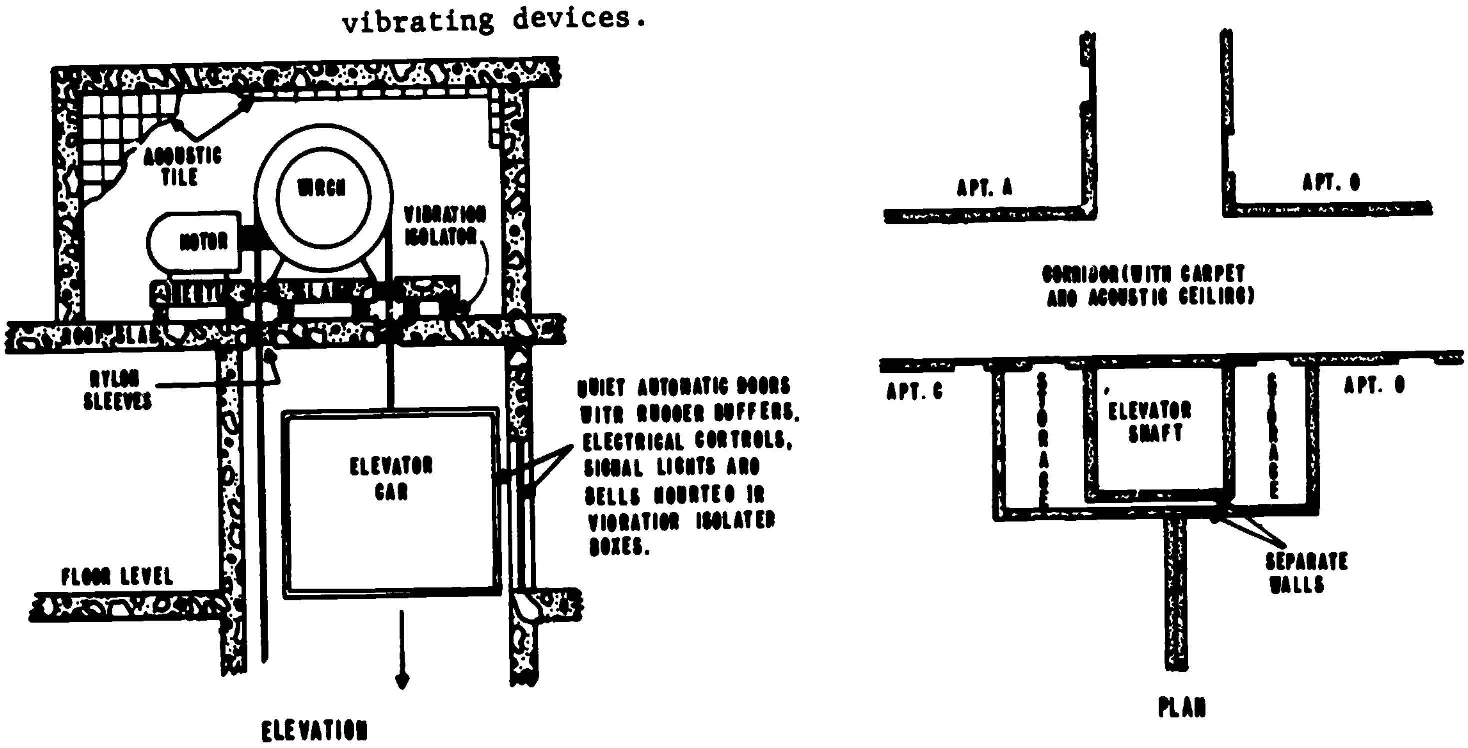


Fig. 8.14. Elevator Installation.

EXPANSION JOINTS

Plan and use expansion joints for the additional purpose of reducing transmission of structure-borne noise and vibration, e.g. around equipment rooms. (See "INERTIA BLOCKS".)

FANS

Large-diameter, slow-speed fans are less noisy than the opposite type, and should be used particularly in heating and air-conditioning systems. (See "APPLIANCES".)

FLEXIBLE CONNECTORS

See Figures 8.15 and 8.16.

Use flexible connectors in plumbing, heating and electrical systems which are connected to vibrating equipment such as washers, dryers, compressors, pumps and blowers. Connectors such as flexible boots, conduits and rubber hoses should be installed as near to vibrating equipment as possible. Proper installation of flexible connectors is important to minimize excessive wear.

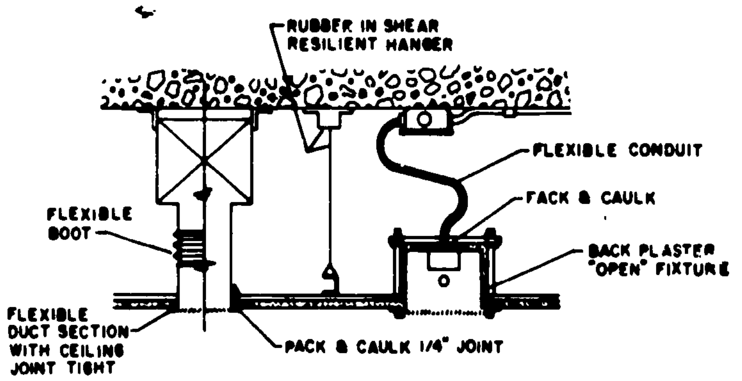


Fig. 8.15. Flexible Connectors.

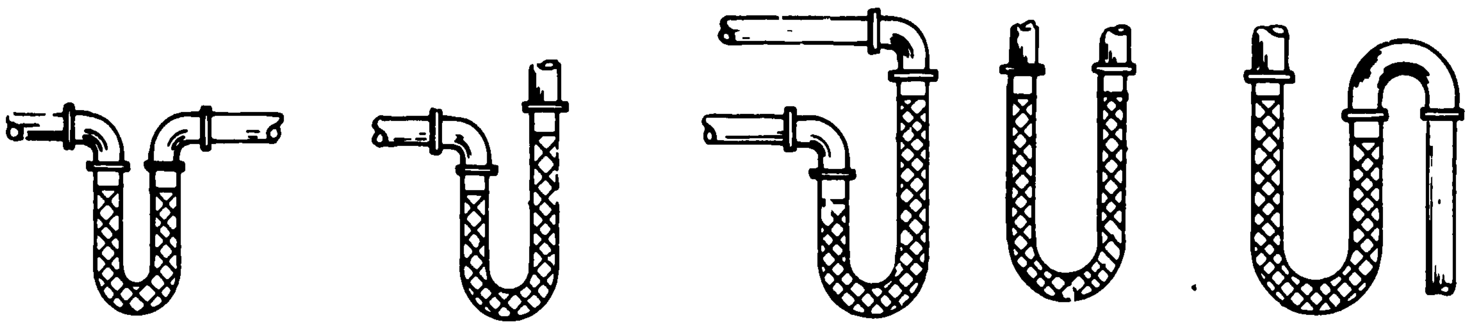


Fig. 8.16. Proper Installation of Flexible Connectors.

FLOOR-CEILING STRUCTURES

See Figures 8.17 and 8.18.

Remember that floor systems must provide an acceptable degree of both airborne and impact sound insulation. Depending on the functions of the spaces to be separated, select floors with the proper type of construction as well as appropriate STC and IIC values. Avoid running structural floors continuously through dwelling units. Use discontinuous type construction. Avoid running floating floors continuously through dwelling units. Each dwelling unit should have a separate floating floor structure. Use carpets and pads and floors floated on resilient underlays to reduce impact noise.

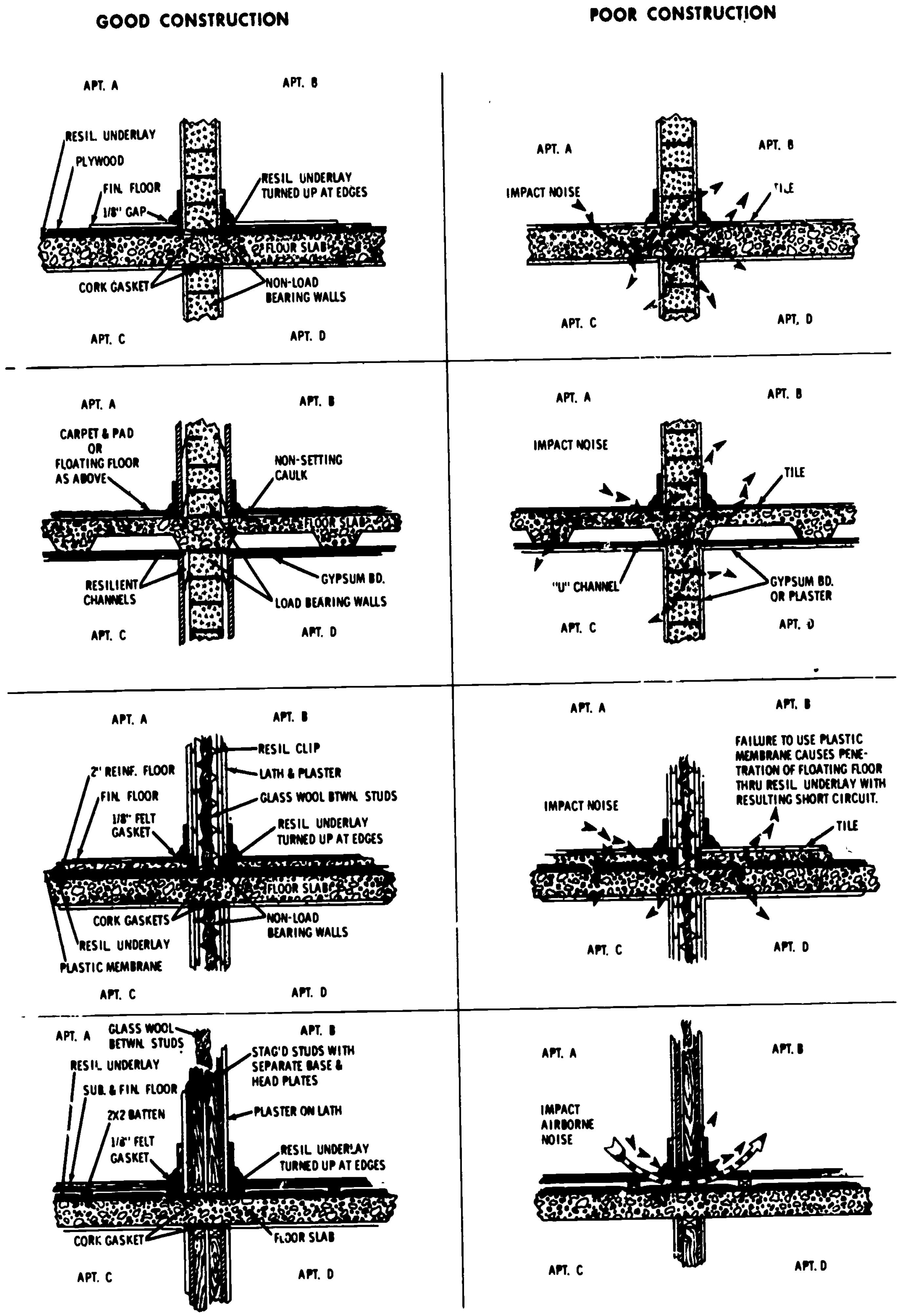


Fig. 8.17. Architectural Detailing of Wall and Floor Junctions.

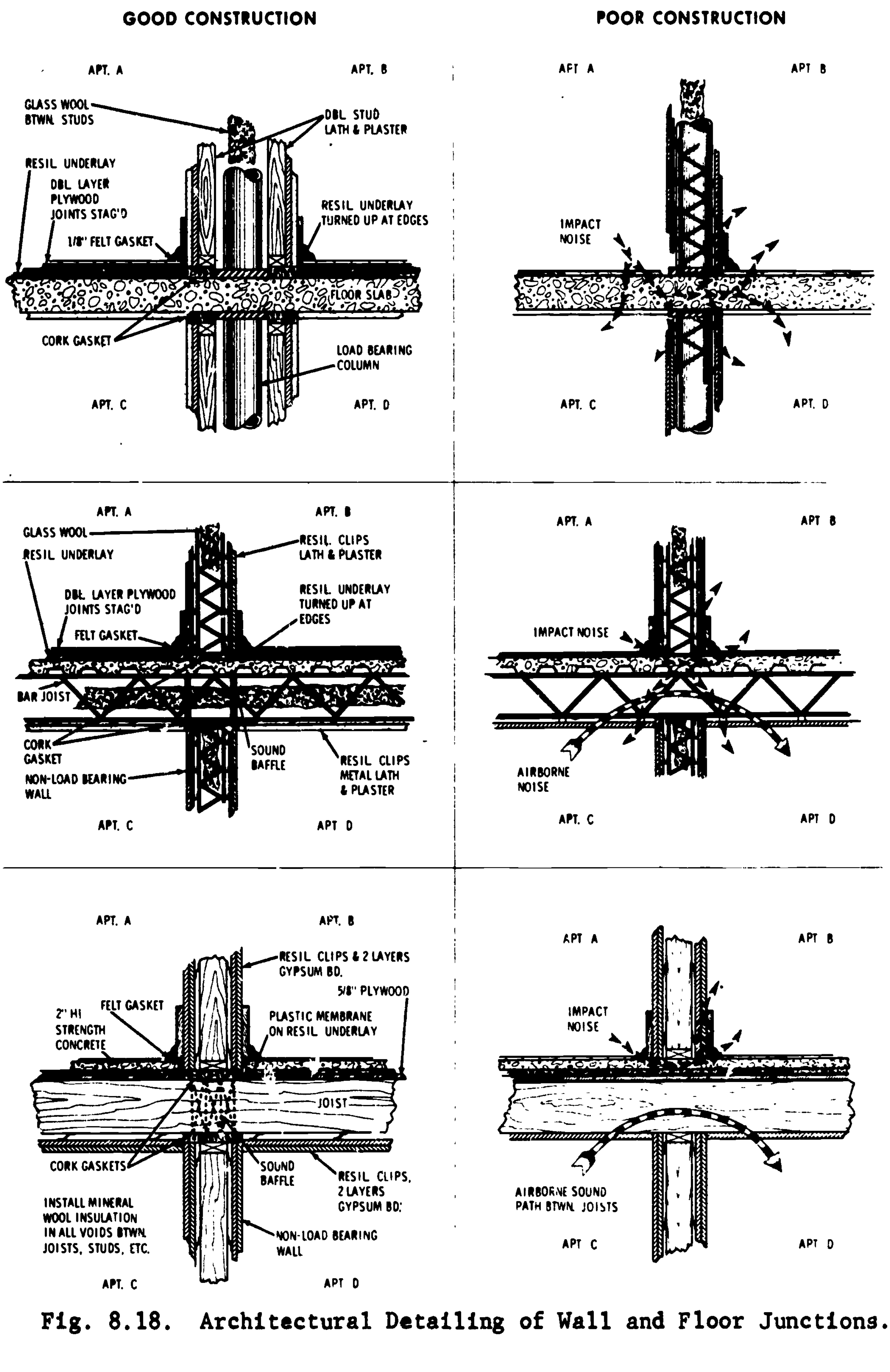


Fig. 8.18. Architectural Detailing of Wall and Floor Junctions.

FLOOR CONSTRUCTION

See Figures 8.19 through 8.28.

Many of the floor structures which provide adequate impact isolation involve a "floating" construction; that is, either a wooden raft or concrete "screed" supported on a resilient layer of some kind which rests on the basic structural floor. The following points are relevant to these types of floors.

a. The total construction between spaces must be airtight. This applies to walls as well as floor-ceiling construction.
b. The "floating" construction must not in any way touch the surrounding construction through any rigid material.
c. Note that most resilient materials which are used are penetrable by water. Be extremely careful to seal all pipe, chase or duct penetrations of the construction with a flexible, non-hardening material which will exclude water from the material.
d. Floating concrete screeds poured over resilient materials require a waterproof membrane between the blanket and the concrete to prevent formation of "fins" or other short circuiting between joints in the resilient material. As workmen are usually not particularly careful when pouring concrete, a rigid, protective layer (e.g. 1/4-in. plywood) is recommended to prevent rupture of the membrane during placement of reinforcing and pouring of concrete.
e. Floating wood rafts are easily "shorted out" by nailing through the resilient material to the sub-floor. Care in detailing and specification is mandatory to point out to the contractor the requirements for resilient construction.
f. Edge joints at the perimeter of a floated construction are potential trouble spots. Do not attach solid base boards to both the wall and the floor. Do not "short out" the resilient construction with toe moldings.
g. For floating screeds, 150 sq ft is about the largest area of 2-in. concrete which can be poured without reinforcement to prevent edge curl. For larger floors, the use of reinforcement or thick (4 in.) rafts of concrete is necessary.
h. Some settlement of resilient material (about 3% of initial thickness) may be expected over a long period of time. Allow for this contingency in architectural details.
i. Some of the "floating" ceiling constructions call for spring clip support of battens under joists. Note that nailing through the batten into the joists must be avoided in these cases.

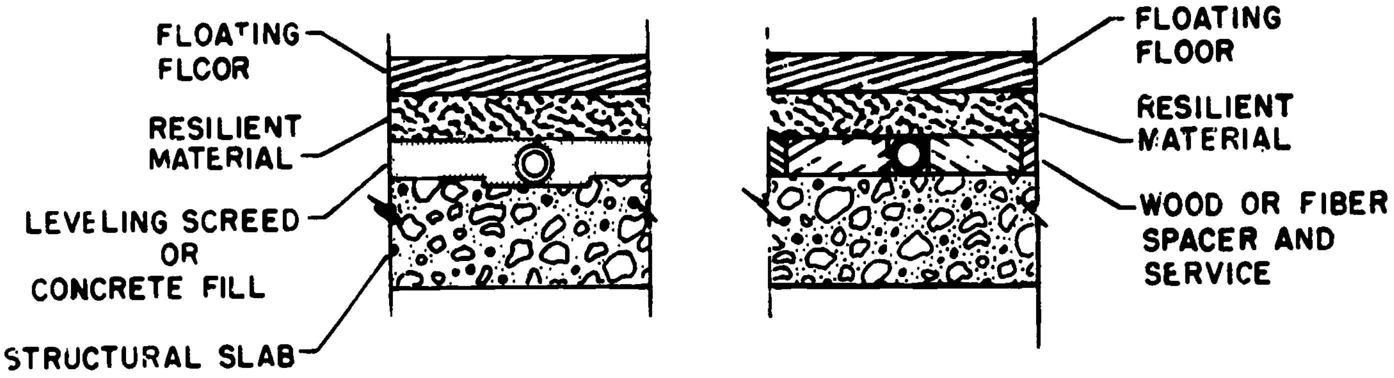


Fig. 8.19. Acceptable Service Arrangement under Floating Floors.

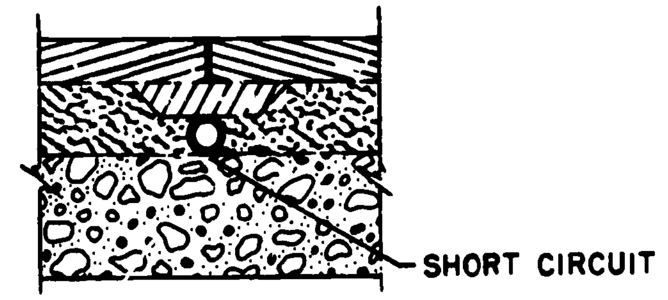


Fig. 8.20. Unacceptable Service Arrangement under Floating Floors.

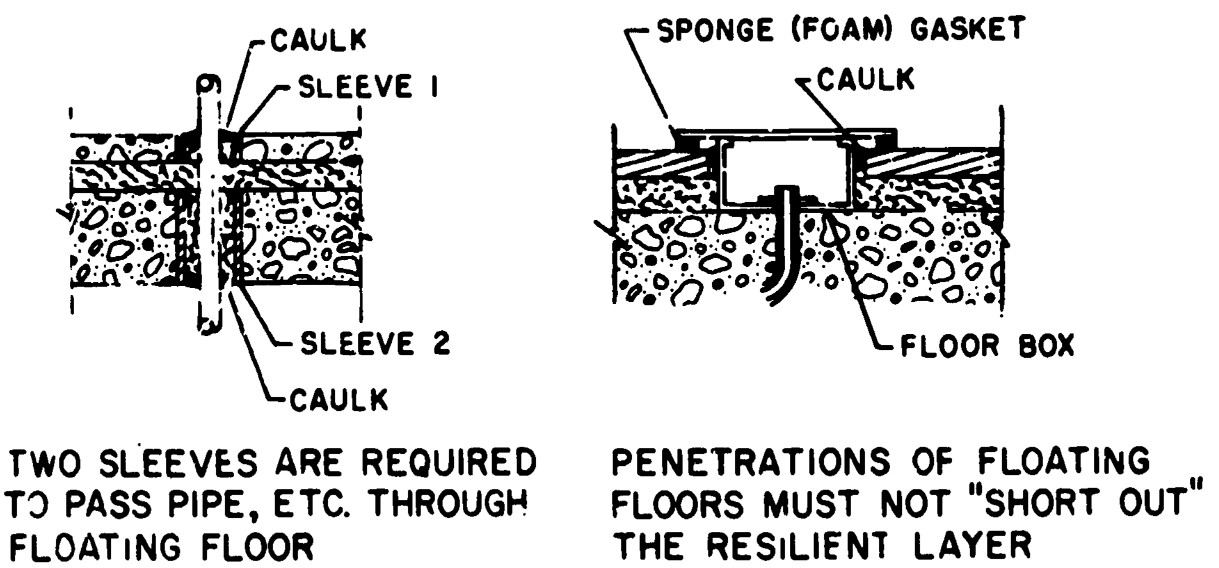


Fig. 8.21. Service Arrangement through Floating Floors.

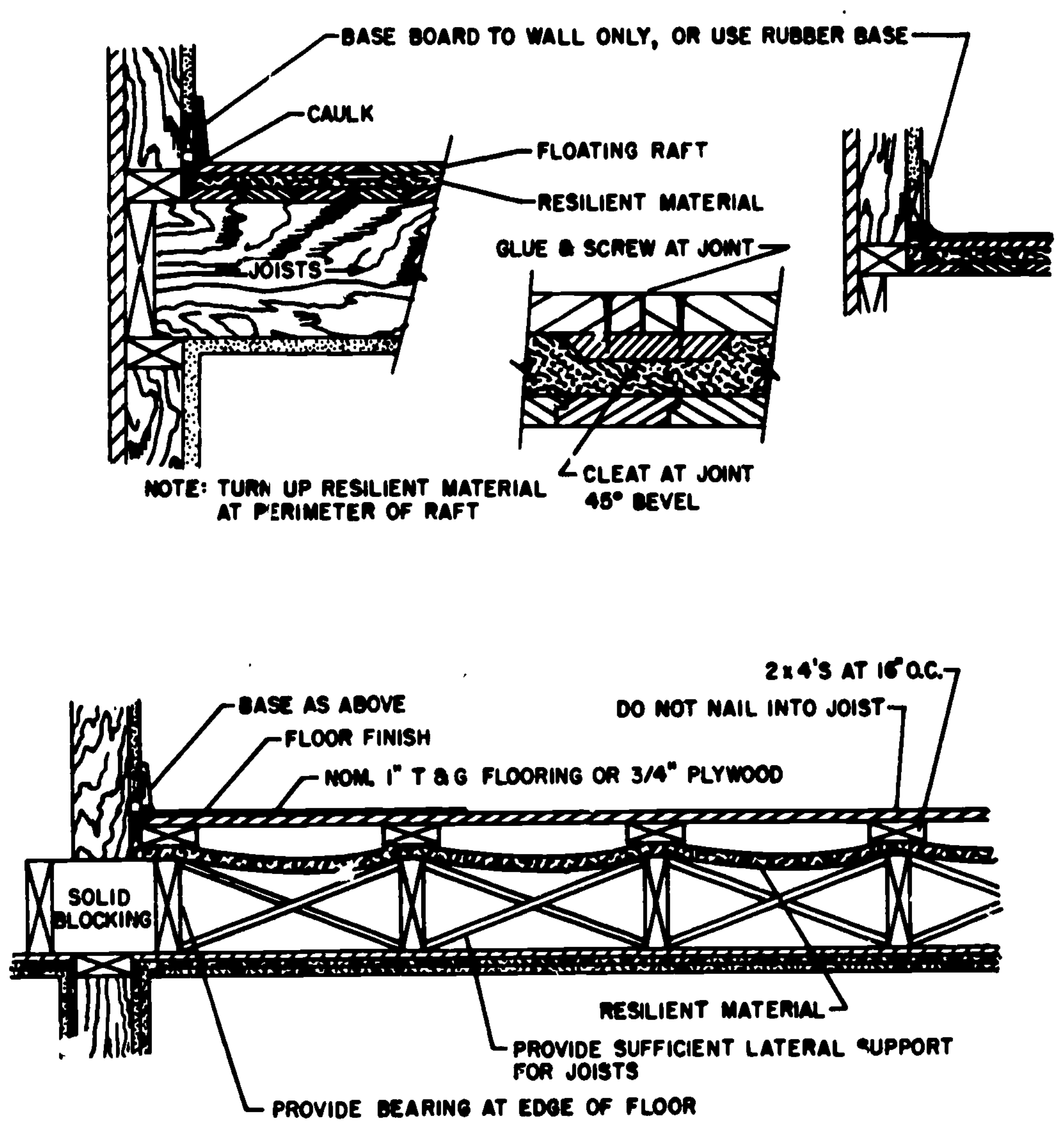
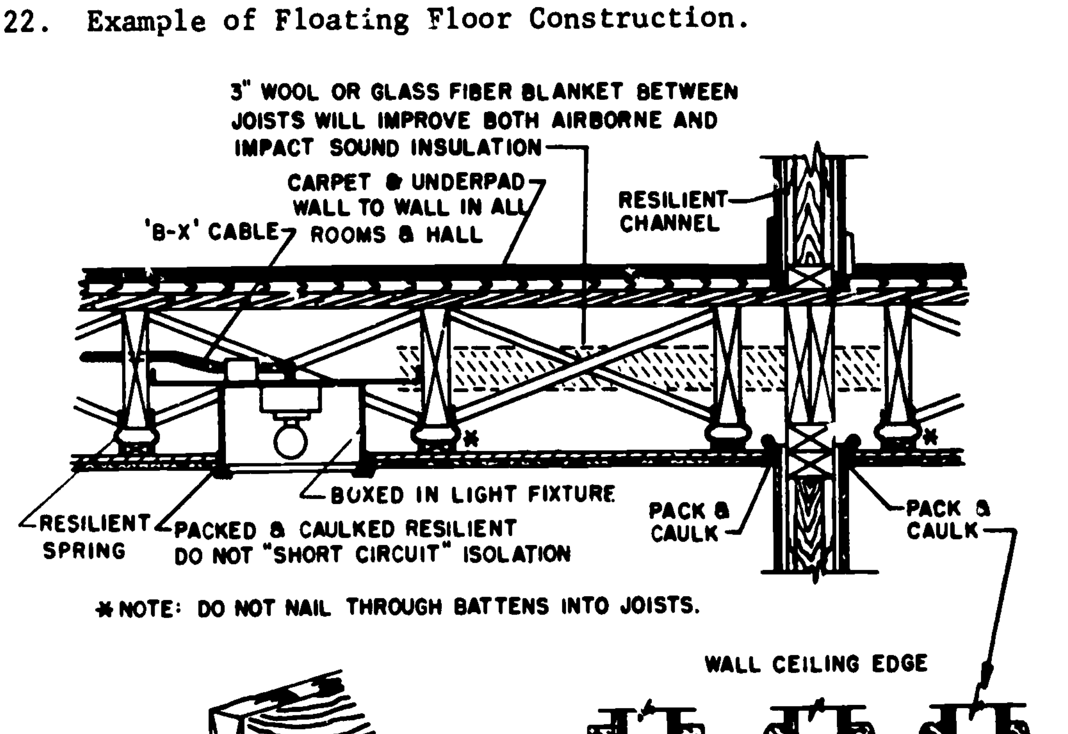


Fig. 8.22. Example of Floating Floor Construction.



Spring clip
and channel

Fig. 8.23. Example of Resiliently Hung Ceiling.

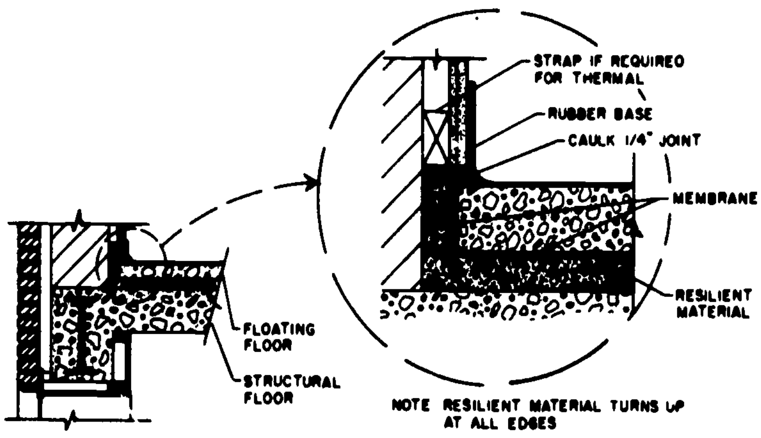


Fig. 8.24. Constructional Detailing of a Floating Floor.

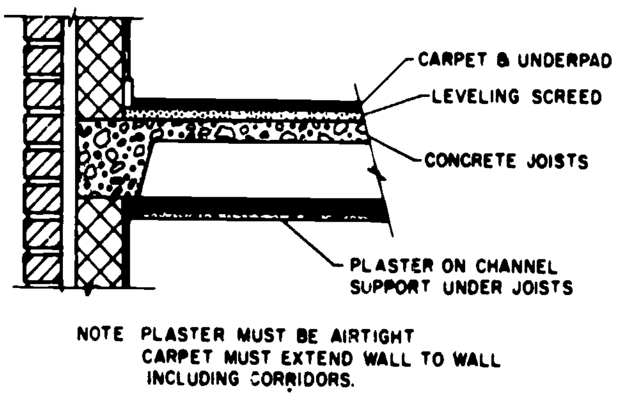
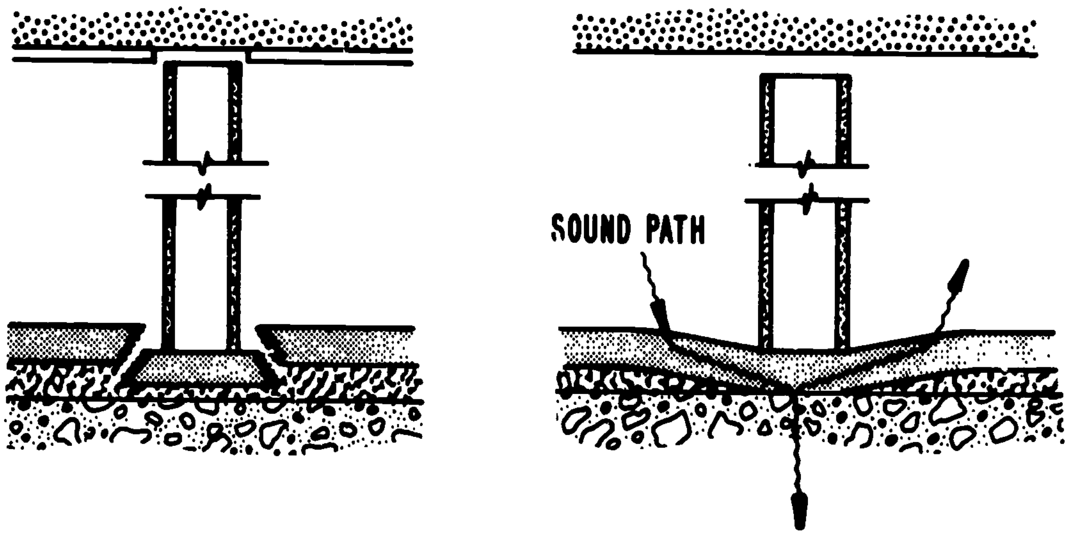


Fig. 8.25. Constructional Detailing of a Conventional Floor.

Caution must be exercised when supporting partitions on floating floors to prevent structural failures or short circuiting of the floating element, as illustrated.



For proper installation of floating floors and partition walls see other illustrations of such constructions in this chapter.

Fig. 8.26. Problems Associated with Floating Floors.

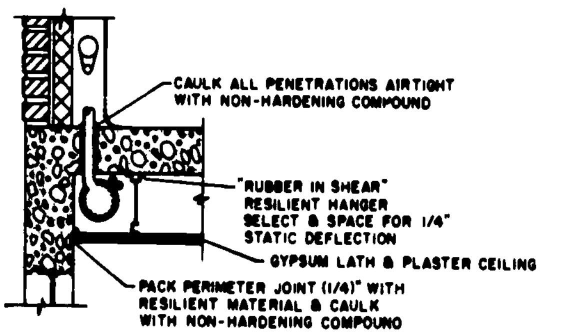


Fig. 8.27. Constructional Detailing of Resiliently Hung Ceilings.

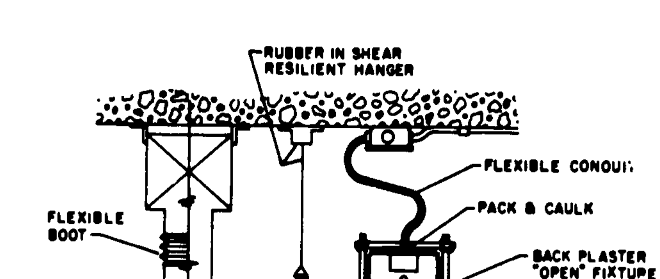


Fig. 8.28. Flexible Connectors Re: Resilient Ceilings.

FLOOR JOISTS — See Figures 8.29, 8.30 and 8.31.

Continuous runs of floor joists which span across dwelling units act as flanking paths for transmission of structure-borne and airborne noise. This occurs where joists are parallel to party walls as well as perpendicular to such walls. The solution to this problem involves blocking of spaces between joists as well as using discontinuous type joist construction. Likewise, proper bonding or joining of floor structures to exterior or load bearing walls is necessary for the control of flanking noise transmission.

FURNACES — See Figures 8.32 through 8.36.

Installing separate heating and cooling systems within individual dwelling units has become the source of many occupant complaints. The excessive noise produced by such systems is generally due to the following factors: (1) a center hall closet installation of the equipment near bedroom or living room areas, (2) a direct motor-driven small-diameter, high-speed blower, and (3) a large central air return duct or grille. Solutions to this problem are: locate such equipment near an exterior wall in a non-critical area such as a kitchen, select equipment with belt-driven large-diameter slow-speed blowers, and use sound absorbing lining in return duct.

GARAGES — See Figure 8.37.

Garages located directly below dwelling units are frequently a cause of complaints regarding both airborne and impact noise; the latter results from slamming or operating garage doors. Measures must be taken to insulate against both types of noise.

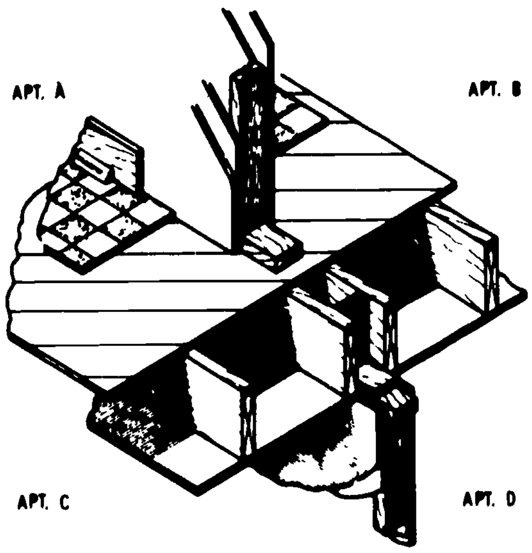
GARBAGE CANS — The collection of garbage, particularly from galvanized metal cans, is generally not only a noisy but most disturbing operation, especially during the early morning hours. Ways of coping with this problem involve: (a) locate collection point away from noise sensitive areas, (b) use flexible plastic rather than metal containers, and (c) schedule collection time later in the day.

GRILLES — See Figure 8.38.

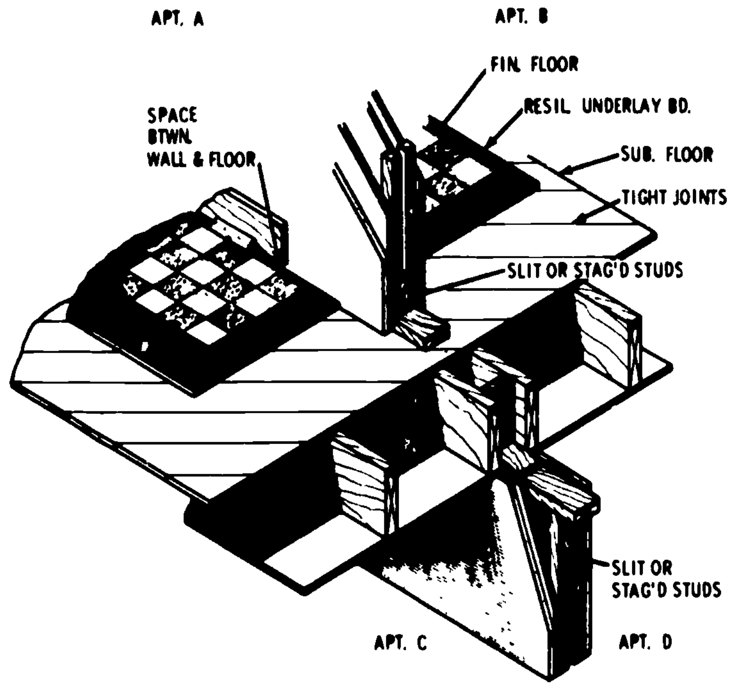
For a given mass-flow, large area grilles are less noisy than small area units. Avoid using sharp edges, loose fittings, or wide-angle deflectors or louvers. Avoid ceiling-corner locations. Central ceiling or above-center wall locations are usually less noisy.

INCINERATOR CHUTES — See Figure 8.39.

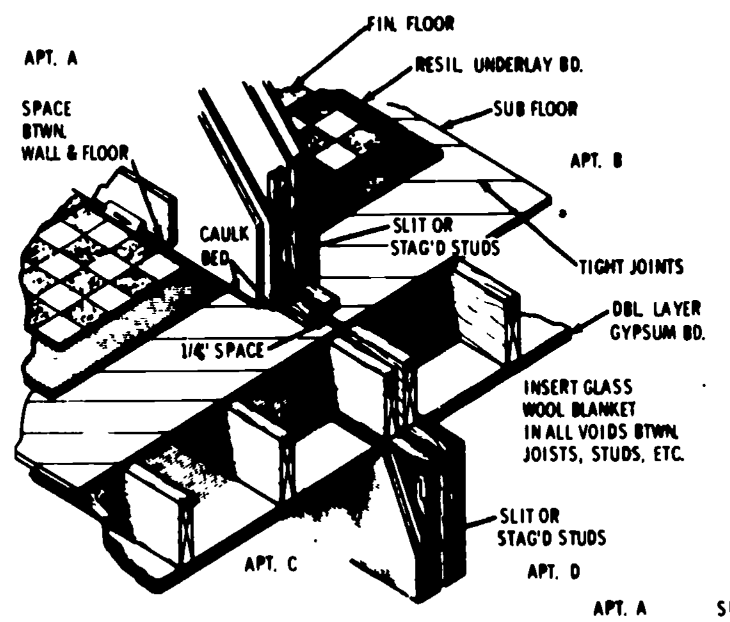
Incinerator chutes which are quite noisy should be isolated from structural walls by means of resilient inserts between chute and clamps or holders. Vertical alignment of the chute should be plumb and outer surfaces should be coated with visco-elastic material similar to that used in undercoating automobiles.



POOR

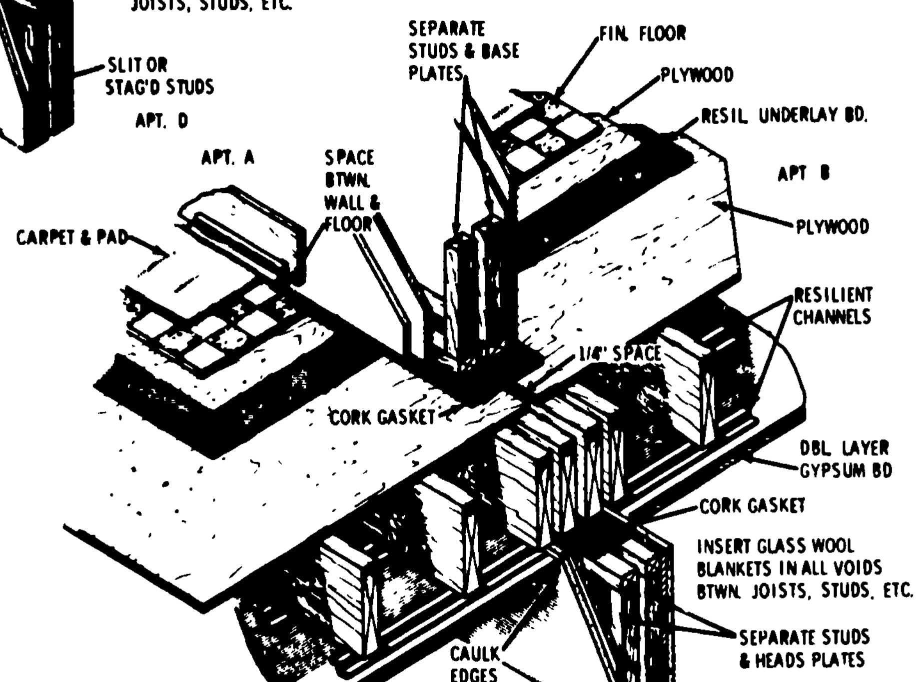


FAIR



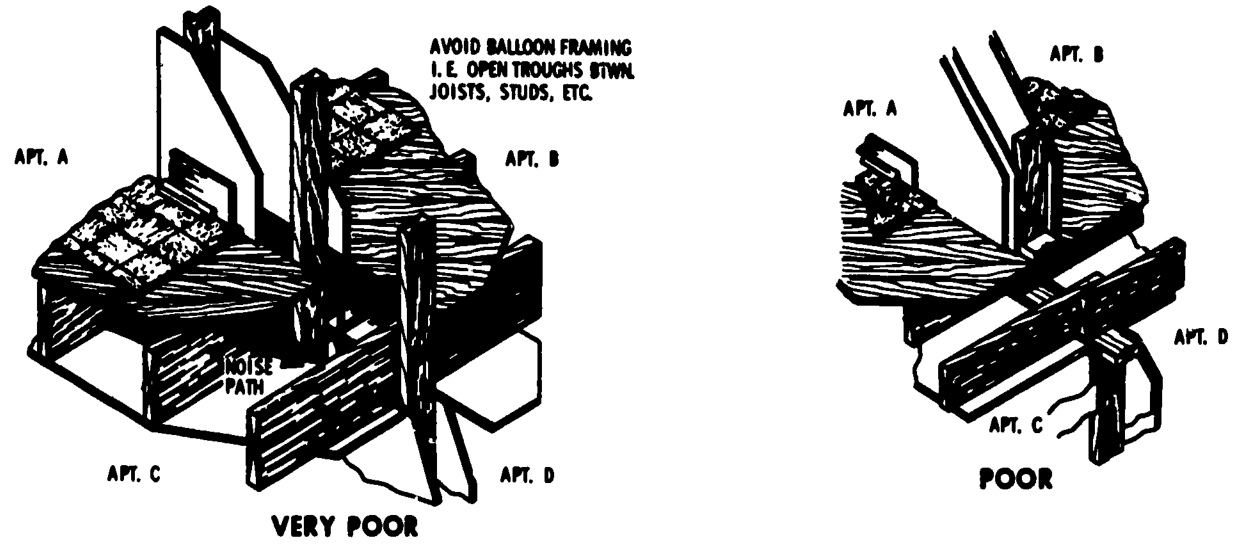
GOOD

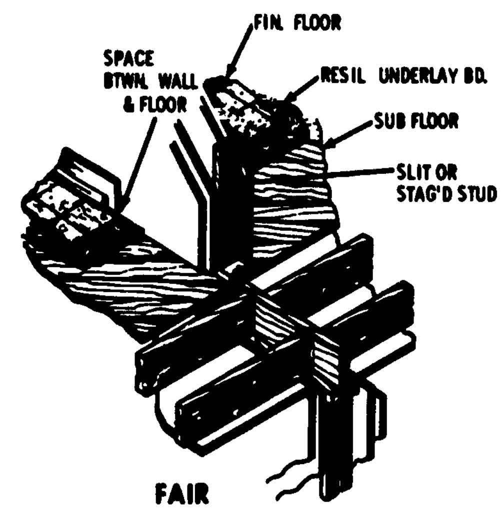
In buildings of wood frame construction, proper installation of joists whether parallel or perpendicular to party walls is essential for good sound insulation.



BEST

Fig. 8.29. Architectural Detailing of Wall-Floor Junctions: Walls Parallel to Floor Joists.





In buildings of wood frame construction, proper installation of joists whether parallel or perpendicular to party walls is essential for good sound insulation.

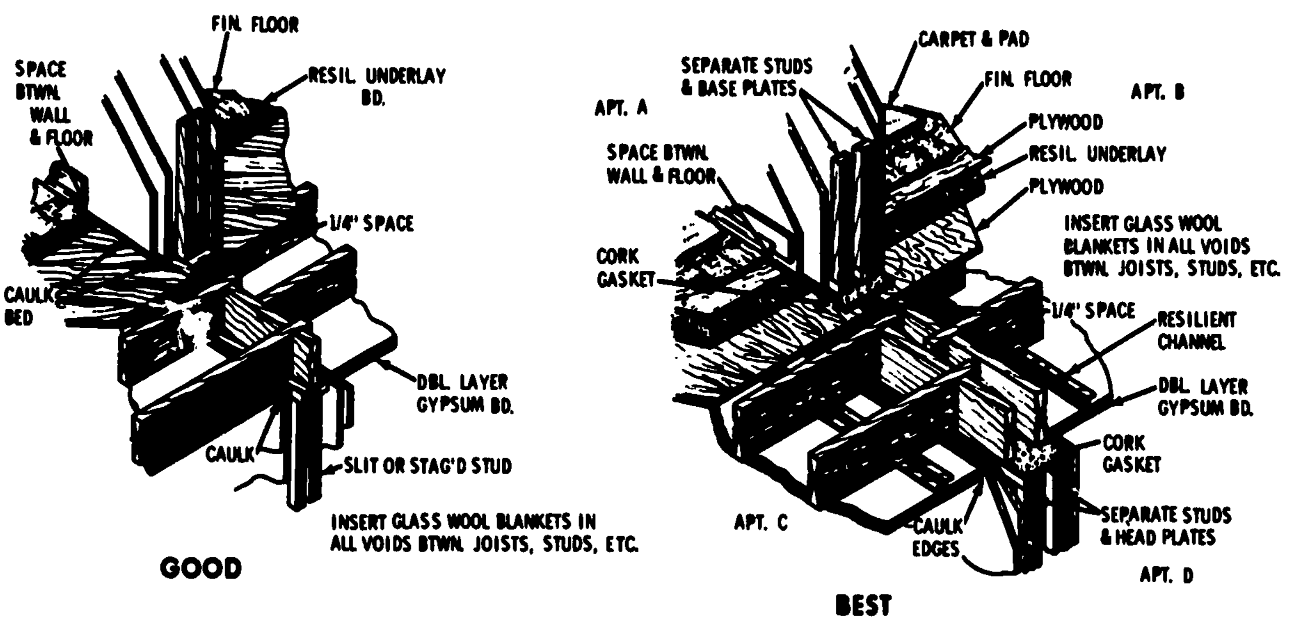


Fig. 8.30. Architectural Detailing of Wall-Floor Junctions: Walls Perpendicular to Floor Joists.

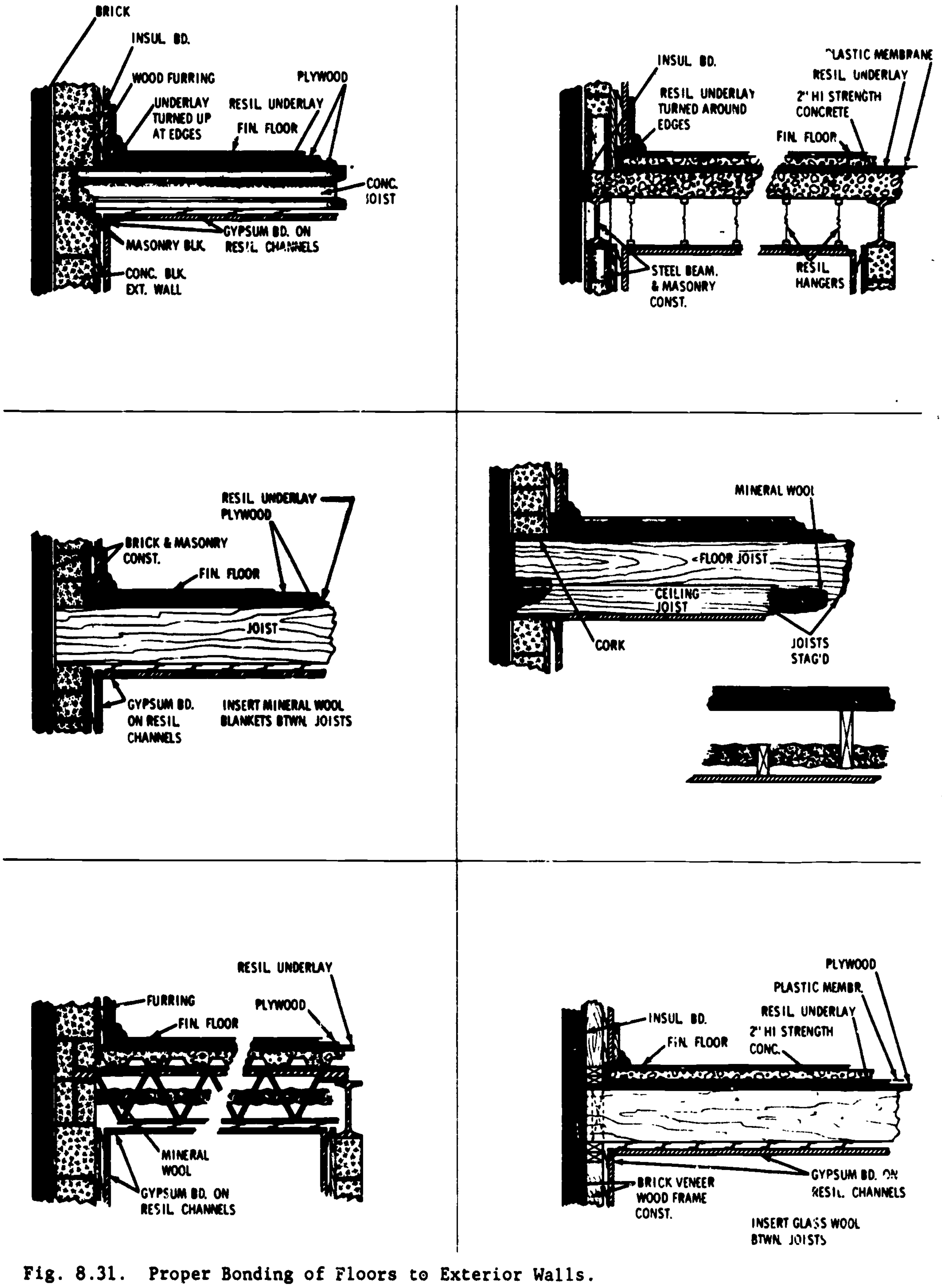


Fig. 8.31. Proper Bonding of Floors to Exterior Walls.

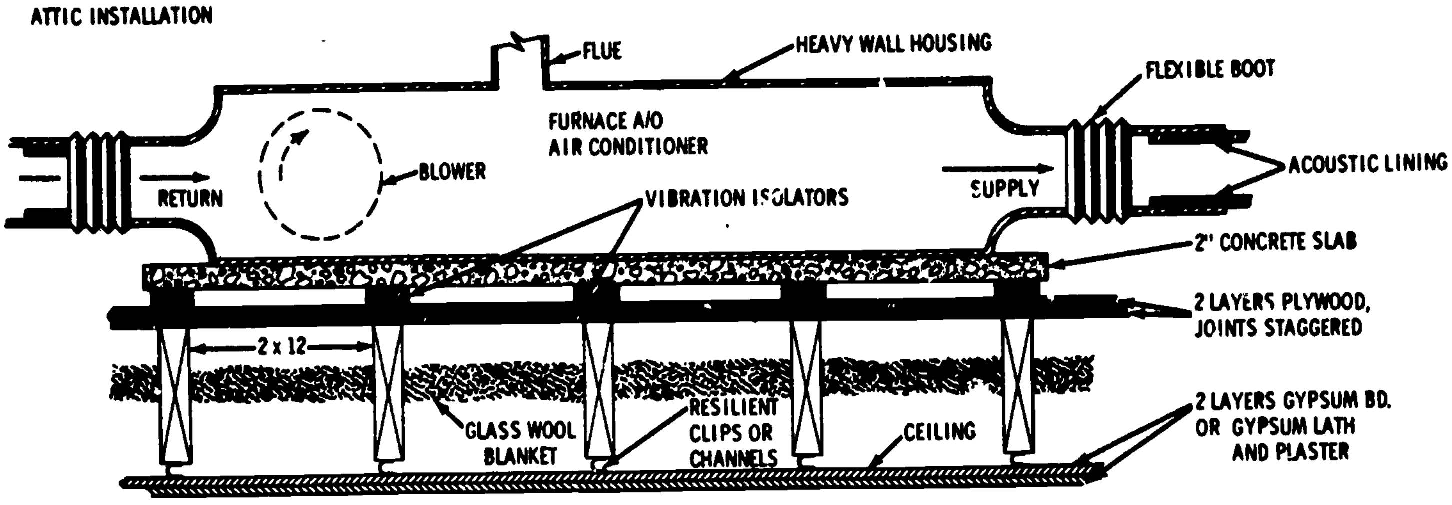


Fig. 8.32. Attic Installation of Furnace and/or Air Conditioner.

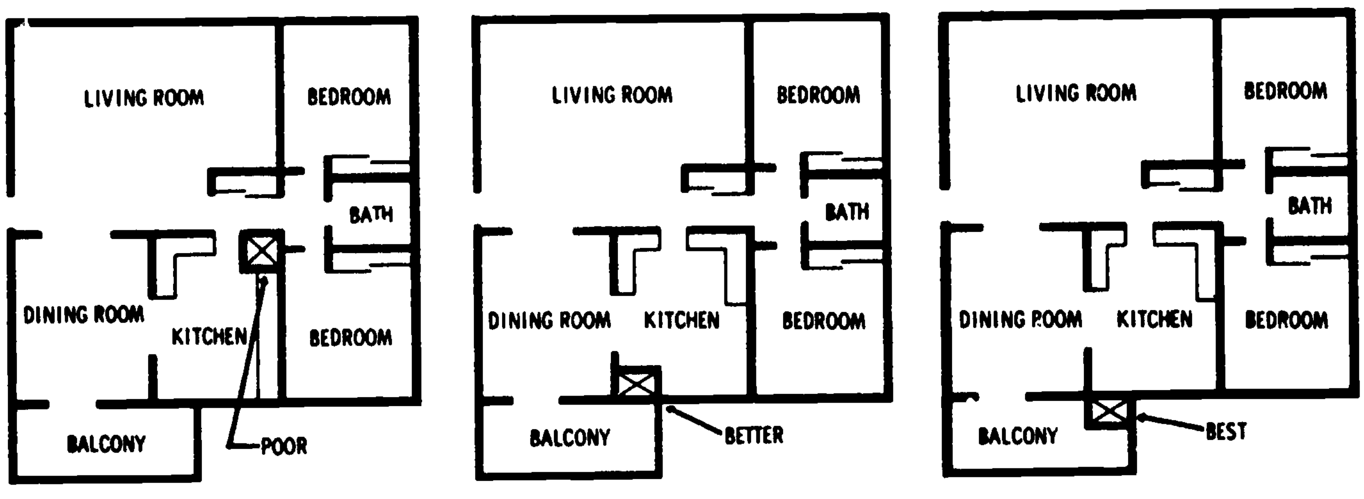


Fig. 8.33. Location of Furnace-Air Conditioner Unit.

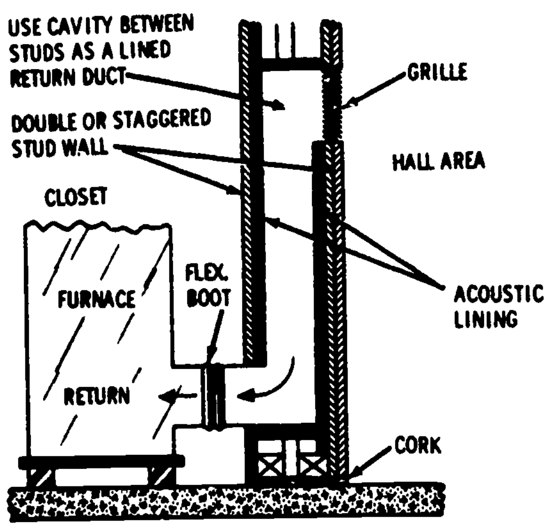


Fig. 8.34. Design of Return Duct of Closet-Installed Furnace.

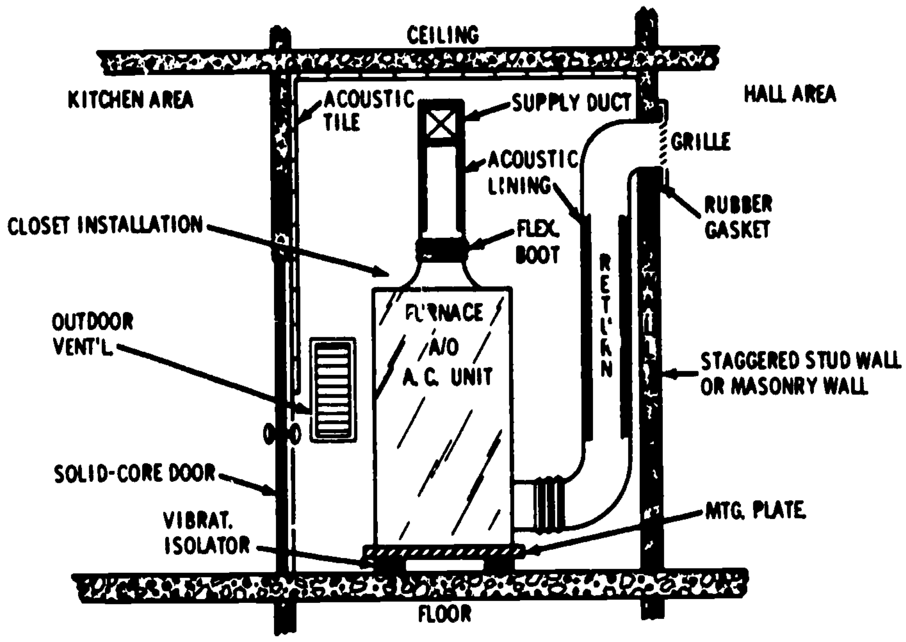


Fig. 8.35. Closet Installation of Furnace.

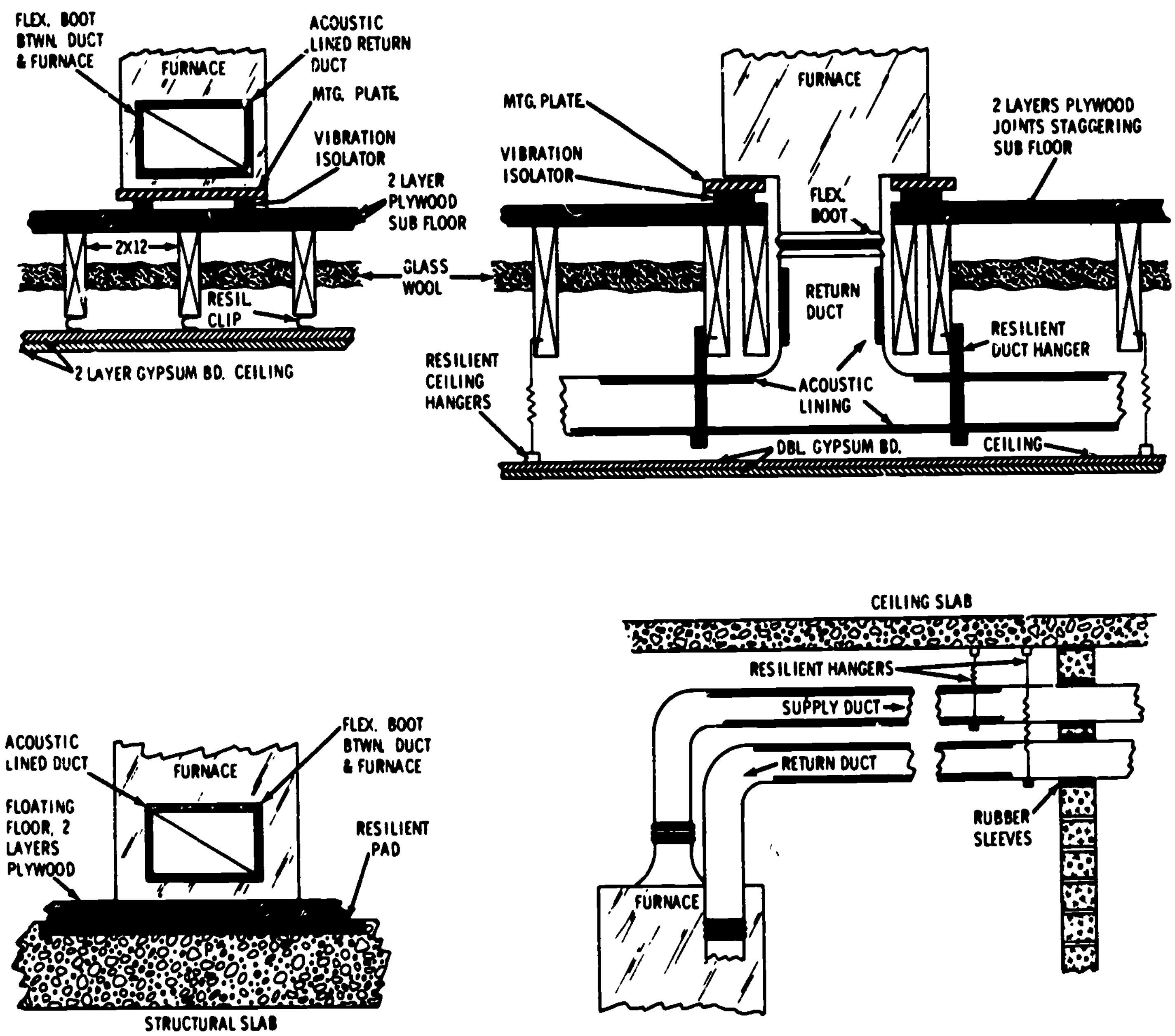


Fig. 8.36. Proper Installation of Furnace Ductwork.

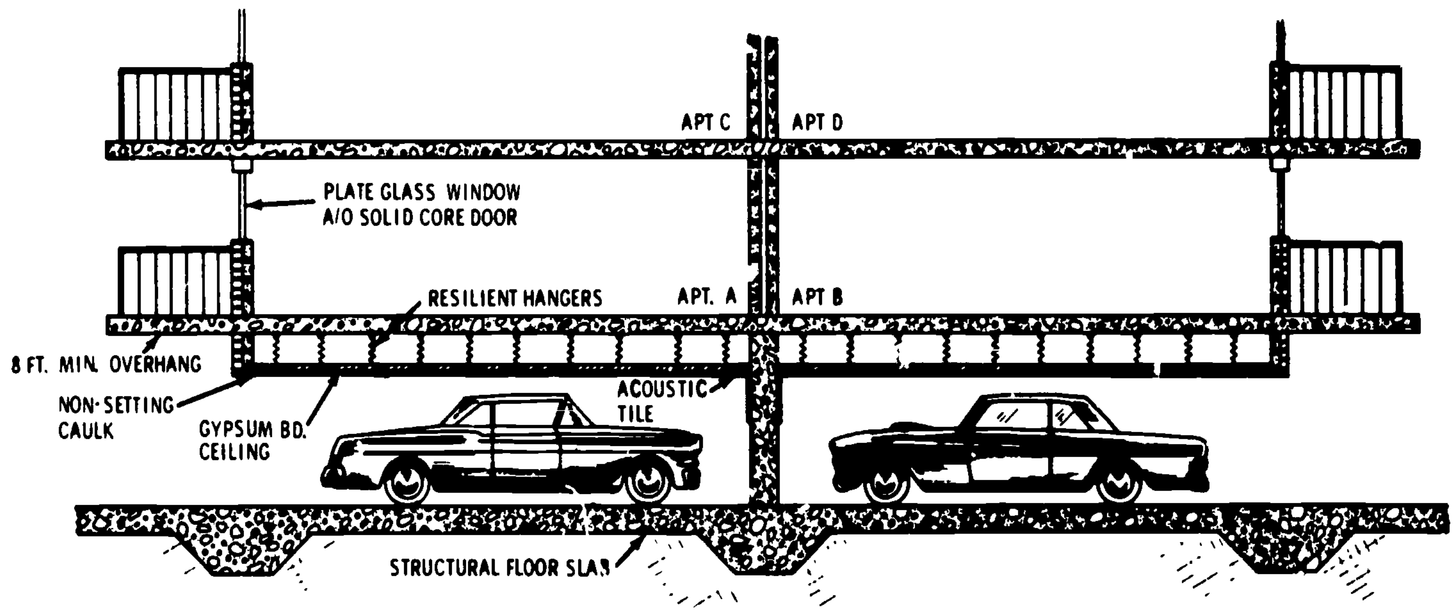


Fig. 8.37. Acoustical Treatment of Garages.

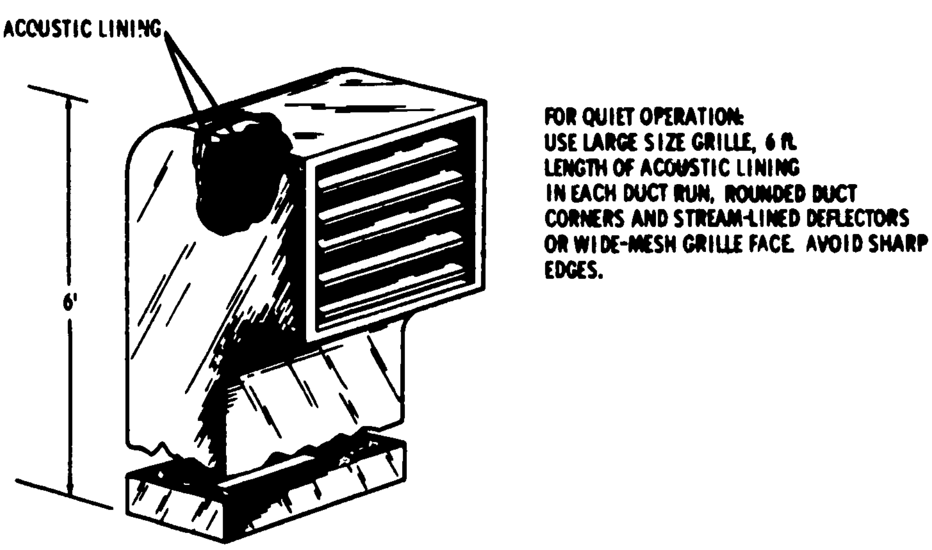
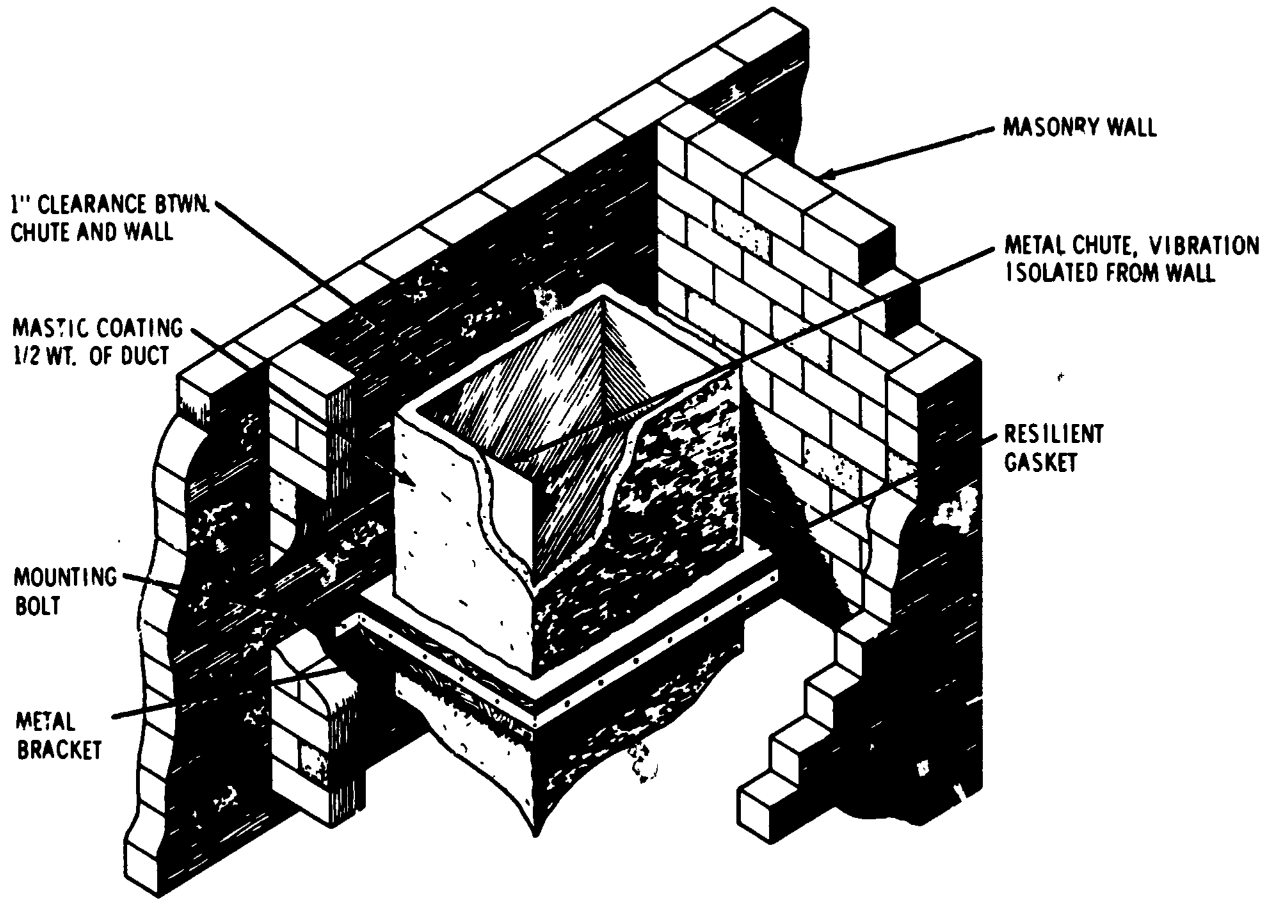


Fig. 8.38. Acoustical Design and Treatment of Grilles.

INERTIA BLOCKS — See Figure 8.40.
Large heavy electro-mechanical equipment should be mounted on vibration isolated inertia blocks for better weight distribution and more efficient isolation.

JOINTS MORTAR, GYPSUM BD. — Poor mortar joints in masonry wall construction frequently result in serious noise leaks. Special care should be used in laying block walls and as a precautionary measure exterior surfaces of the wall should be coated with plaster, grouting mix or masonry paint. All joints in gypsum board construction should be supported or backed with a furring strip, nailing channel or scrap strips of gypsum board to effect an airtight seal and reduce cracking at joints due to warping or contraction. All joints should be sealed and taped.



INCINERATOR CHUTE

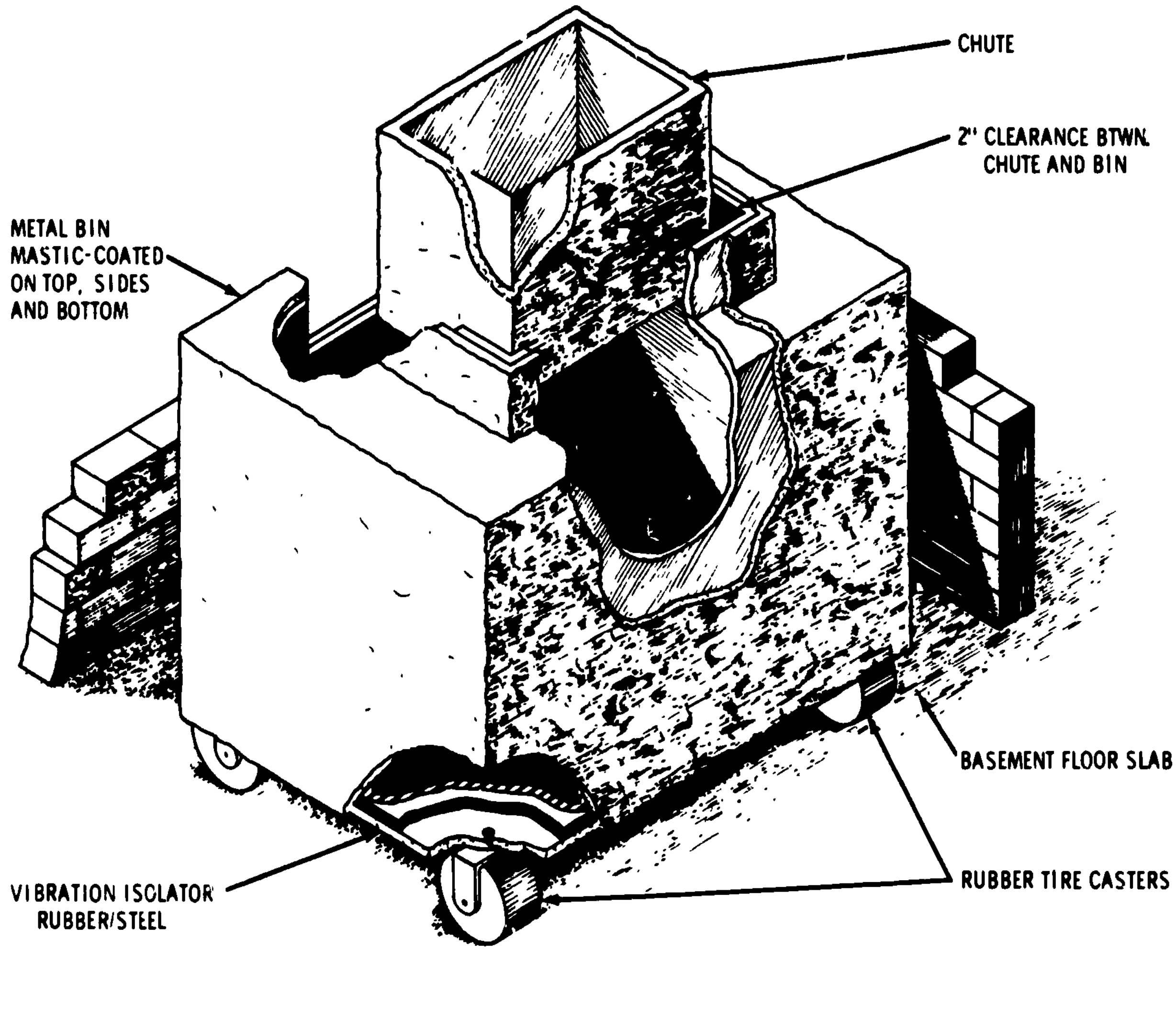


Fig. 8.39 Proper Installation of Incinerator Chutes and Bins.

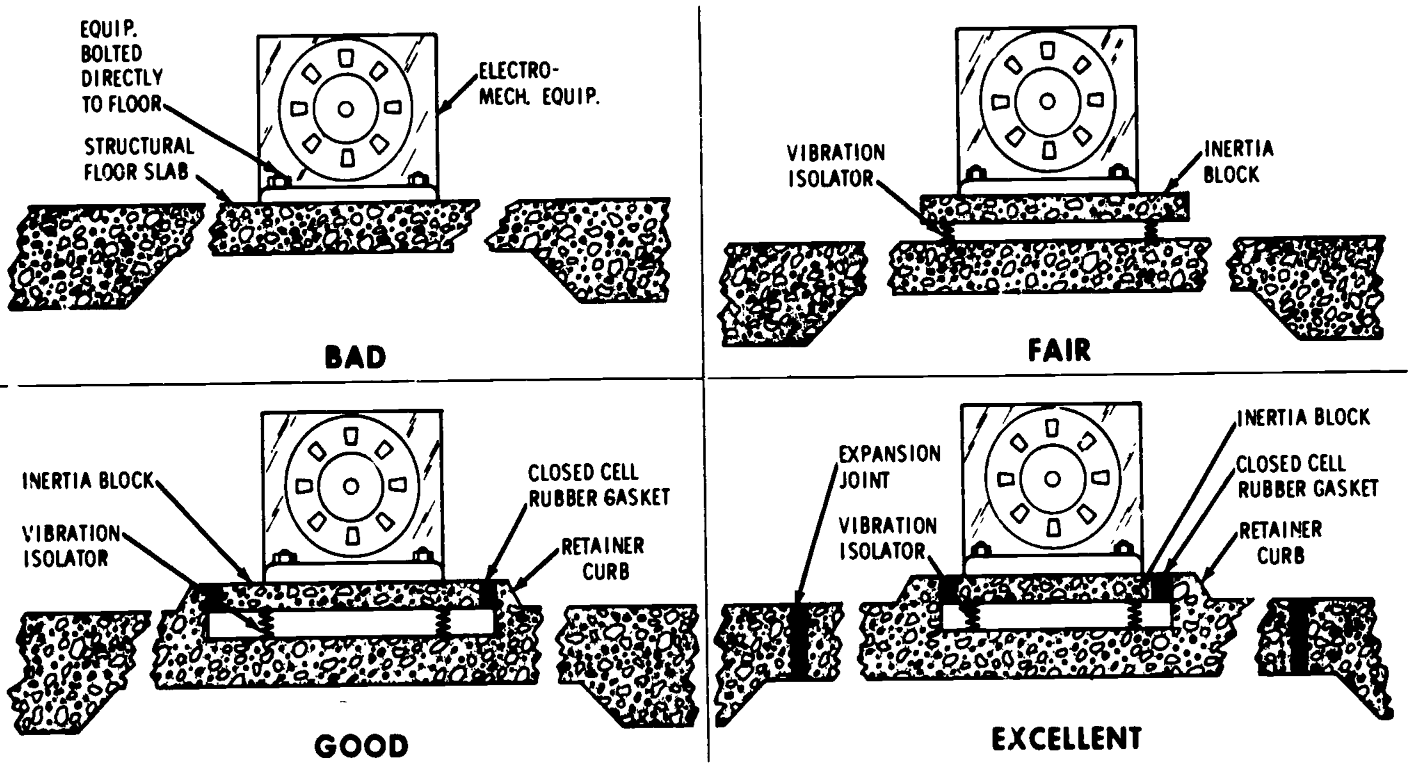


Fig. 8.40. Vibration Isolation of Mechanical Equipment.

KITCHEN CABINETS

See Figure 8.41.

Avoid installing kitchen cabinets on party walls, since they are a source of impact noise. Cabinets should never be mounted on walls constructed with resilient elements. The mounting bolts will "short circuit" the advantages of such construction.

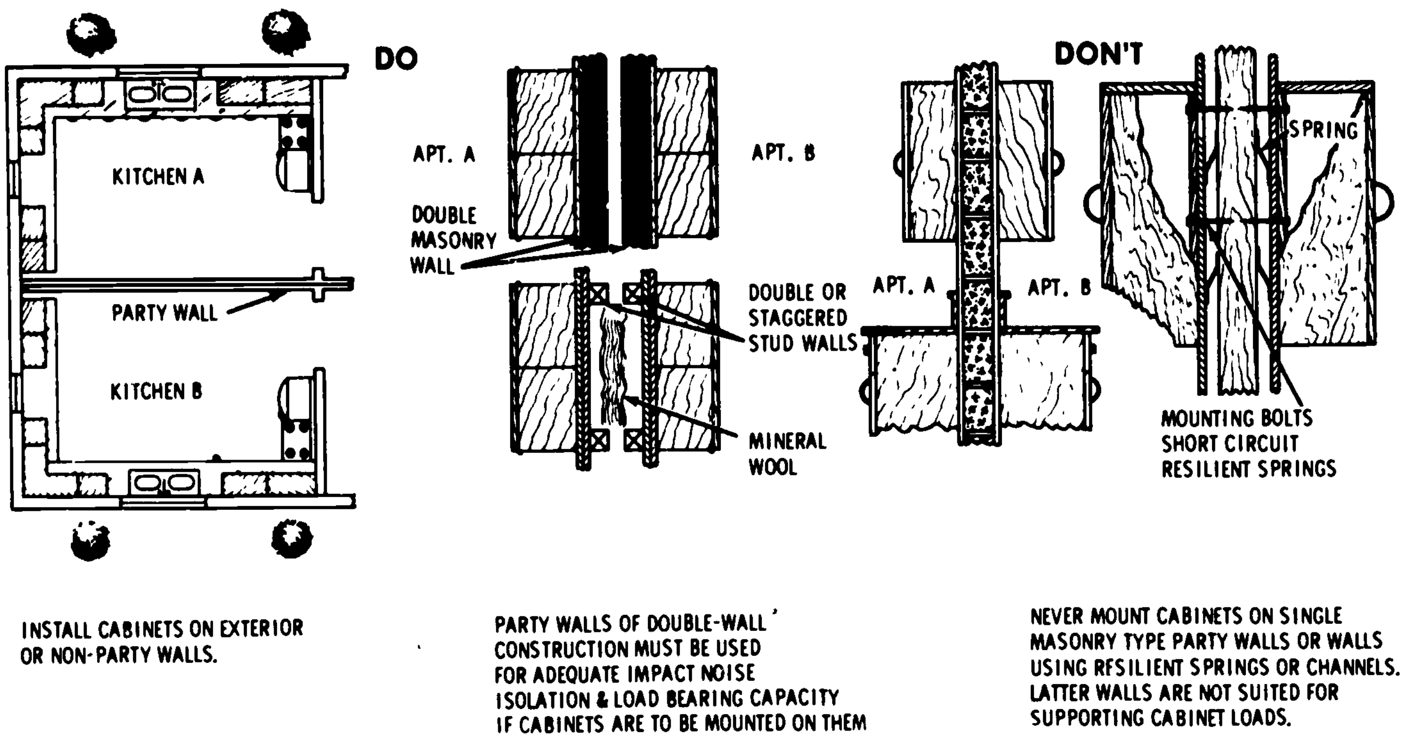


Fig. 8.41. Installation of Kitchen Cabinets.

LAUNDRY ROOMS See Figure 8.42.

Laundry rooms located adjacent to or below dwelling units are potential trouble spots if adequate precautionary measures are not taken. Such rooms should be located away from dwelling areas.

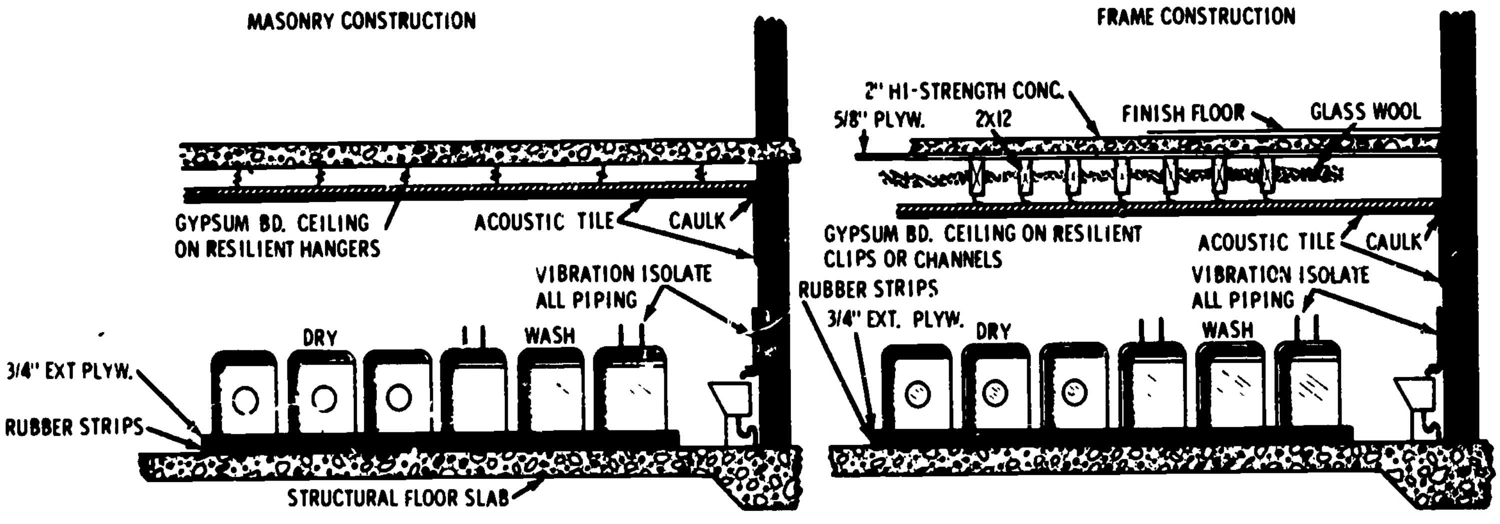


Fig. 8.42. Acoustical Treatment of Laundry Rooms.

LIGHTING FIXTURES See Figure 8.43.

Special techniques must be used during installation of surface or recessed-mounted light fixtures in order to preserve the sound insulation of wall or floor-ceiling structures, especially if such structures involve spring clips or resilient channels. Fluorescent lights frequently produce a disturbing hum. If such lights are to be used, select types which have an external ballast. The ballast unit should be vibration isolated by means of rubber grommets from the base of the light fixture as well as the ceiling or wall surface. Silent light switches should be installed particularly in party walls and preferably throughout the entire dwelling unit.

MASKING NOISE Although masking noise may be quite effective in overriding disturbing noises, it should not be used as a technique for improving the sound insulation between dwelling units in lieu of using partitions with high STC or IIC ratings. See Chapter 6 for limitations on use of masking noise.

MECHANICAL EQUIPMENT ROOMS See Figures 8.44 and 8.45.

Such rooms should be located in basement areas far removed from dwelling areas. All mechanical equipment and associated distribution systems should be mounted or supported on vibration isolators. Very large or high capacity equipment should be housed in separate buildings. Consideration should be given to selection of equipment on the basis of low noise output as well as desired capacity ratings. See Figures 8.46 and 8.47 for illustrations of the effectiveness of various sound insulating techniques relative to noisy mechanical equipment.

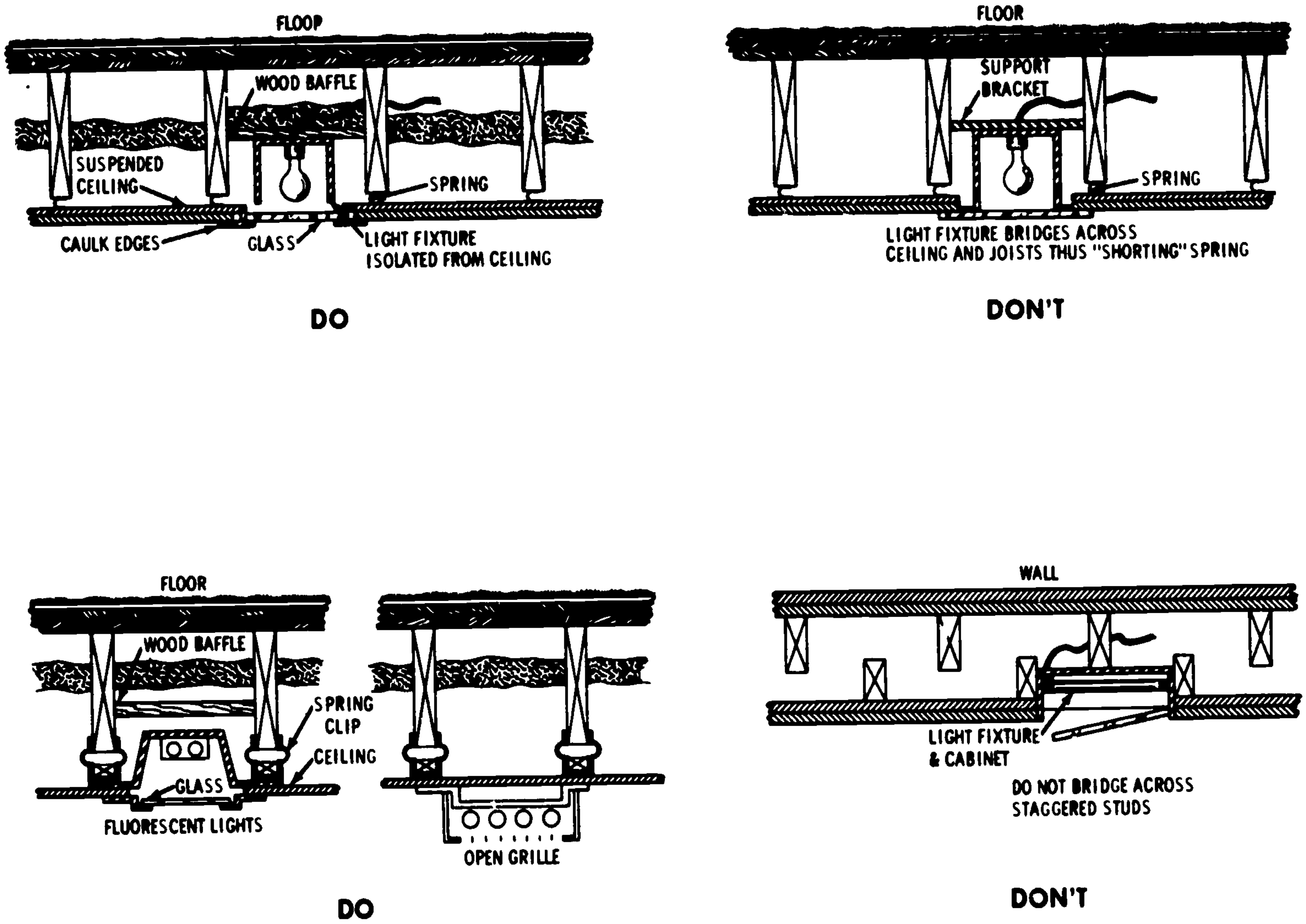


Fig. 8.43. Installation of Lighting Fixtures

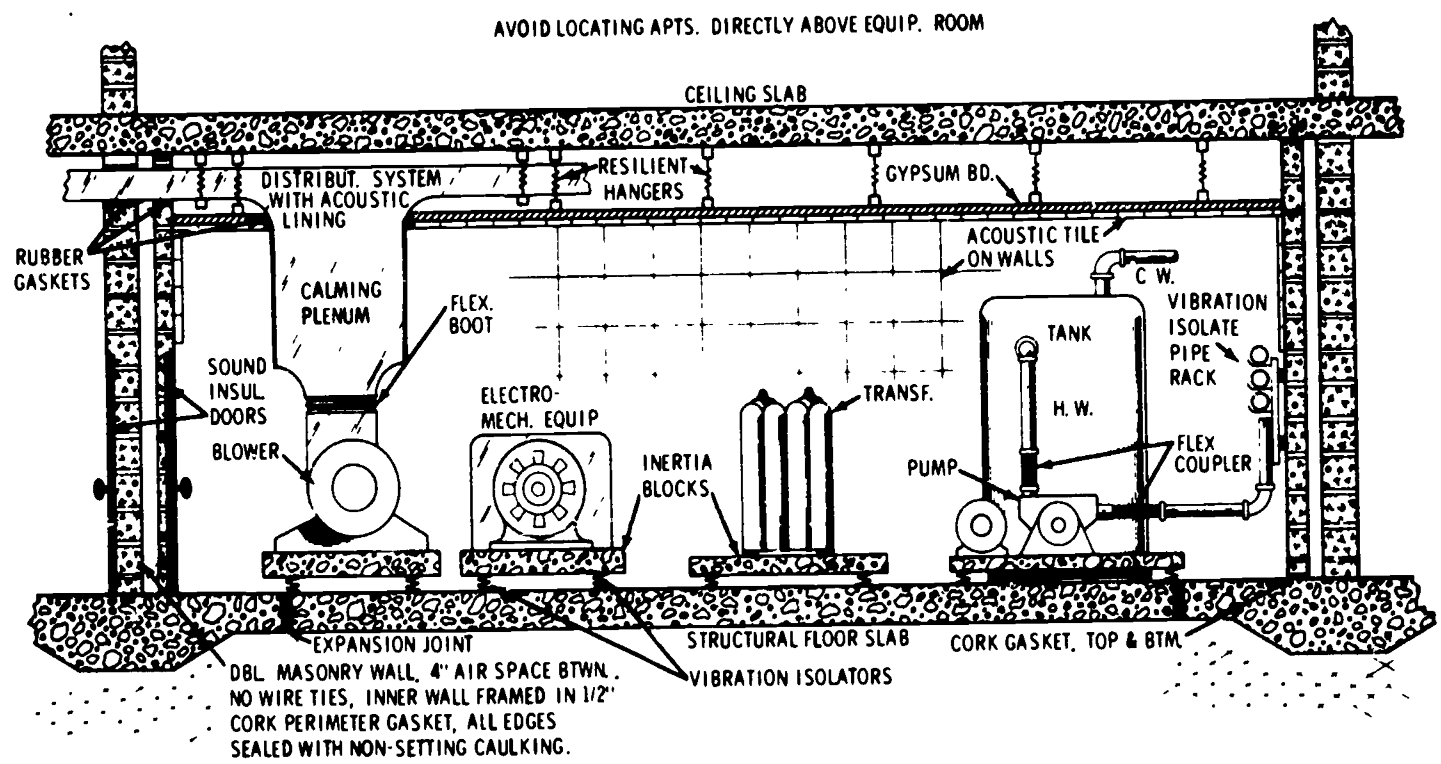


Fig. 8.44. Acoustical Treatment of Mechanical Equipment Rooms.

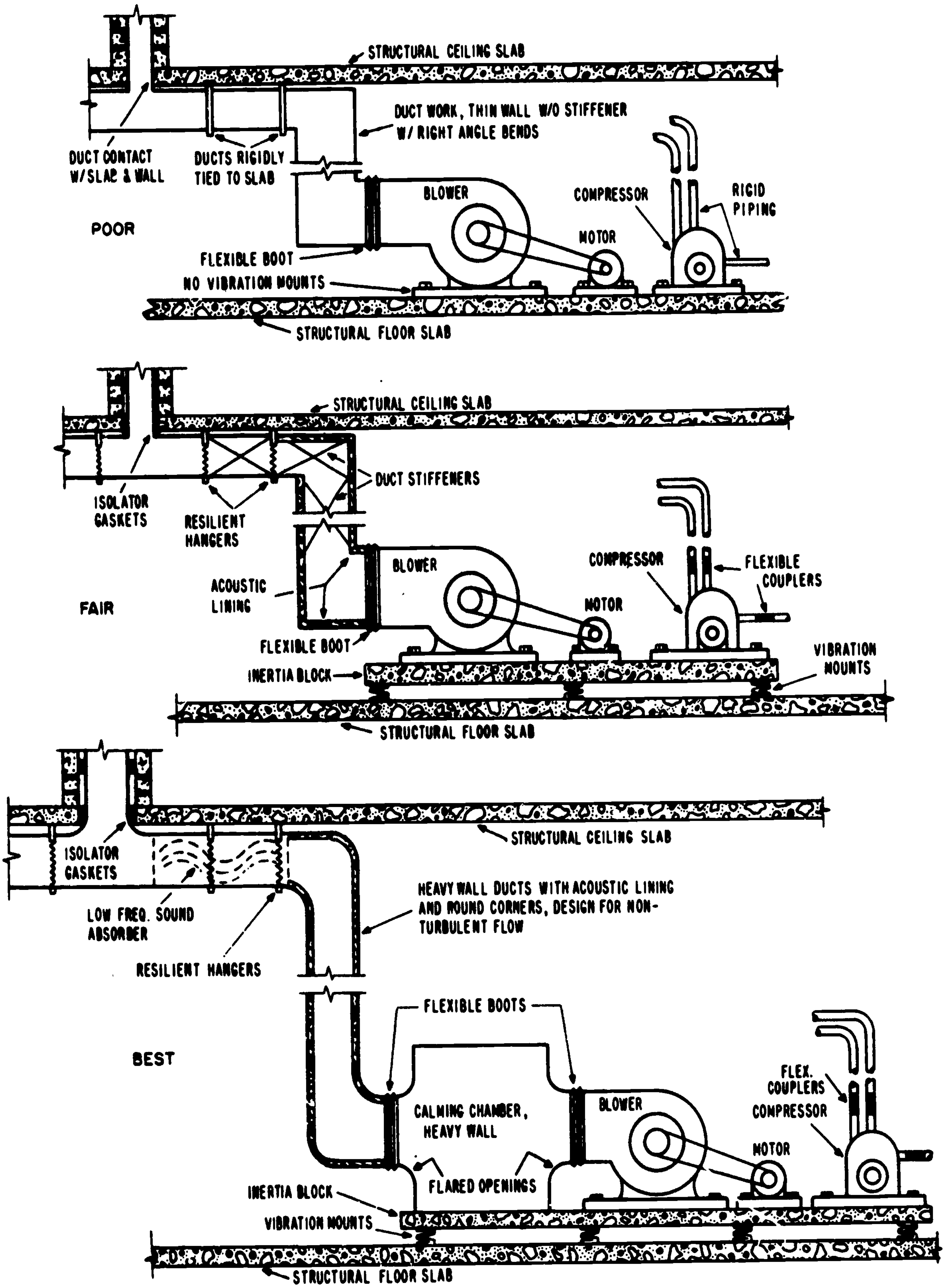
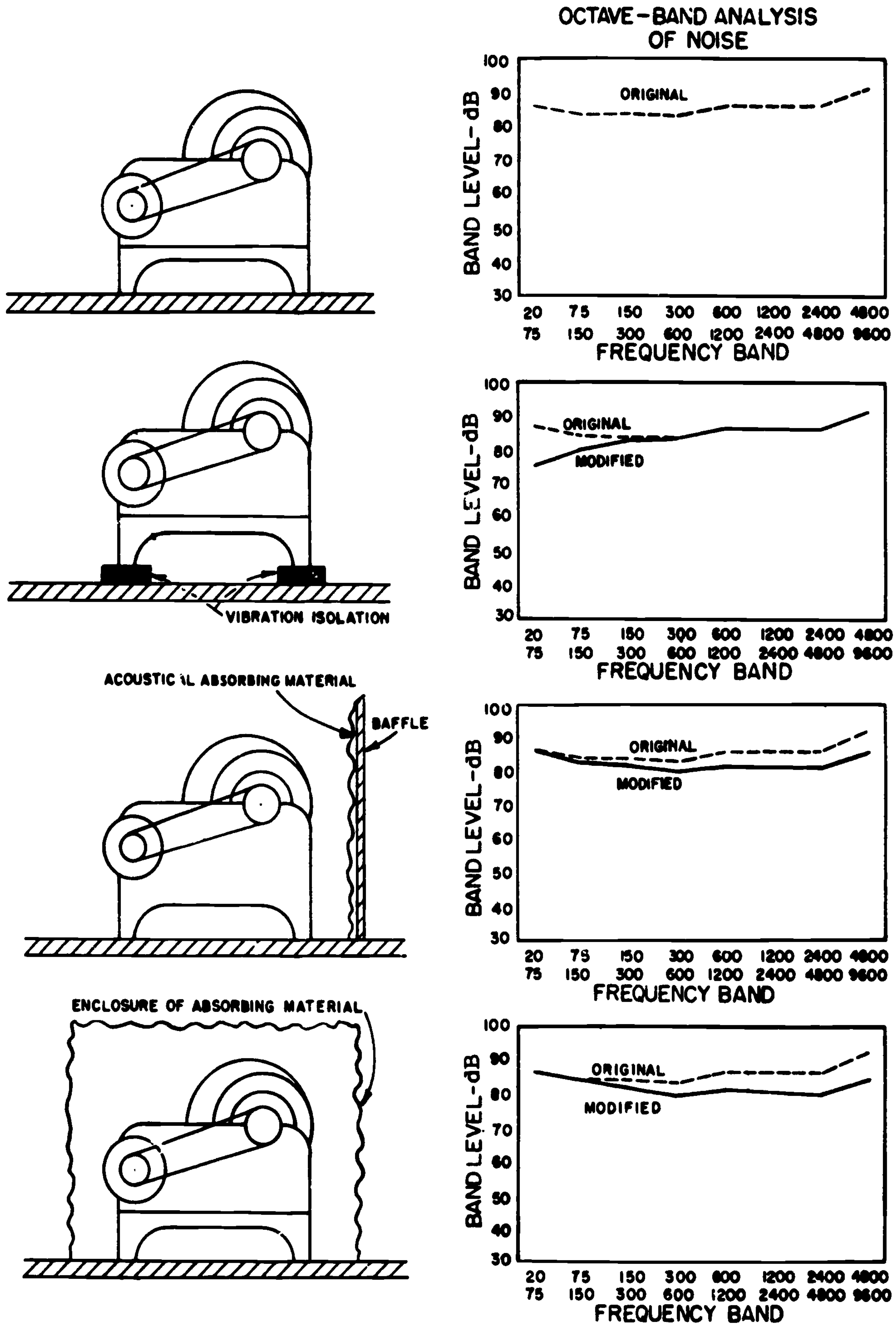
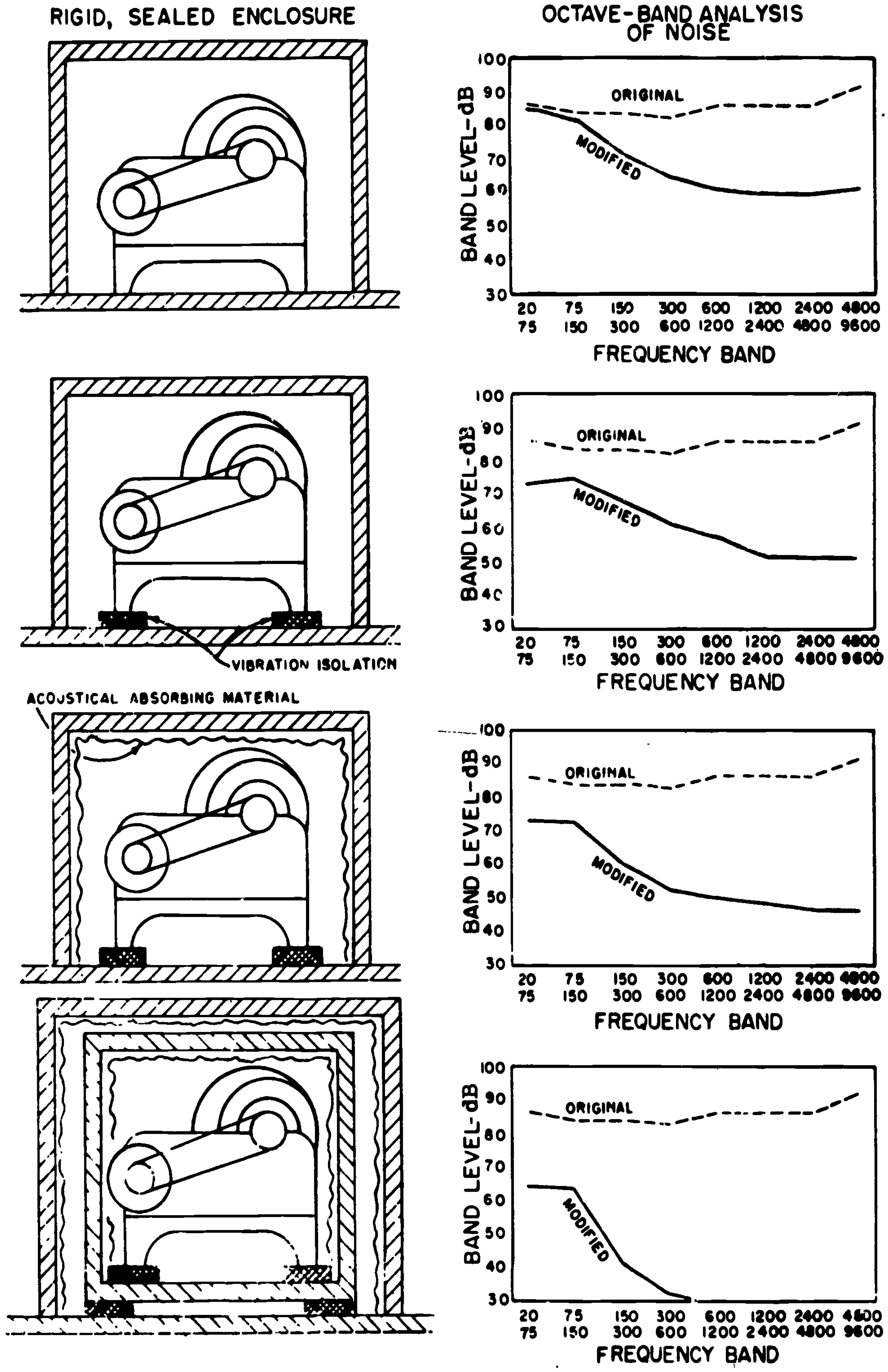


Fig. 8.45. Installation of Air-Distribution Equipment.



Courtesy of General Radio Company

Fig. 8.46. Effectiveness of Various Sound Insulating Techniques, Re: Noisy Mechanical Equipment.



Courtesy of General Radio Company

Fig. 8.47. Effectiveness of Various Sound Insulating Techniques, Re: Noisy Mechanical Equipment.

MIXED CONSTRUCTIONS

See Figures 8.48 and 8.49.

Avoid mixing construction of floor-ceiling and wall partitions, unless provisions have been made to prevent transmission of flanking noise.

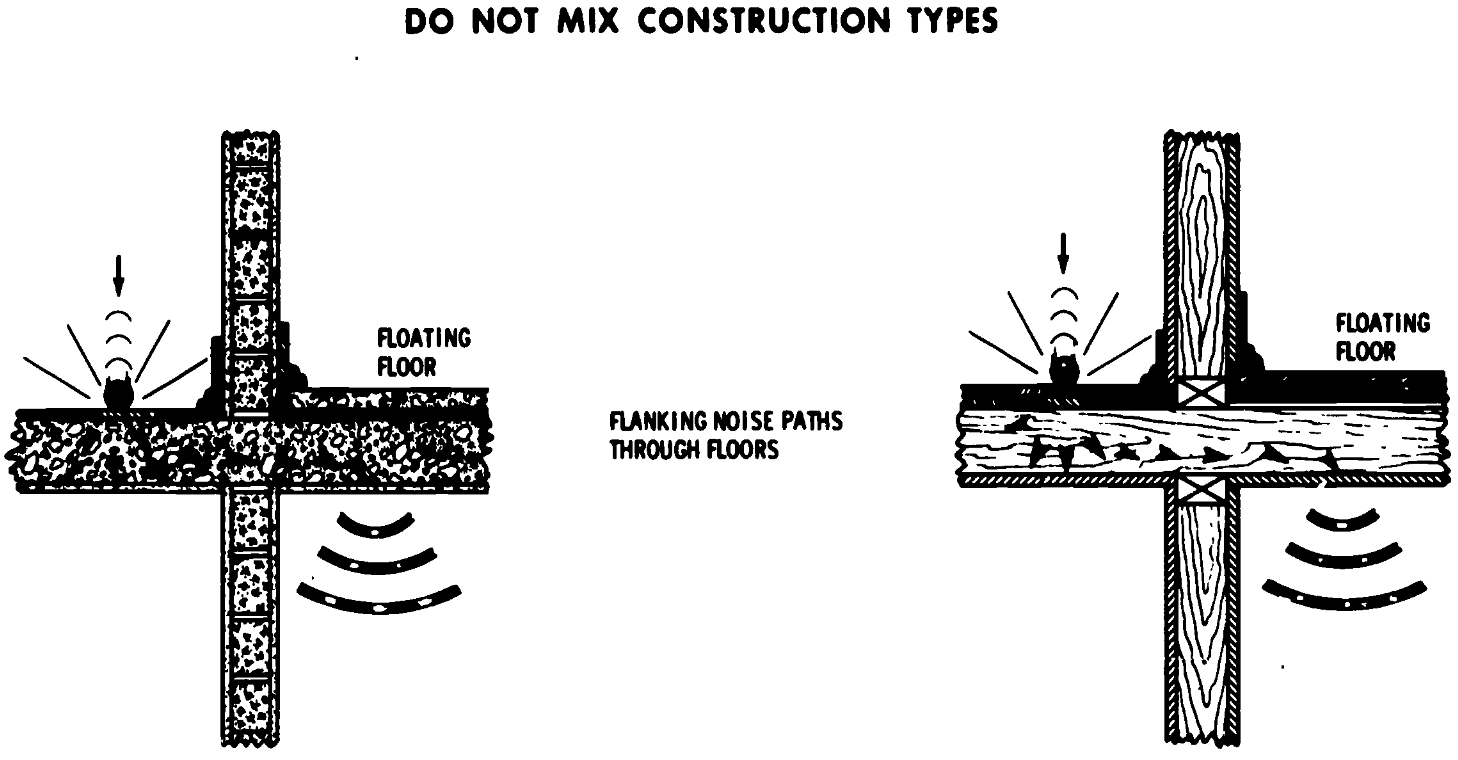


Fig. 8.48. Acoustical Failures Due to Mixed Constructions.

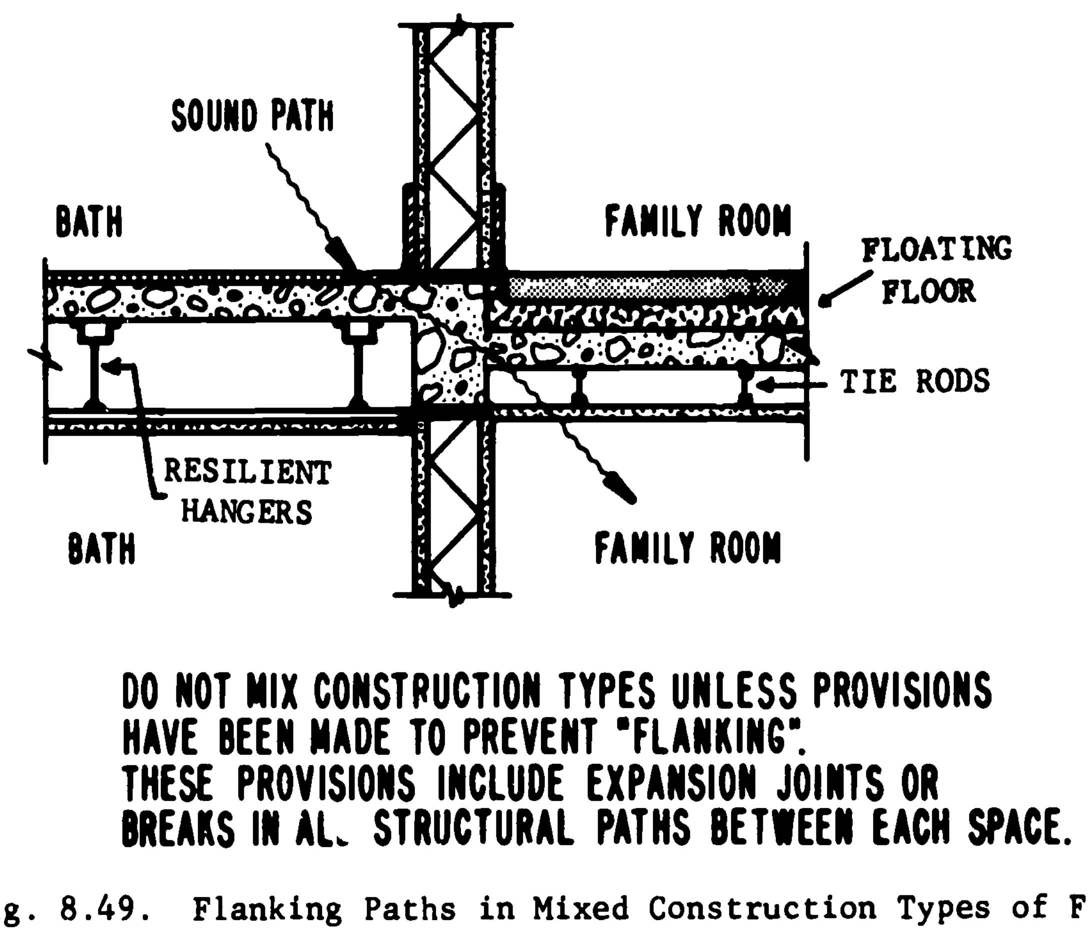


Fig. 8.49. Flanking Paths in Mixed Construction Types of Floors.

NOISE BARRIERS

See D in Figure 8.76.

Use noise barriers wherever practicable as a supplemental noise control device, e.g. as a partial exterior wall between dwelling units or as a patio or garden wall opposite living room or bedroom areas which might front on noisy streets.

OPENINGS IN WALLS

One should remember that small openings, cracks or holes in wall and floor-ceiling structures may become very serious noise leaks, particularly in walls with high STC ratings.

PLENUM SPACES

See Figure 8.50.

Open ceiling plenums, attic spaces, basement areas and crawl spaces which span uninterruptedly across dwelling units serve as flanking transmission paths of airborne noise. Such areas should be completely subdivided with full height partitions or barriers directly above and below the party walls separating dwelling units.

PLUMBING

Probably because of its characteristic invasion of one's privacy, plumbing noise ranks as the most disturbing and offensive noise to which building occupants are exposed. The following should be used to minimize plumbing noise.

I. See Figures 8.51 through 8.57.
   a. Isolate pipes, fittings and fixtures from building structures, especially lightweight partitions, by means of resilient sleeves, mounts and underlayments.
   b. Use simple design pipe layouts, i.e. long straight runs with a minimum of elbows and T connectors. Large radius elbows and connectors should be used to minimize excessive water turbulence and hammering.

II. See Figures 8.58 through 8.61.
   a. Reduce water pressure and velocity by means of pressure reducing valves and oversized piping, respectively.
   b. Use large air or fluid chambers in both hot and cold water lines to reduce water hammer produced by appliances equipped with quick closing valves.
   c. Use full ported faucets, valves, etc., to reduce hissing noise.
   d. Remove air and gas bubbles from plumbing systems to reduce gurgling noise.
   e. Avoid using oversize pumps in hot water heating systems.
   f. Locate steam valves in isolated basement equipment rooms or preferably in underground pits outside of building.

III. a. Avoid locating supply and drain pipes near quiet bedroom and living room areas.
   b. Bathroom party walls should be completely surfaced on both sides from floor to ceiling before tubs are installed.
   c. Seal all openings or cracks around pipe penetrations.
   d. Install solid core doors equipped with gaskets and drop closures in bathroom areas.

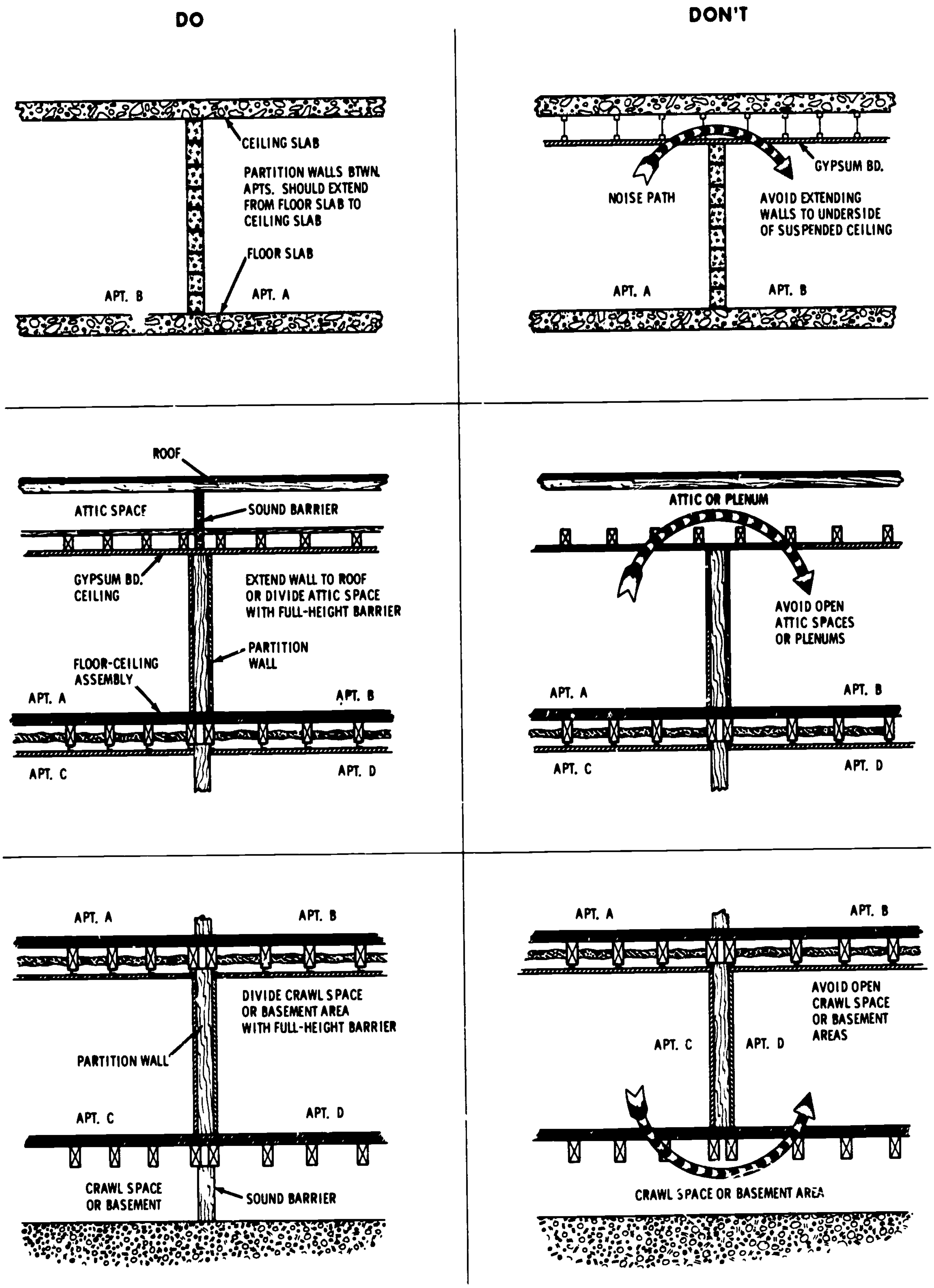


Fig. 8.50. Insulation against Airborne Noise in Plenum Spaces.

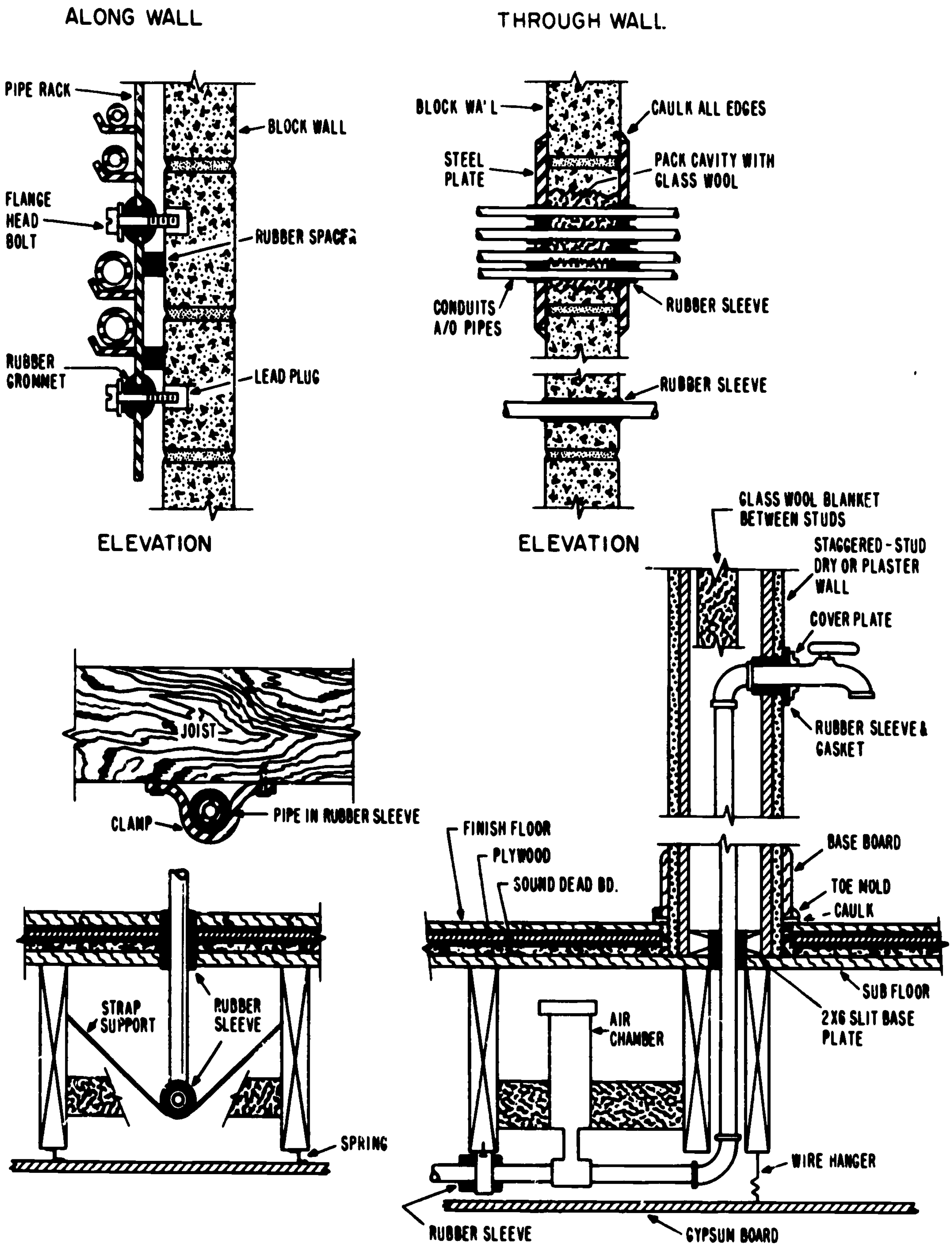


Fig. 8.51. Proper Installation of Pipe Runs.

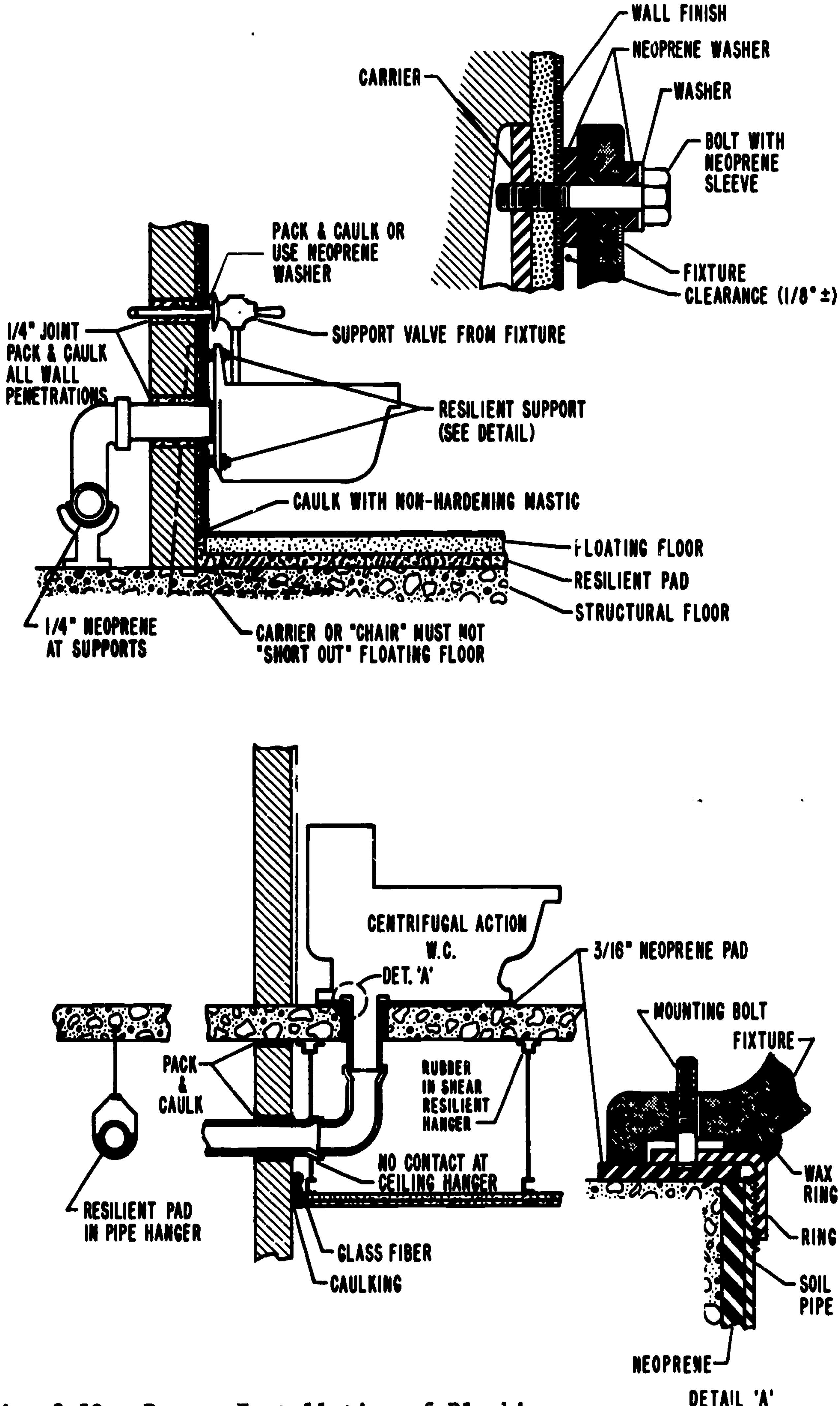


Fig. 8.52. Proper Installation of Plumbing Fixtures.

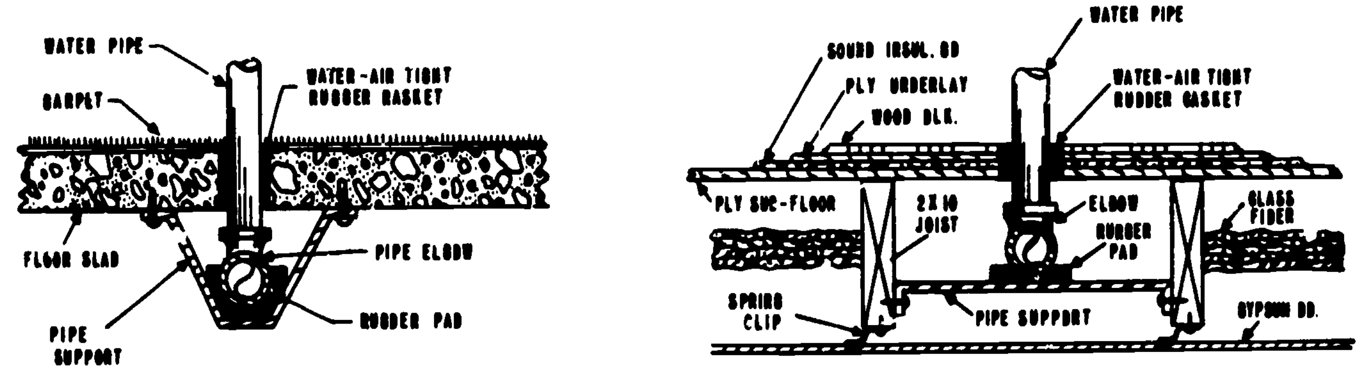


Fig. 8.53. Pipe Penetration through Floors.

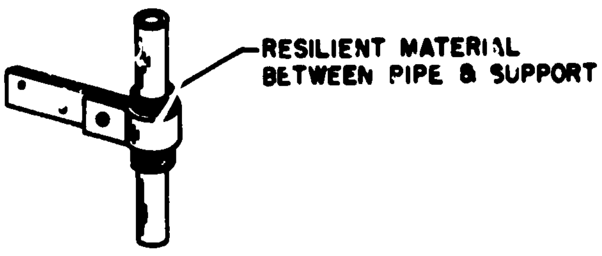


Fig. 8.54. Pipe Support.

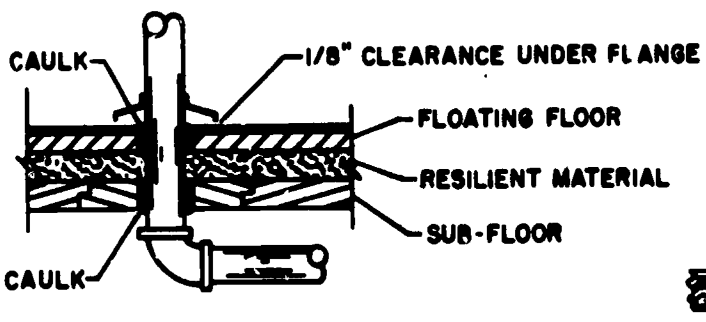


Fig. 8.55. Pipe Penetration through Wooden Floating Floor.

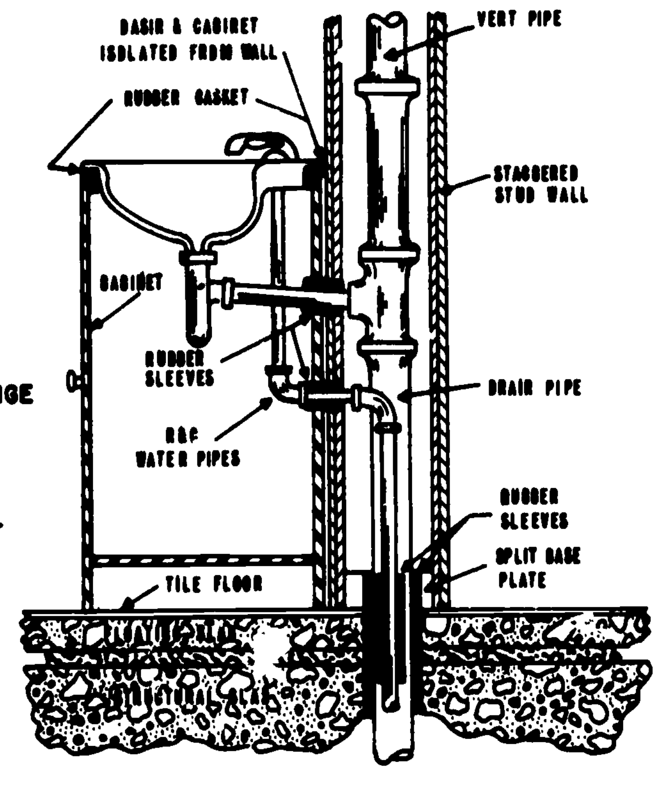


Fig 8.56. Proper Mounting of Piping and Fixtures.

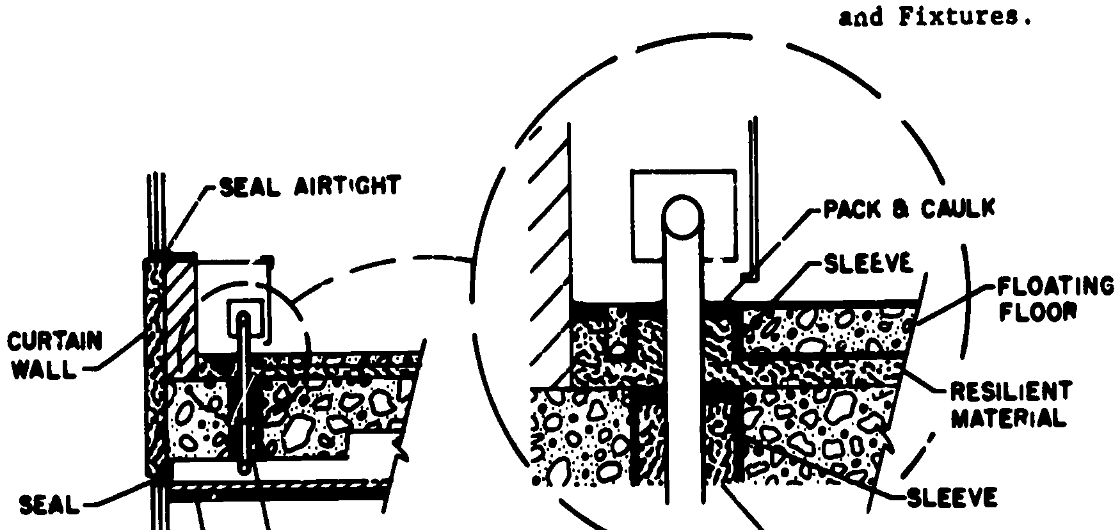


Fig. 8.57. Pipe Penetration through Masonry Floating Floor.

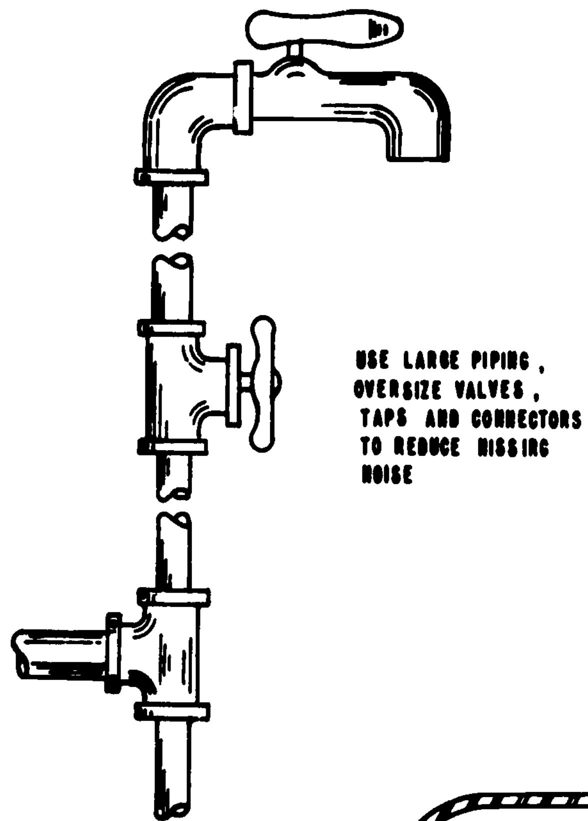


Fig. 8.58. (On the Left)
Reduction of Hissing Noise
in Plumbing.

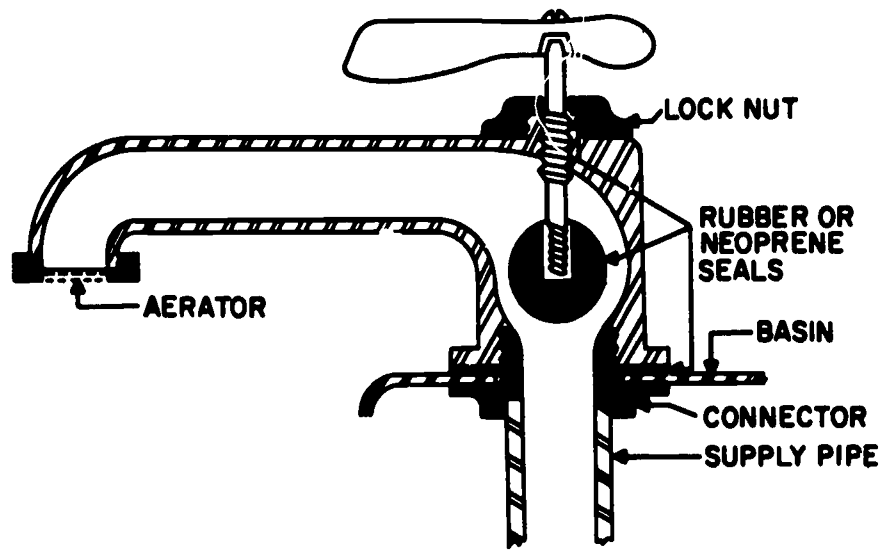


Fig. 8.59. Design and Installation of Water
Faucet for Quiet Operation.

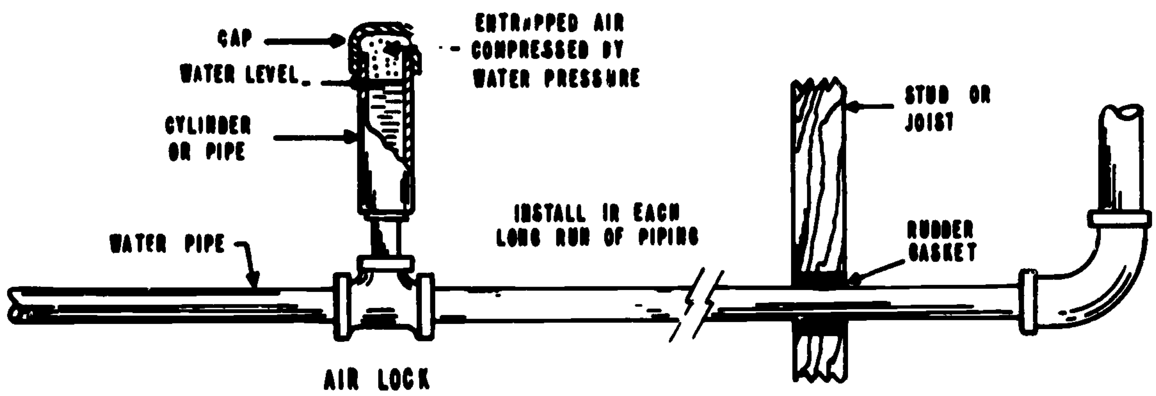


Fig. 8.60. Installation of Air Lock in Plumbing.

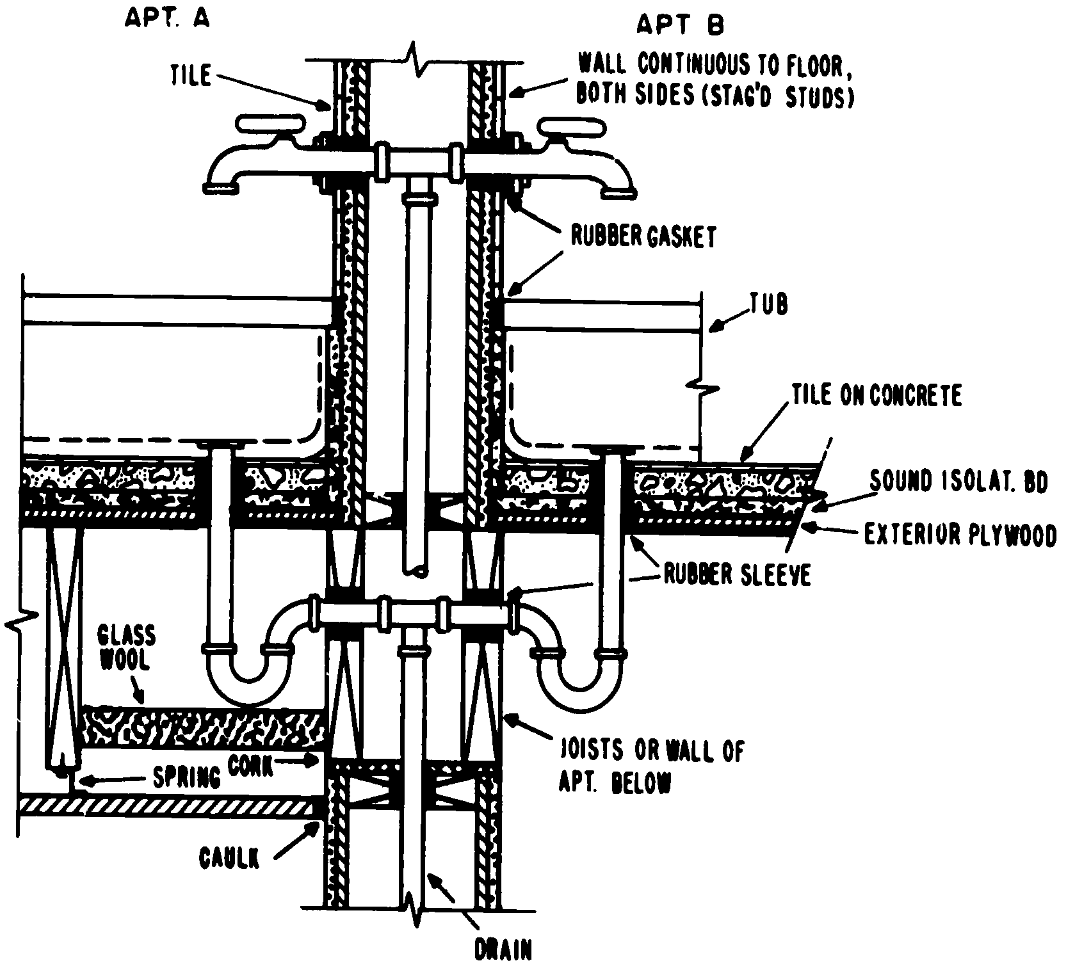


Fig. 8.61. Bath Tub and/or Shower Installation.

RAIN GUTTERS AND SPOUTS

See Figure 8.62.

The plunking noise of water dropping down a rain pipe, particularly during the night, is more disturbing than that of dripping faucets, simply because one cannot turn it off. The following measures should be used to minimize such noise.

a. Avoid installing vertical drain pipes outside of bedroom or living room areas.
b. Isolate vertical drains from building structure by using rubber sleeves at gutter spouts and pipe clamps, and use soft vinyl or rubber elbow at base of drain.
c. Coat either interior or exterior pipe surfaces with a mastic compound to dampen vibration.

RESILIENT ELEMENTS

Resilient elements such as spring clips or channels, rubber sleeves, flexible boots, rubber, cork or felt inserts, and carpets, pads or glass fiber underlays should be used wherever practicable for purposes of isolating vibrating devices or systems from building structures to reduce transmission of impact and structure-borne noise.

REVERBERATION

Reverberation or noise build-up in such areas as entrance lobbies and corridors can be controlled by using such materials or furnishings as acoustical tile ceilings, carpets and pads, draperies and upholstered furniture

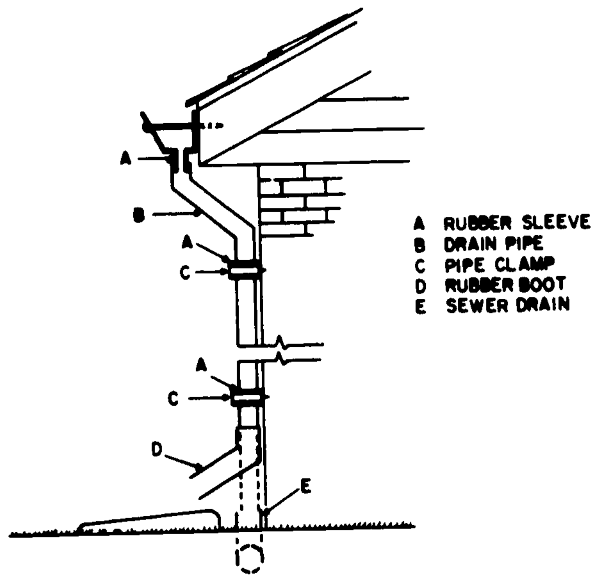


Fig. 8.62. Proper Installation of Rain Gutters and Spouts.

RISERS

See Figure 8.63.

Vertical ducts or ventilation risers mounted on the exterior of buildings frequently are the cause of noise complaints. Such devices often rattle in windy areas or snap, crackle and pop, owing to thermal expansion and contraction with outdoor temperature variation. Further, the outdoor noise of aircraft, traffic, etc., are easily transmitted by the thin-wall duct and carried into the building interior. All exterior ductwork should be of double-wall construction with acoustic lining and silencers.

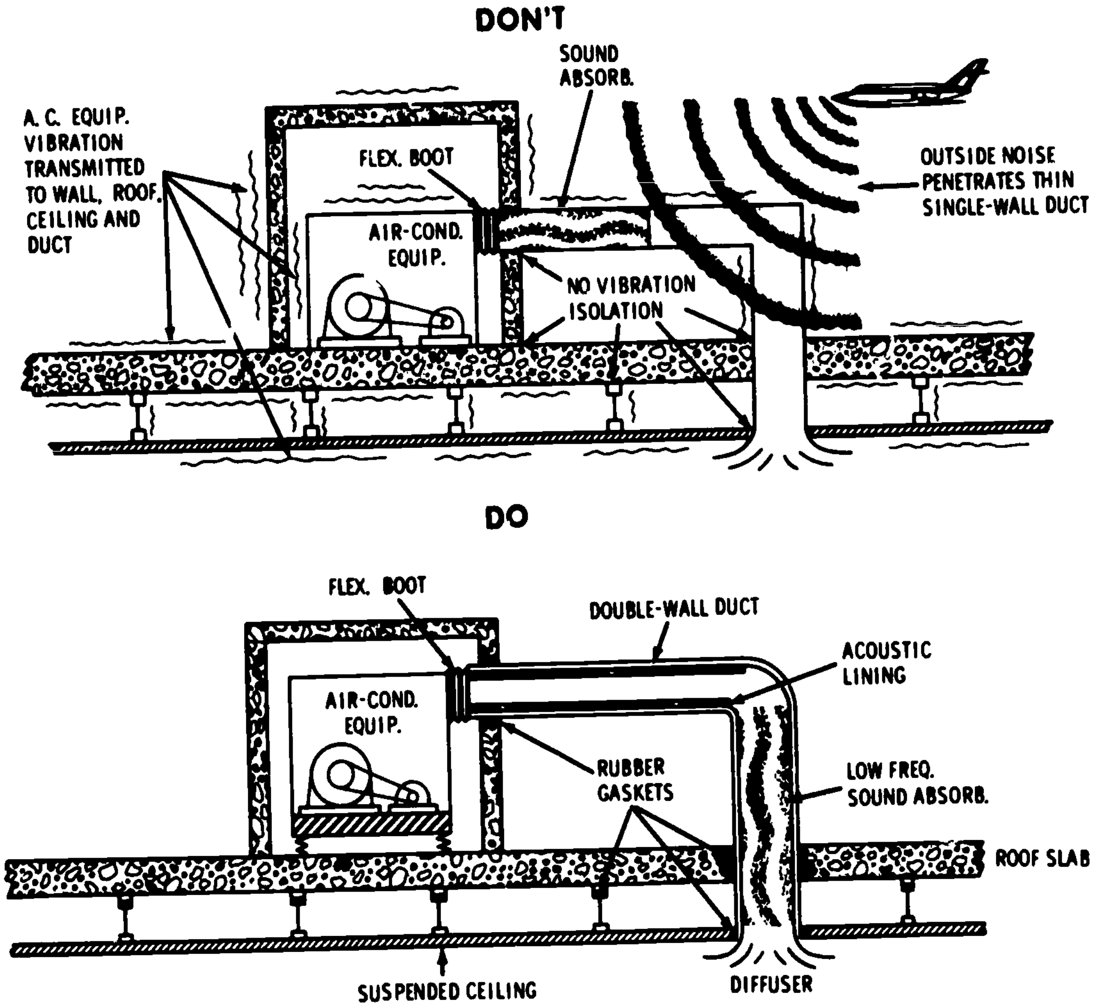


Fig. 8.63. Installation of Roof Mounted Air-Conditioning Equipment.

RODS, ROLLERS See Figure 8.64.

Closet or shower rods and paper rollers or dispensers should be vibration isolated from wall by means of rubber cups, grommets or spacers.

ROOFS See Figures 8.63 and 8.65.

Penetrations in roofs, particularly for ventilation and exhaust systems, often allow excessive transmission of outdoor noise into the building if precautionary measures are not taken.

Roof mounted equipment such as ventilation fans, compressors and cooling towers invariably give rise to problems involving excessive airborne and structure-borne noise radiation as well as vibration. The noise and vibration isolation of such equipment is substantially more efficient and much easier to cope with in basement installations.

SOUND ABSORBERS, SILENCERS See Figure 8.66.

Sound absorbing materials in the form of duct lining, prefabricated silencers or blankets should be used wherever practicable in noisy ventilation or air distribution systems or between studs and joists of discontinuous type of wall and floor-ceiling structures. Sound absorbers such as acoustical tile and carpeting should be used in reverberant areas.

SQUEAKING FLOORS

Squeaking floors frequently are the cause of a number of noise complaints. Such floors, which usually are found in wood frame construction, generally are more of a nuisance to the apartment dwellers who walk on them than to those who live in an apartment directly below. This problem often arises in some types of floating floor structures, e.g. wood block flooring cemented directly onto a resilient glass or wood fiber board underlayment. Excessive deflection of the unit blocks with respect to each other usually is the cause of squeaking. In order to minimize the problem, hard board or plywood sheets should be sandwiched between the finish block flooring and the resilient underlayment for better dynamic load distribution.

The overall problem of controlling squeaking floor structures in general depends primarily on the following factors:

a. control of moisture or humidity,
b. use of straight, flat, good quality lumber,
c. proper nailing,
d. control of excessive deflection of basic floor structure under load, and
e. use of building paper layers between finish and subflooring.

For a more detailed discussion relative to preventing and/or correcting squeaking floors refer to Chapter 7.

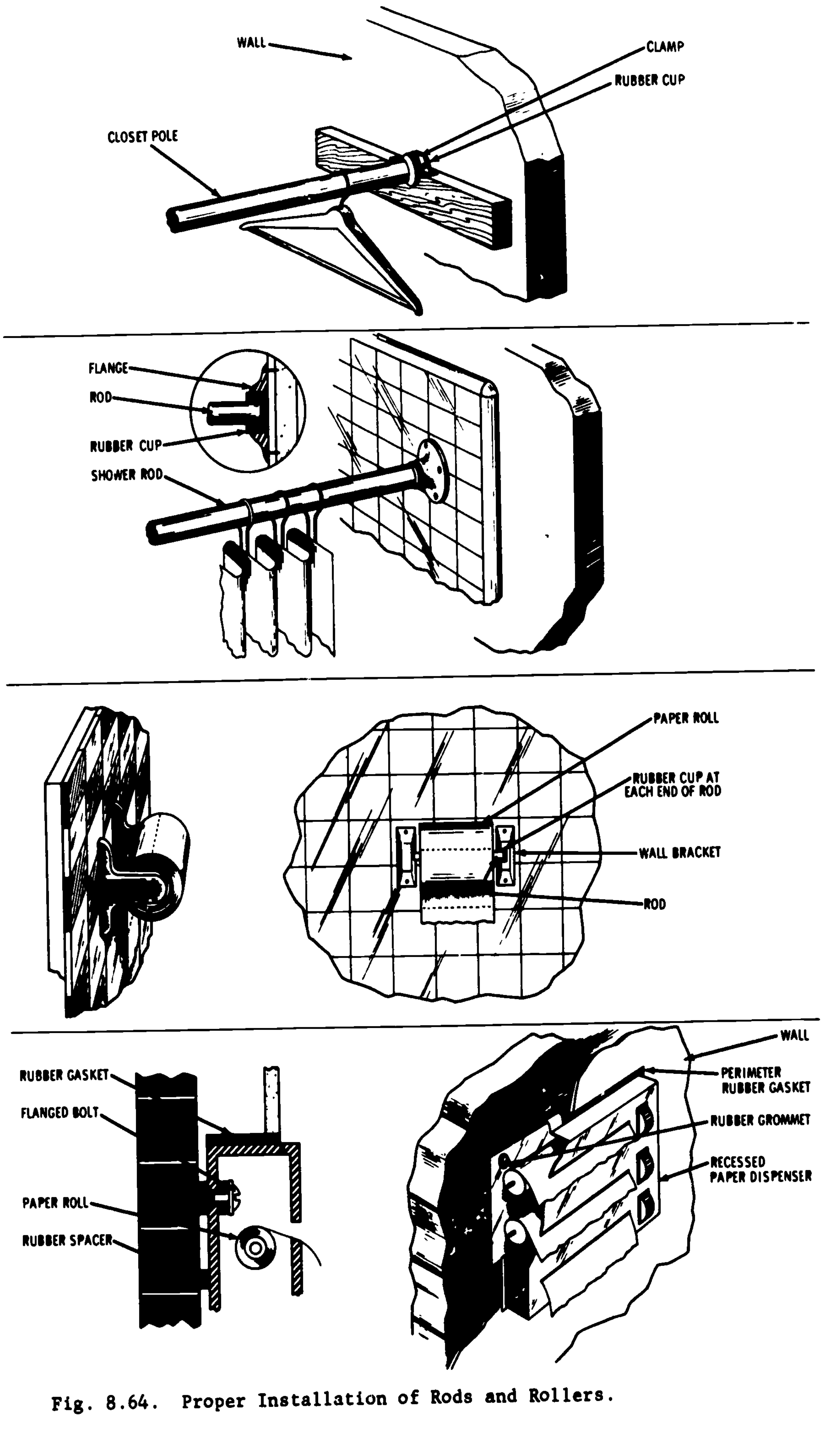


Fig. 8.64. Proper Installation of Rods and Rollers.

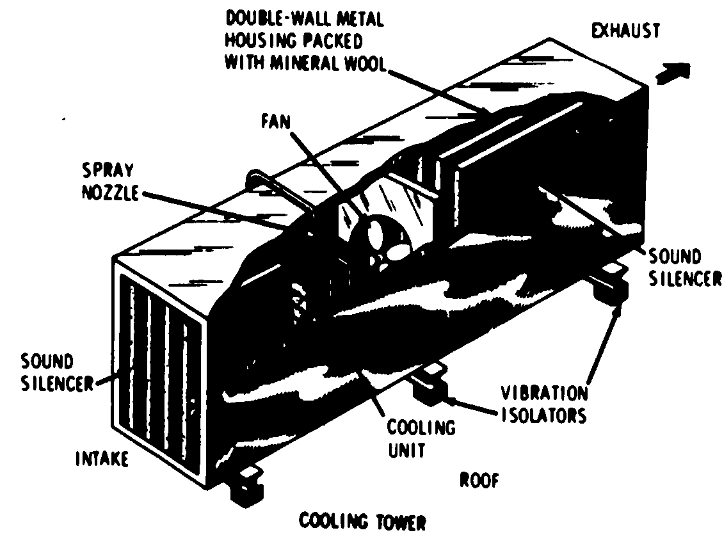


Fig. 8.65. Acoustical Design of Roof Mounted Cooling Tower.

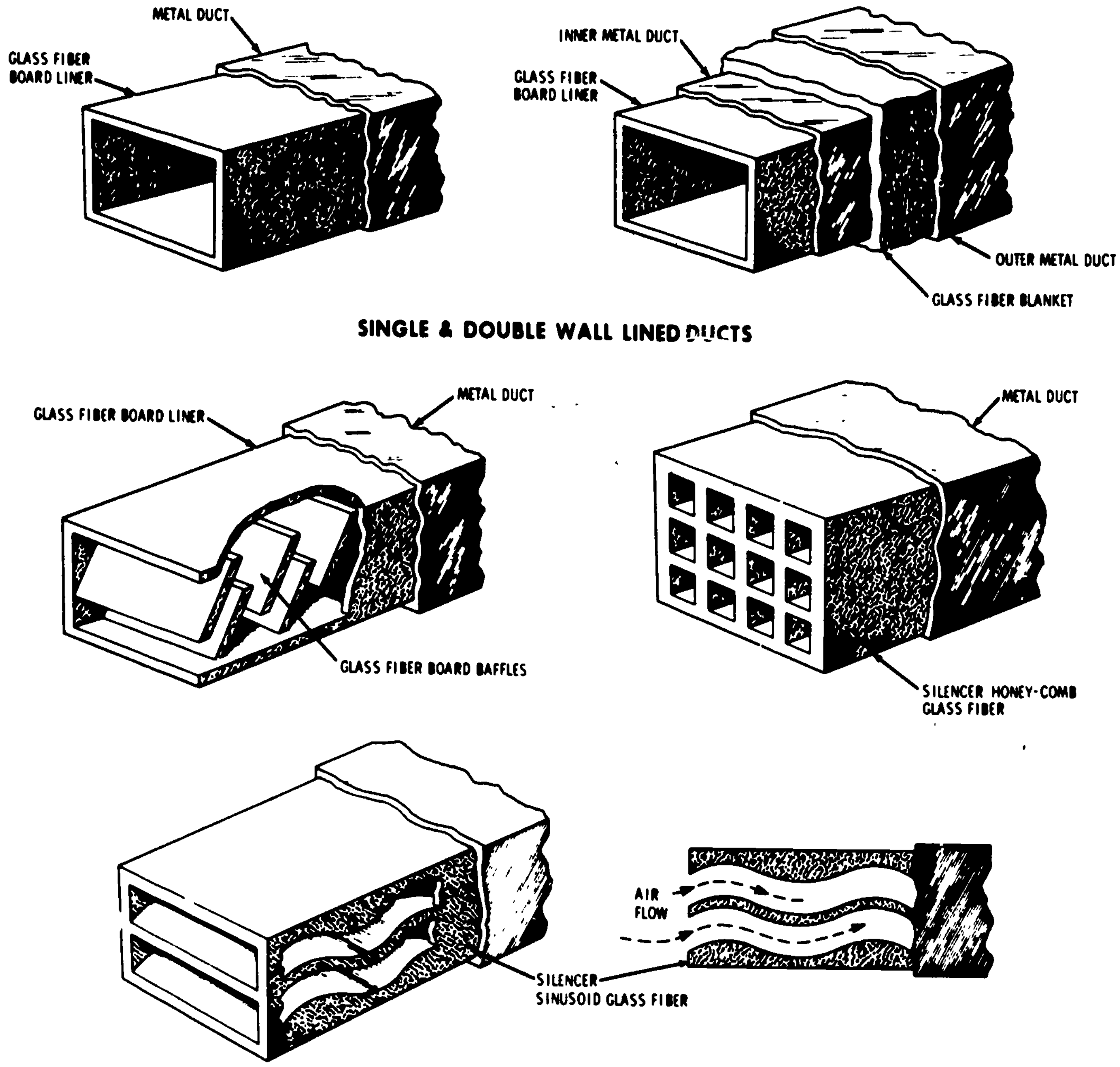


Fig. 8.66. Duct Silencers and Baffles.

STAIRCASES

See Figures 8.67 and 8.68.

Staircase traffic is a source of irritating airborne as well as impact noise, especially in multifamily dwellings of wood frame construction where many children reside. Ways of avoiding this problem involve:

a. isolating the staircase from the building structure,
b. using double or staggered stud wall construction or walls with resilient elements along side of staircase.
c. avoiding the nailing of stair stringers to adjacent wall studs,
d. requiring that staircase walls be completely surfaced before staircase is installed, and
e. installing rubber pads or carpets on stair treads.

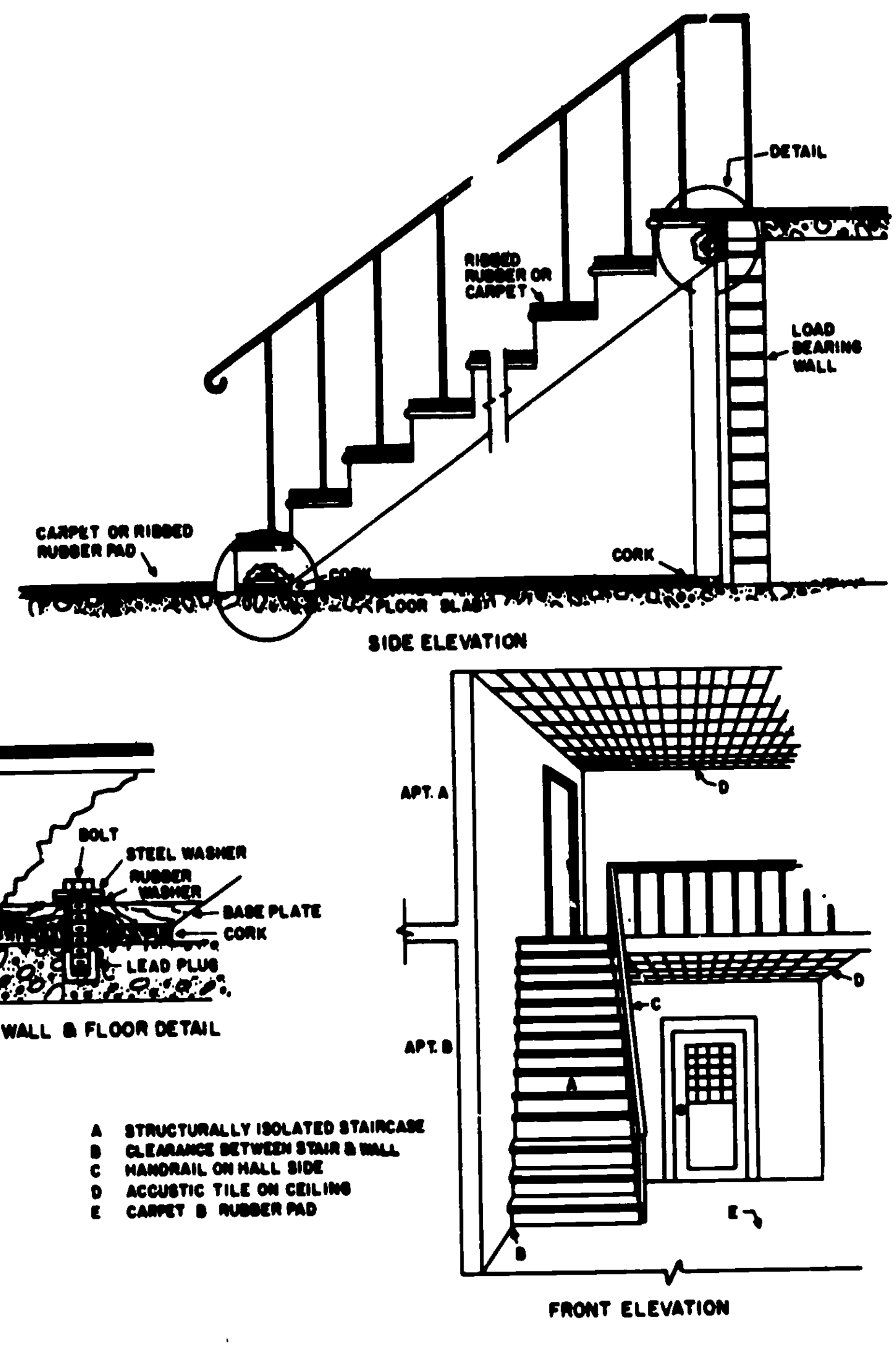


Fig. 8.67. Proper Installation of Staircases.

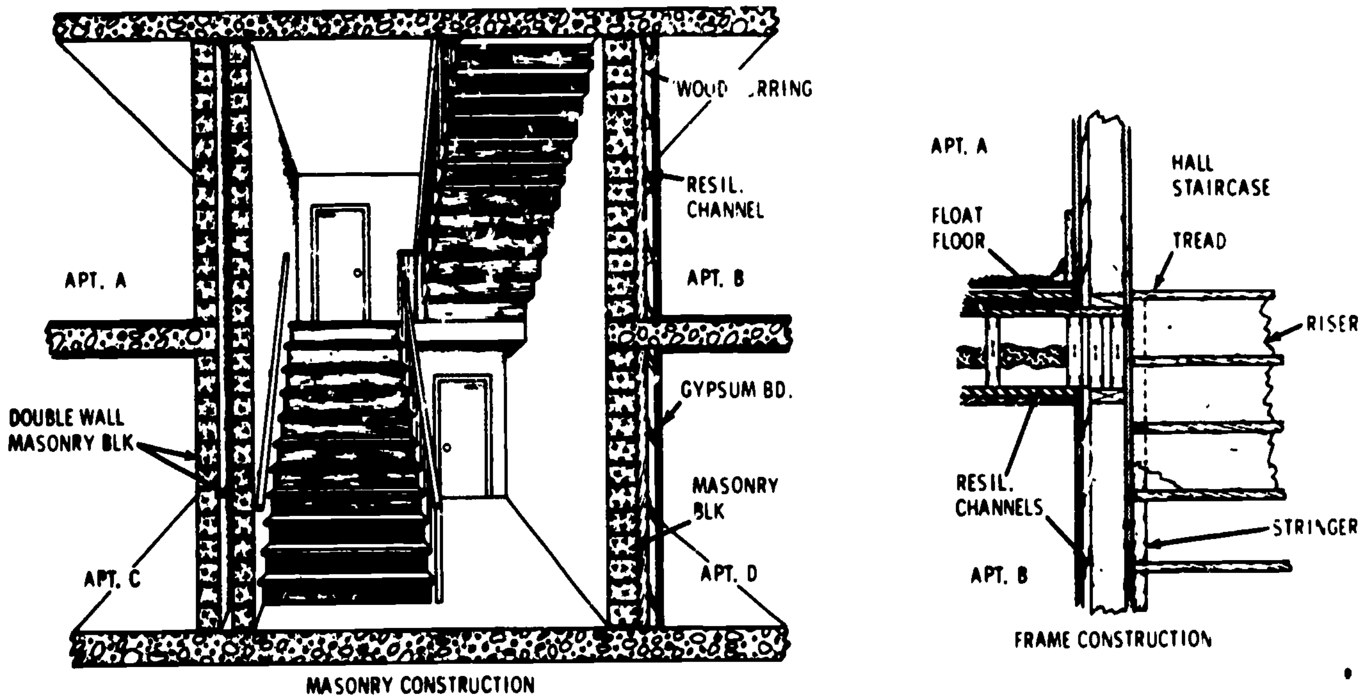


Fig. 8.68. Acoustical Isolation of Staircases.

TELEPHONES See Figure 8.69.

Avoid mounting of telephones on party walls, particularly of light frame construction. Because of the poor sound insulation afforded by such structures, the occupants in adjacent apartments seldom know which of the telephones is actually ringing.

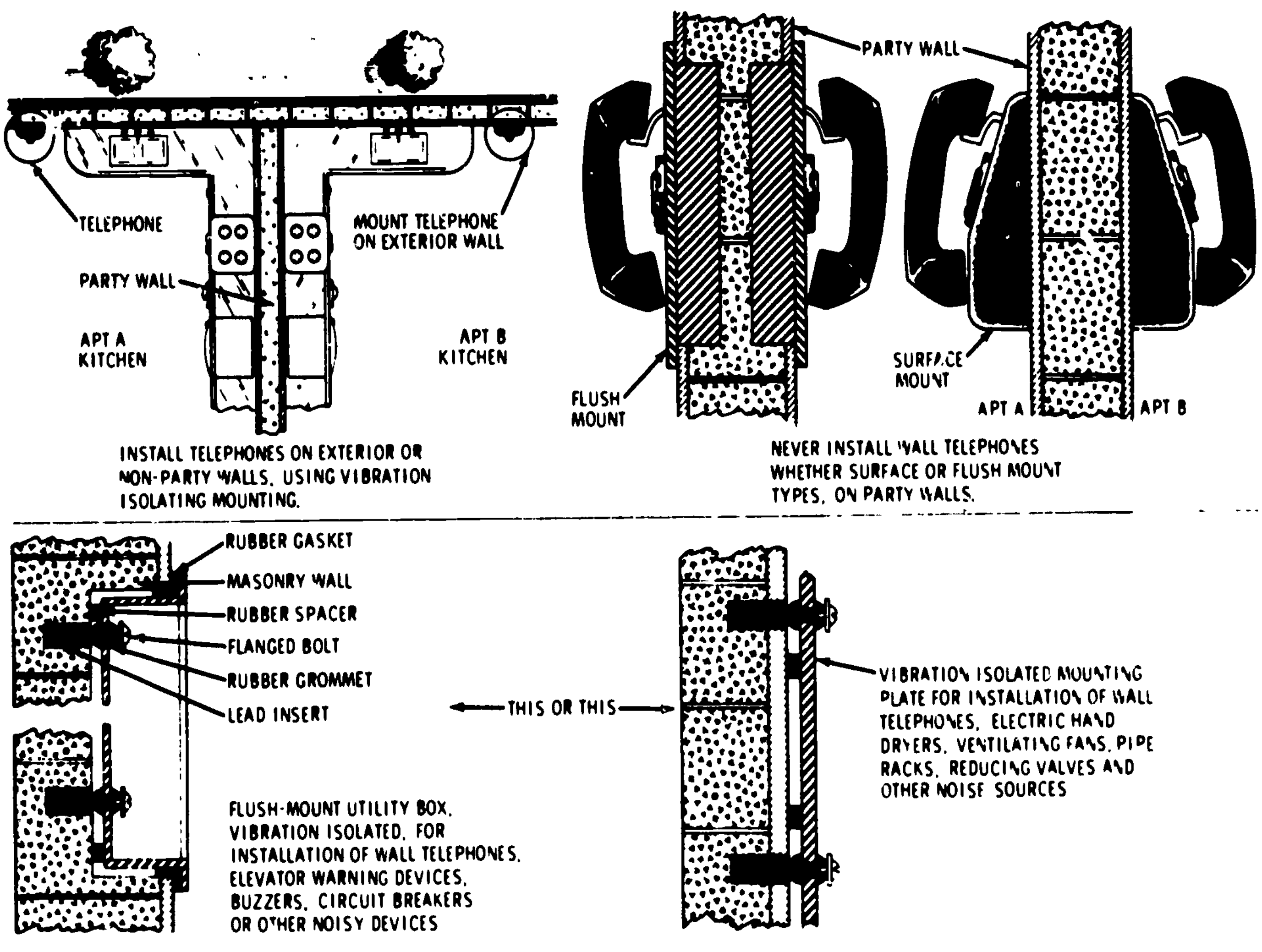


Fig. 8.69. Installation of Wall Mounted Telephones.

TELEVISIONS Among sources of airborne noise, televisions rate as the most frequent cause of occupant complaints. Although the intruding noises from the neighbors' TV sets usually are distracting, the greatest irritation or annoyance comes from the over-frequent, intermittent, raucous TV commercials, which often are blared out at noise levels 5 to 10 dB higher than the normal program level. To discourage occupants from locating their TV sets against party walls, the TV antenna outlet should not be installed in party walls. Room layouts should be planned so that the most favorable TV locations will be along exterior or non-party walls in order to minimize this potential noise problem.

TRANSFORMERS See Figure 8.70.

Transformers are particularly disturbing noise sources because of their low frequency humming and vibration. As a consequence they should be installed in basement equipment rooms far removed from living quarters. Large power transformers should be installed in underground vaults or walled-in enclosures far removed from the apartment building.

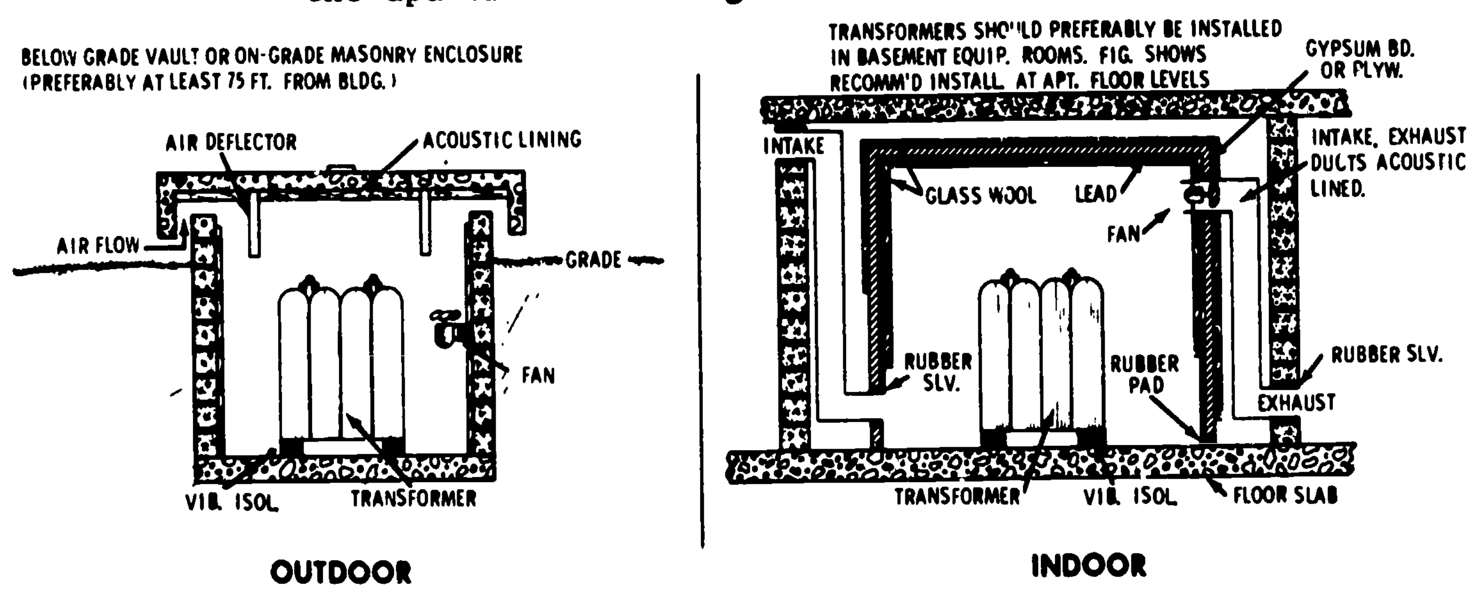


Fig. 8.70 Transformer Installation.

UNDERCOATING Undercoating, such as used on automobiles, may be used effectively as a vibration damper on ductwork, metal sliding or folding doors, incinerator chutes, etc.

UNDERLAYMENTS For purposes of impact noise isolation, materials such as glass fiber, cork and rubber are quite effective as resilient underlays in floating floor constructions and particularly under bath tubs and shower stalls.

VENT OPENINGS For a given mass-flow of air, large area vent openings have a lower air velocity and therefore are less noisy than vents of smaller cross-sectional area.

VIBRATION ISOLATORS Vibration isolators should be used under all large electro-mechanical equipment, if vibration and structure-borne noise transmission are to be minimized.

WALLS

See Figures 8.71, 8.72 and 8.73.

The following measures should be considered to ensure that partition walls will provide adequate sound insulation.

a. Depending on the functions of the spaces to be separated, select a wall with proper type of construction as well as an appropriate STC value.
b. Partition walls should extend full height, i.e. from floor to ceiling. In bathroom areas, party walls should be completely surfaced on both sides, before bath tubs are installed.
c. Similarly, full height partition walls should be installed in attic or basement areas directly above and below party walls separating dwelling units for pur poses of eliminating flanking transmission of airborne noise.
d. **Regardless of the type of wall considered, whether of single, double or discontinuous construction, it is preferable to use materials of greater mass per unit area if a choice exists, e.g. use solid-core rather than hollow-core masonry units, heavy aggregate instead of lightweight aggregate in concrete or plaster mixes and thick sheets as opposed to thin sheets of gypsum board in dry wall constructions.**
e. Partition walls should be decoupled or isolated from adjoining building structures or surfaces by using gasketing material at the peripheral edges.
f. Avoid "short circuiting" the effectiveness of a high performance wall by back-to-back installation of electrical outlets and recessed cabinets.
g. All holes and cracks in and around the wall should be properly sealed to ensure an airtight installation.

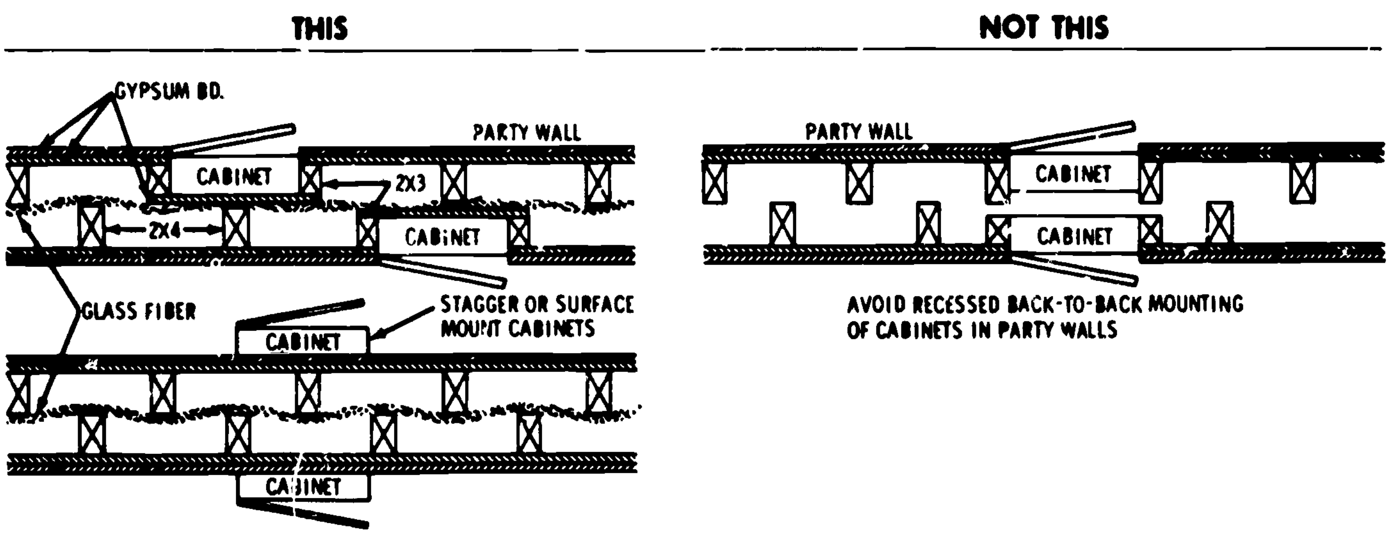


Fig. 8.71. Wall Installation of Cabinets.

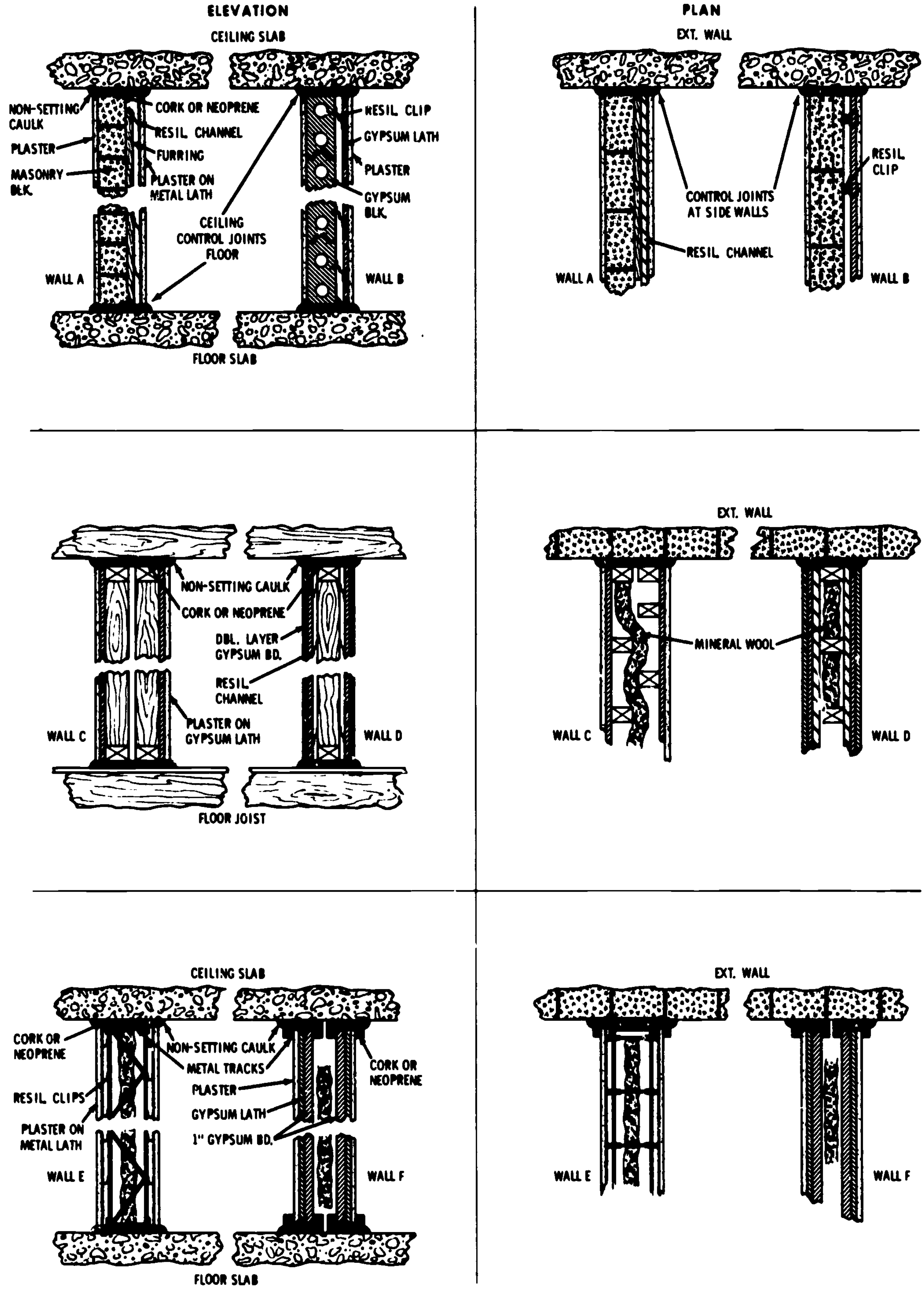


Fig. 8.72. Bonding of Partition Walls to Ceilings, Floors and Exterior Walls.

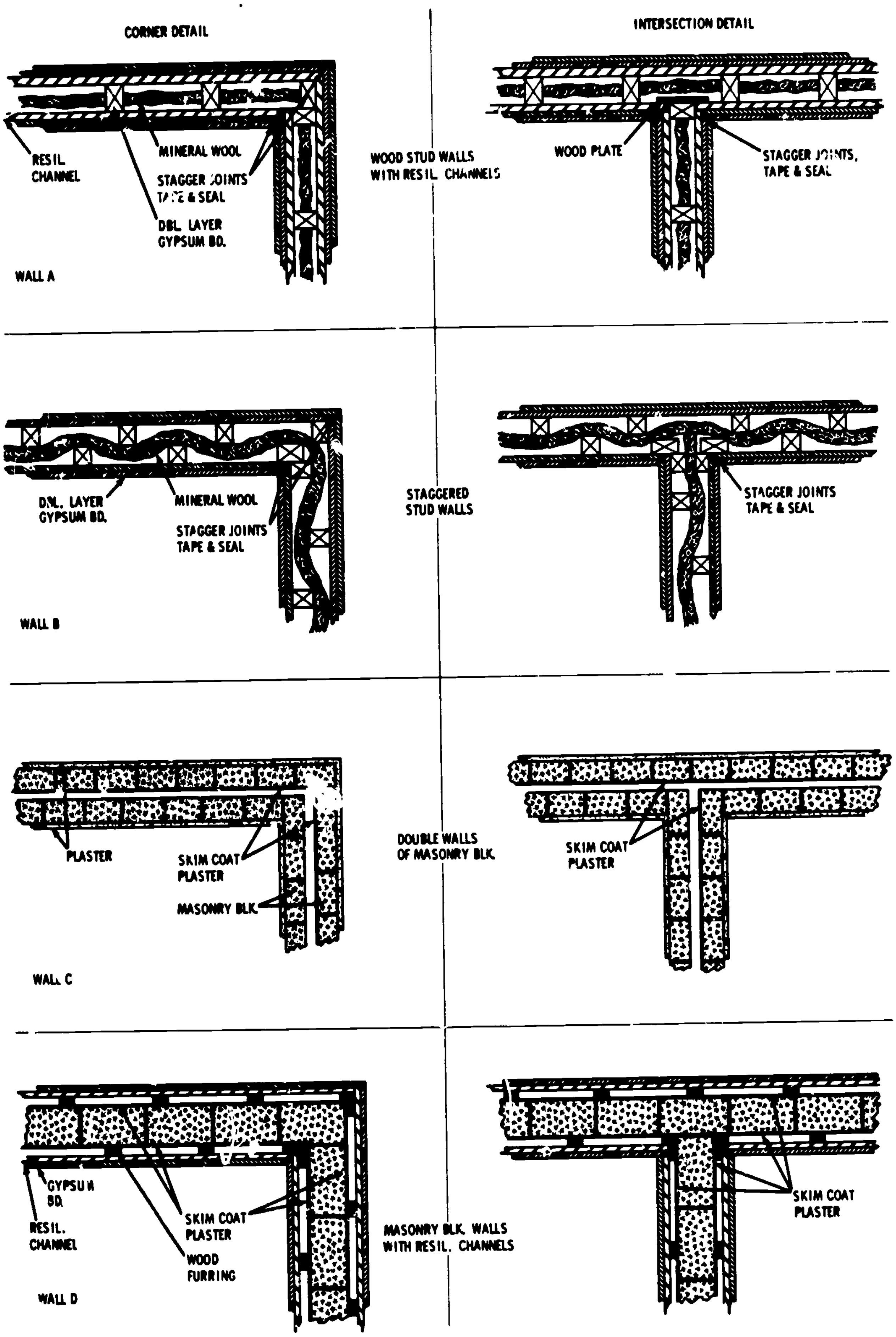


Fig. 8.73. Framing of Sound Insulating Walls at Corners and Intersections.

WALLS, EXTERIOR CURTAIN

A number of noise problems are associated with some types of curtain walls, particularly of the prefabricated metal panel units used for exterior facing of buildings. The chief noise complaints involve:

a. Poor sound insulation of outdoor noise due either to poor seals and/or performance of the panels themselves

b. Disturbing noises produced by rattling or drumming of curtain walls in windy areas and the snapping, crackling or popping of such units due to thermal expansion or contraction with outdoor temperature variation.

WINDOWS

See Figures 8.74, 8.75 and 8.76.

Avoid building designs with large-area window exposures which face heavy traffic arteries or other noisy areas, unless windows are properly designed for adequate sound insulation. In this connection the following measures should e observed.

a. use heavier, thicker or laminated glass or double pane construction. Additional sound insulation may be obtained from windows of double pane construction by (1) separating glass panes at least 6 inches, (2) sloping one of the panes with respect to the other, (3) using glass panes which differ in thickness, and (4) lining the side walls between the glass panes with acoustical material.

b. use gasketing around the peripheral edges of the window to ensure airtightness.

c. use lever-type locking devices which force window to seal tightly against gasketing rather than spring-loaded catch or hook type locks.

d. use wooden or heavy gage metal tracks or slides in lieu of lightweight metal or plastic tracks to minimize window rattling, vibration or resonance.

e. locate and install windows such that flanking noise transmission or cross-talk from one apartment to another is minimized.

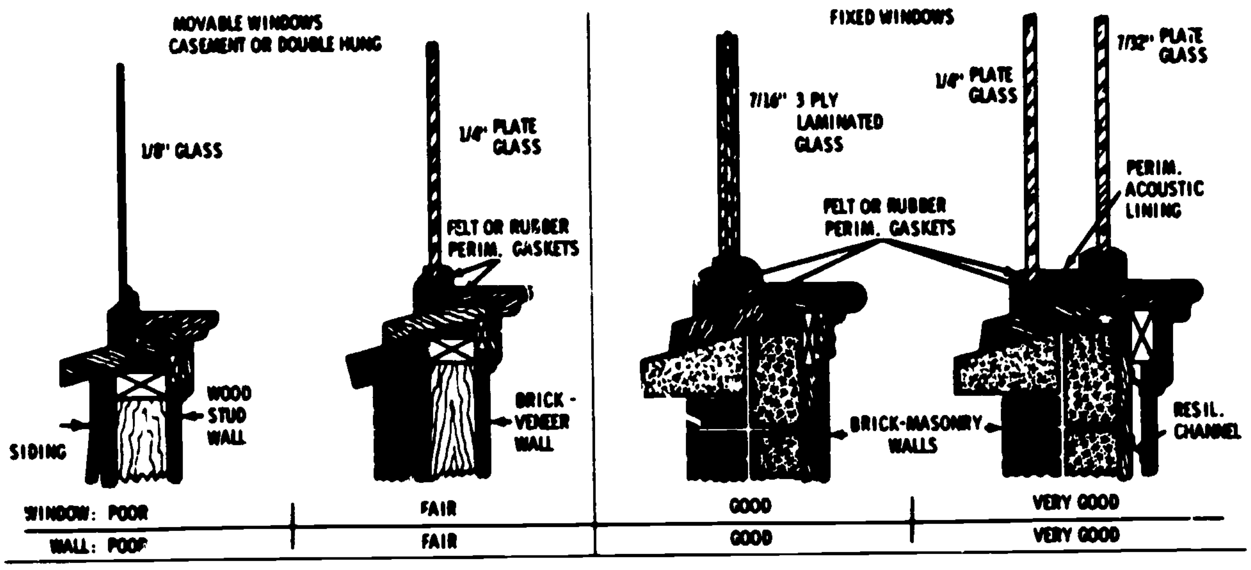


Fig. 8.74. Sound Insulation Effectiveness of Window-Wall Assemblies.

——— 1/8-in. plate glass
– – – – 1/4-in. plate glass
——— 0.45-in., 3 ply, laminated glass panel
– – – – 0.62-in., 4 ply, laminated glass panel
–·–·– 0.80-in., 5 ply, laminated glass panel

Aluminum framed windows with glass panes isolated with neoprene gaskets;

——— two 1/4-in. glass panes, 1/2-in. air space.
– – – – 1/4-in. and 3/16-in. glass panes, 2 1/2-in. air space.
–·–·– 1/4-in. and 7/32-in. glass panes, 3 3/4-in. air space.

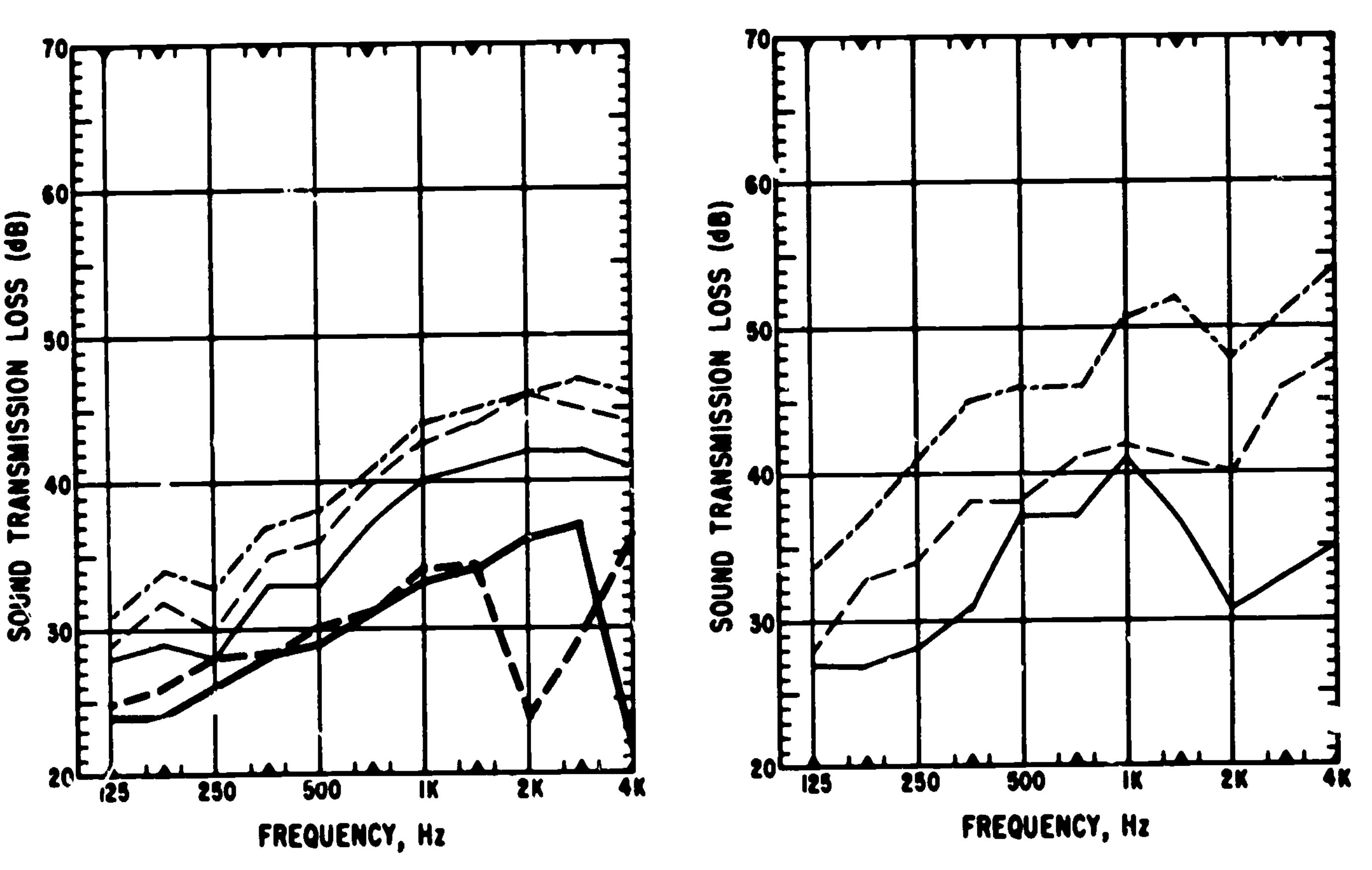


Fig. 8.75. Sound Transmission Loss of Windows.

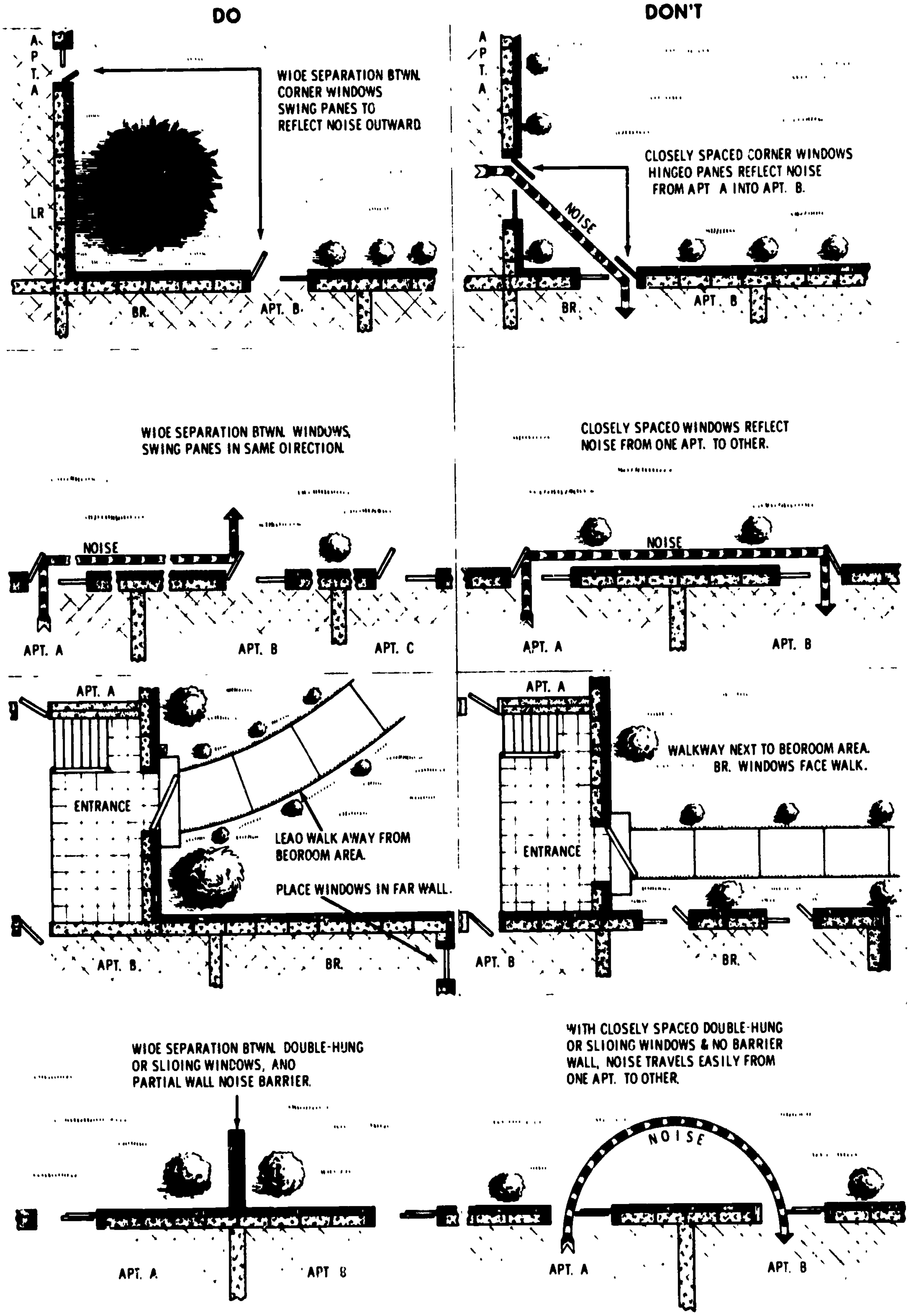


Fig. 8.76. Window Arrangement.

CHAPTER 9

DEVELOPMENT OF CRITERIA

A. INTRODUCTION

The urgent need for adequate sound insulation criteria, particularly in multifamily dwellings, has been firmly established. Criteria which are suitable to all situations and environments would be virtually impossible to establish and very difficult to apply. Therefore, one of the objectives of this guide is to establish criteria which will satisfy a majority of the occupants most of the time, and yet will be relatively easy to administer.

B. FACTORS TO CONSIDER

Before satisfactory sound insulation criteria can be established, the following factors must be considered.

1. The characteristics of the intruding noises, i.e. intensity and frequency distribution. This point requires a large scale investigation since the characteristics of these noises are not constant quantities, but vary with the many sources operating singly or in combination under widely different conditions.
2. The sound insulation performance of wall and floor structures, particularly as integrated systems in a building complex.
3. The limits of the intensity, duration, and irregularity of noise subjectively acceptable to the majority of occupants. These parameters are particularly elusive since subjective surveys inevitably include responses motivated by environmental conditions other than acoustical. Consequently, the results of such surveys are approximate at best.
4. Finally, the limitations of using background noise for masking purposes. Although the use of masking noise can be beneficial in certain cases, it has been extended and overemphasized to the point where it fails more frequently than it succeeds. The concept of "masking noise" in this context simply involves using the ambient acoustical environment beneficially for "masking" or overriding the annoying intruding sounds. A descriptive definition of masking noise might be that existing steady sound which has the following pleasing characteristics:
   (a) low intensity with a wide-band frequency distribution, void of any pure-tone components;
   (b) an omnidirectional source, such that its location is not evident to the observer;
   (c) the ability to reduce the detection of intruding noise without becoming annoying itself.

Many examples of sources of masking noise are given in the literature, including steady vehicular traffic, heating, air-conditioning and ventilating equipment, industrial and commercial activities, and of course, the conglomerate activities of everyday life.

A major point of concern is the fact that in recent years, there has been a tendency toward inordinate emphasis upon this concept of "masking noise", which in turn has led to unfortunate results. For instance, vehicular traffic noise is seldom steady and the operation of heating and air-conditioning equipment may be cyclic. Hence, the masking noise is not constant and may itself become a source of annoyance. To design buildings with the intention of utilizing devices which electronically produce masking noise is sheer folly for this is tantamount to an intentional increase of the din which already surrounds us. However, with proper caution and discretion such devices can be profitably employed, particularly in office buildings, to ameliorate specialized noise conditions. On the other hand, heating, air-conditioning and ventilating systems might be initially designed to produce a reasonable noise provided that these systems themselves never become sources of noise complaints. This is usually difficult to achieve in practice because of the oversights and problems involved in actual installation of the equipment in the building. In any event, the noise levels produced by such systems should not exceed the lowest anticipated night-time background levels by more than 5 dB at any frequency.

For a more detailed discussion of the use of masking noise, see Chapter 6.

C. AN EMPIRICAL APPROACH

One approach to the development of a criterion can be illustrated by considering a hypothetical situation. Assume two families, A and B, occupying adjacent units in a suburban apartment house. Family A is a typical family with two children; the father works outside the home between the hours of 7:30 a.m. and 6:00 p.m.; the mother remains at home; the children retire between 8:00 and 9:00 p.m. and the parents between 10:00 and 11:00 p.m. On the other hand, family B is not quite as typical but certainly not unusual. They have no children and both husband and wife work on the night shift. Let us assume that Mr. and Mrs. B usually arrive home from work between the hours of 2:00 and 3:00 a.m. and customarily prepare and eat a meal and then relax before retiring between 6:00 and 7:00 a.m. The necessity for acoustical privacy in this situation should be immediately apparent. Careful grouping within the apartment complex of families with similar activities and schedules might be a plausible solution; but what can be done for people who work alternating schedules? The correct solution is to plan and construct buildings with adequate sound insulation.

Considering the above hypothetical case and recalling the problems outlined earlier, an attempt will be made to arrive at a reasonable criterion of acoustical insulation to be provided by the partition separating the sleeping areas of these two apartment units. Curve (1) of Figure 9.1 represents the anticipated peak levels and frequency distribution of noise produced by household appliances and everyday activities. This curve represents the average data collected from an extensive literature survey as well as unpublished results from several investigators including NBS. The levels are adjusted to 1/2-octave frequency bands. Although subjectively acceptable noise levels are difficult to substantiate, there is some evidence that an NC-20 to NC-25* range is acceptable in sleeping areas of an apartment in a suburban location. Curve (2) of Figure 9.1 represents a NC-20 criterion, which also is adjusted to 1/2-octave frequency band levels.

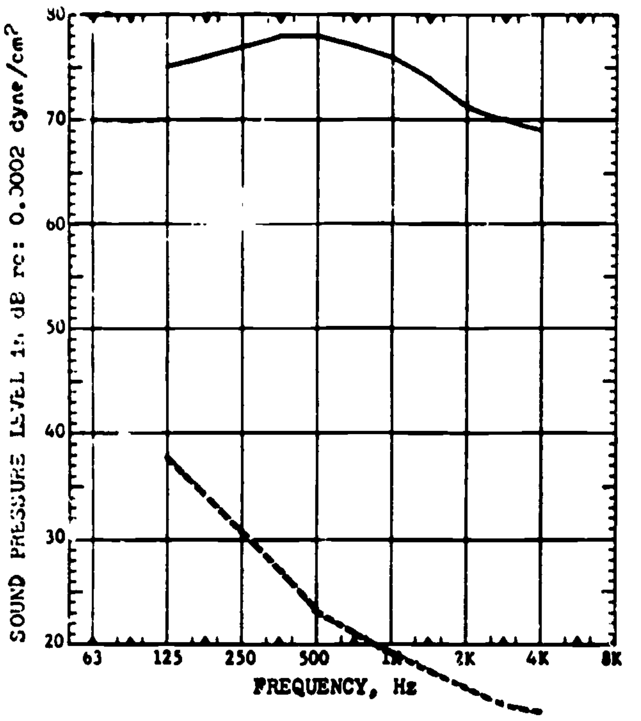
*Details of the NC (Noise Criterion) curves may be found in "Noise Reduction", edited by L.L. Beranek, McGraw-Hill Book Company, Inc. 1960.

By subtracting the values of curve (2) from those of curve (1), one obtains the sound pressure level differences required to reduce the anticipated noise levels to the assumed acceptable levels. Then, interpreting these sound pressure level differences as sound transmission loss values, one could arrive at a sound insulation criterion for this situation. For medium-sized rooms in residences, this interpretation is reasonable; however, strictly speaking, the sound absorption of the rooms and the partition area must be considered. To establish a criterion in this case, it is also assumed that the measured sound transmission loss values of partitions are represented directly by the values of given sound transmission class (STC) contours. This is seldom the case, but for establishing a criterion with a single-figure rating, this is a reasonable approximation. To satisfy the conditions above, a partition with an STC of 58 or 59 would be required. However, one should not stop at this point, but consider the possibility of using other factors.

Based upon physical measurements and a literature search, curve (3) of Figure 9.2 represents the anticipated indoor background noise levels existing during the "quiet-hours" of night. Proceeding as above and subtracting the values of curve (3) from those of curve (1), one finds that the partition would have to provide additional sound insulation, perhaps an STC of 62 or 63 because the ambient background noise levels are lower than the assumed acceptable levels. Nothing has been gained in this respect, but the analysis should be continued. By subtracting the values of curve (4), which represents the anticipated indoor daytime background noise, from those of curve (1), one finds that a partition with a rating of STC 57 or 58 would suffice for normal daytime activities; however, there could be problems of acoustical intrusion during the night. Curve (5) of Figure 9.3 shows the sound pressure levels of a well-designed continuously operating air-conditioning system which provides useful masking noise. The levels are somewhat greater than both the natural daytime and nighttime background levels, but not excessively greater than the latter, and yet sufficient to allow a partition with a lower sound insulation performance to be utilized successfully in this situation. Finally, curve (6) of Figure 9.4 shows the noise levels after they have been reduced by a partition with a rating of STC = 55. In addition, these noise levels, along with the masking levels and the background levels fall in the NC 20-25 range, which is generally considered acceptable for sleeping areas in a suburban location. The masking noise is such that it is unnoticeable during the day and barely audible though not disturbing at night.

The foregoing illustrations, of course, deal intentionally with a rather severe set of conditions and inherently include a number of broad assumptions. Nevertheless this procedure, when employed by acoustical consultants and engineers, works reasonably well in individual situations.

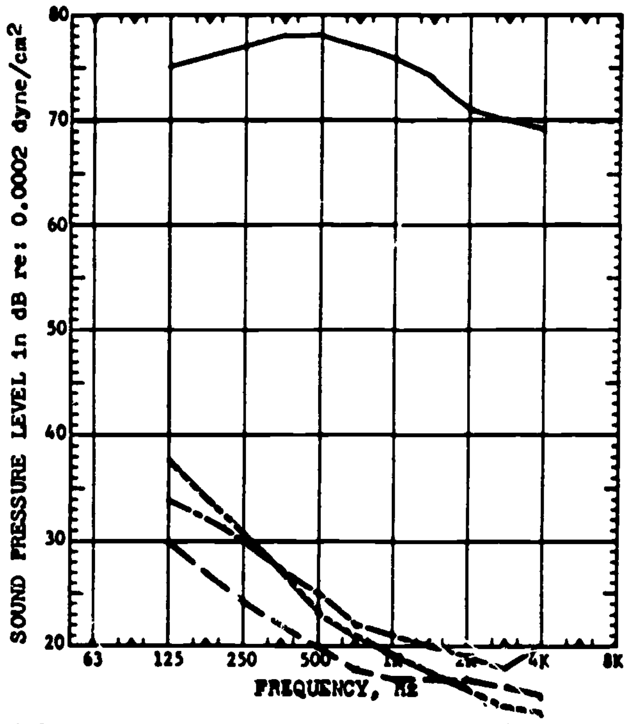
Fig. 9.1



(1)——Anticipated peak noise levels.

(2)----Assumed acceptable levels. (NC-20 adjusted to 1/2-octave band levels)

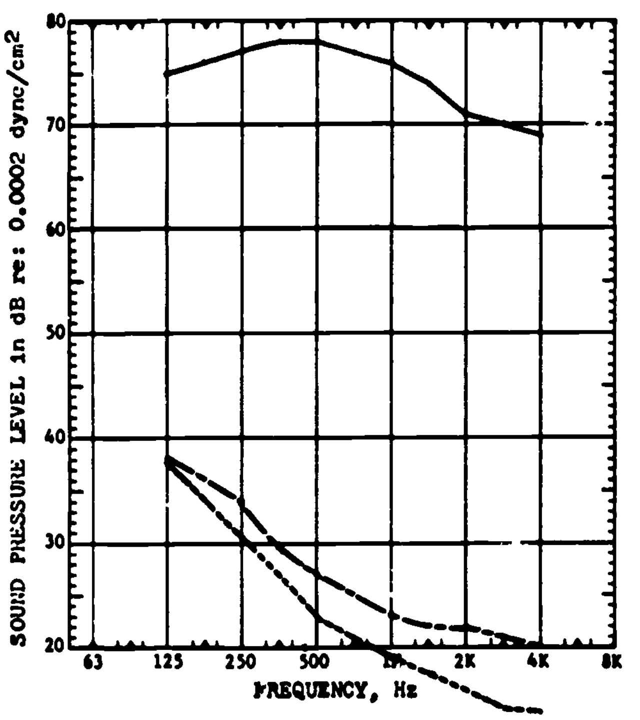
Fig. 9.2



(3)— —Anticipated indoor nighttime background levels.

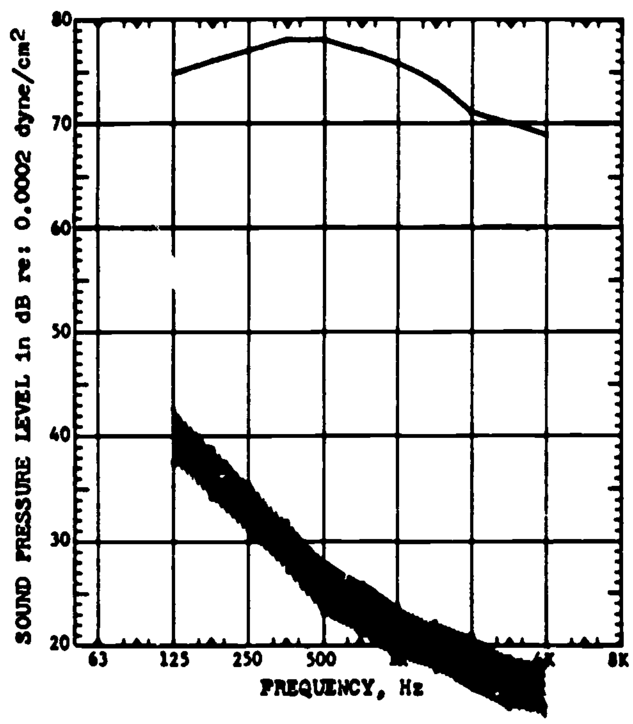
(4)-·-·Anticipated indoor daytime background levels.

Fig. 9.3



(5)-·-·Acceptable masking levels generated by A-C unit.

Fig. 9.4



(6)— —Noise levels after STC=55 reduction.

Assumed acceptable levels NC-20-25 range adjusted to 1/2-octave band levels.

D. IMPACT NOISE PROBLEM

The preceding discussion dealt specifically with an approach to the development of insulation criteria for walls, which applies equally well to floor-ceiling structures. However, the serious problem of developing impact sound insulation criteria for floor-ceiling structures remains. It would be indeed convenient if a similar analysis could be drawn to deal with that problem. Unfortunately, this is not the case because of the inherent complexity of (1) the generation and transmission of impact noises, (2) the measurement and specification of the insulating properties of structures against such sounds, and (3) the determination of subjective reaction to these noises. The fundamental thesis is that the occupant does not care how the intruding noises are generated and transmitted; he knows only that his apartment is noisy and consequently, he is unhappy until the intruding sounds have been reduced to an acceptable level.

For illustrative purposes, reconsider the hypothetical situation of families A and B. Let us first assume that family A lives above family B. The alarm clock rings in Apt. A at 6:00 a.m.; Mr. and Mrs. B have just retired; Mr A jumps out of bed and performs his ritual "setting-up" exercises, which might run the gamut from "push-ups" to a bit of weight lifting, while Mr. B counts each repetition. In the meantime, the two children have hopped from their beds and are playing a game of tag and bouncing a ball. Mrs. A, who has wandered sleepily to the kitchen, creates a racket by slamming cabinet doors, drawers, dishes, etc. in the course of setting the table and preparing breakfast. Meanwhile, Mr. A is taking his shower and Mr. B unhappily recalls his childhood days when rain on the tin roof was nostalgically pleasant. Of course, when the A's sit down to breakfast, there is that seemingly constant sliding of chairs; the baby, in a cranky mood, tosses his bowl of cereal onto the floor. In due time, things settle down to some extent, and Mr. and Mrs. B are now annoyed only by the garbage disposal unit, the automatic dishwasher, and the vacuum cleaner (which all transmit vibrations to the floor-ceiling structure) as well as the normal romping of active, healthy children.

We could further illustrate these problems by having family B, along with their schedule and activities, living above family A; however, we shall allow the readers to use their imaginations on that set of conditions. Suffice it to say that the sources of impact sounds are many and varied.

Recently, much emphasis has been placed upon the specific problem of noise generated by footsteps, especially those of women wearing high-heeled shoes. This is a serious source of impact sounds, particularly in multi-story office buildings where the combination of hard-heeled shoes and hard-surfaced floors is quite common. The problem of floor excitation due to walking also exists in multifamily dwellings; however, a survey of the number of hours per day in which the housewife performs her chores while wearing high-heeled shoes, and the time elapsed after a career woman returns home before she sheds the high-heeled shoes worn all day, might yield interesting results. Such a survey compared with one involving other types of foot traffic or impact sources would show that the high-heeled impact noise is not the major problem.

Obviously, before specifying a criterion of impact sound insulation, a standard method for assessing the insulating properties of floor-ceiling structures is necessary. Unfortunately, a standard method of test has not yet been adopted for the United States; although a committee* is presently working toward that end. A method, patterned after that recommended by the International Organization for Standardization**, is being considered. In this recommendation, a "standard tapping machine" is specified as the means of producing repeatable excitation of floor-ceiling structures. Such a tapping machine is shown in Figure 9.5. The impact sound pressure levels produced by the machine in operation on the floor are measured in the room beneath the floor-ceiling structure.

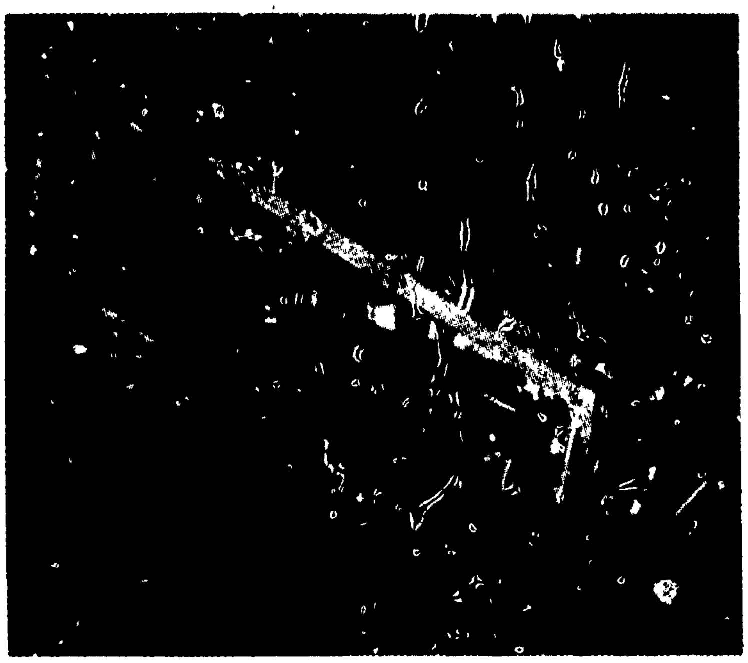


Fig. 9.5. Tapping machine used for generating sound field for impact sound transmission measurements.

Currently, there is some criticism of the efficacy of the tapping machine as an appropriate source of impact excitation, since it does not simulate that produced by walking nor in fact, any other domestic activity or accident. In this regard, we are faced with some very penetrating questions. Shall we standardize a method of test which utilizes actual walkers? Shall we develop a device which simulates the characteristics of the statistically "average" walker? Shall we subject each floor-ceiling structure to a test under all the known actual sources of impact, other than footsteps? Can we develop a device which simulates the characteristics of all these sources? These among other questions relating to the "standard source of impacts" and the subsequent associated rating systems must be answered before this issue can be adequately resolved. However, the problem exists now and until better schemes are developed and proven, we must of necessity use those methods presently available, which indeed have been reasonably successful in Europe and elsewhere for a number of years. Nevertheless, continued

*Sub-Committee VI of Committee C-20 of the American Society for Testing and Materials.

**ISO Recommendation R140-1960(E), "Field and Laboratory Measurements of Airborne and Impact Sound Transmission", January 1960.

investigations of possible solutions to the problem of impact noise in buildings should be encouraged and pursued.

E. SUMMARY OF EXISTING CODES AND RECOMMENDATIONS

Another approach to the development of suitable criteria for acoustical privacy is to examine what has been done in other countries coping with similar problems. An extensive survey of codes and recommendations in existence, as well as those presently under consideration, has been conducted, and a summary is presented here.

Most countries have requirements or recommendations for both airborne and impact sound insulation, although a few deal only with airborne sound insulation. Generally, the methods of test are quite similar throughout the various countries, although the presentation of data and the insulation criteria understandably differ from country to country.

Airborne sound insulation measurements are made using bands of random noise or frequency-modulated sinusoidal tones, and the results are presented as sound transmission loss or normalized level differences according to the following equations:

Sound Transmission Loss $$STL = L_1 - L_2 + 10 \log_{10} S/A \quad (9.1)$$

Ref. Reverberation Time Normalization: $$D_{To} = L_1 - L_2 + 10 \log_{10} T/To \quad (9.2)$$

Ref. Absorption Normalization: $$D_{Ao} = L_1 - L_2 + 10 \log_{10} Ao/A \quad (9.3)$$

where, in all three equations, L_1 and L_2 are the time-space average sound pressure levels, in decibels, measured in the source and receiving rooms respectively. The difference, L_1-L_2, is also known as the Noise Reduction (NR). In equation 9.1, S is the total radiating surface area of the partition, and A is the total sound absorption in the receiving room. In equation 9.2, T is the measured reverberation time of the receiving room, and T_o = 0.5 second is the normalizing reference reverberation time. Similarly, in equation 9.3, A is the total sound absorption in the receiving room, and $A_o = 10m^2$ is the normalizing reference room absorption.

Impact sound insulation measurements are generally performed utilizing a tapping machine which by operating on the floor serves as a repeatable standard source of impact excitation. The resulting impact sound pressure levels are measured in the receiving room located directly below. The presentation of data and the insulation criteria differ among the various countries. The results of the measurements are presented according to one of the following equations of normalized impact sound pressure levels, (ISPL):

$$ISPL_{A_o} = SPL + 10 \log_{10} A/A_o \quad (9.4)$$

$$ISPL_{T_o} = SPL - 10 \log_{10} T/T_o \quad (9.5)$$

where SPL is the time-space average sound pressure level, in decibels re: 0.0002 $dyne/cm^2$, measured in the receiving room. A is the total sound absorption of that room and $A_o = 10m^2$ is the normalizing reference room absorption. Similarly, T is the measured reverberation time of the receiving room and T_o = 0.5 second is the normalizing reference reverberation time. In addition to the matter of normalization, there is inconsistency in the frequency bandwidth of the measurement of sound pressure levels. Measurements are usually made in 1/3-octave or 1/1-octave frequency bands. Confusion arises when the resultant measured levels are compared, for compliance, with required or recommended criterion contours. The problem simply is that of comparing like quantities. In the early days, the electrical filters used for analyzing the sound were octave frequency band filters which separated the audible frequency sound into components, each encompassing one full octave. The resultant values were plotted at the center frequency of each band and labeled "octave-band sound pressure levels". More recently, it was recognized that a greater refinement or "definition" of the sound spectra was necessary, and consequently 1/3-octave frequency band filters were developed. Obviously, the total sound energy in a given octave band should be the same, whether measured in ten 1/10-octave bands, three 1/3-octave bands, or one 1/1-octave band. In other words, the sum of the energy contributions of each of the three 1/3-octave bands comprising a full octave band should result in the value that would be obtained from a single measurement of that full octave band. It follows that the observed single value in each of the 1/3-octave bands will be less than the single value observed for the full octave band.

A problem arose when the existing criterion contours based upon octave band sound pressure level measurements were applied to the 1/3-octave band measurements. To resolve the problem, it was agreed* that measurements should be made in frequency bands not greater than 1/1-octave wide and not less than 1/3-octave wide, and the values should be corrected to correspond to those of full octave bands by the addition of $10 \log_{10} n$ (dB) to the average level when (1/n) octave band filters are used. In the case of 1/3-octave bands, n = 3; therefore $10 \log_{10} (3)$ = 4.77 dB or 5 dB when rounded to the nearest whole number. Some countries plot impact sound pressure level data in octave bands, some plot 1/3-octave band data after adding the 5 dB octave band "correction" to the data and others plot 1/3-octave band data without applying the "correction". As a consequence, the literature contains information which may be confusing and perhaps contradictory. It is scientifically more pleasant and logical to present the data as measured. When comparison with criteria or recommended contours is necessary, these theoretical and sometimes arbitrary reference curves can be adjusted readily to correspond with the measured data. In other words for use with 1/3-octave band data, it is easier to adjust a reference contour by subtracting the value of $10 \log_{10} n$ from it, rather than adding that value to the <u>measured data</u>. Likewise, if the reference contours are based upon 1/3-octave band data, the value of $10 \log_{10} n$ can be added to the contour for comparison with 1/1-octave data. This practice avoids the contradictory situation where exactly the same noise is characterized by octave band data and 1/3-octave band data (adjusting by adding

*By the International Organization for Standardization.

5 dB), but when computed yield total energies which are not the same.

From a scientific point of view, it is technically correct and permissable to convert or express data obtained from 1/3-octave band measurements in terms of 1/1-octave band data, but the converse requires making an assumption about the distribution of sound with frequency which may not agree with the distribution in the particular case considered.

In view of the desirability of 1/3-octave band analysis of noise and the current trend toward standardization of such analyses, the data will be presented as measured in this publication and the reference contours for obtaining single-figure ratings will be adjusted accordingly. Further, it is recommended that future measurements include 1/3-octave band analyses and that subsequent criteria contours be based directly on such data.

The following list gives capsular descriptions of required or recommended airborne and impact sound insulation criteria of various foreign countries. Graphic illustrations of these criteria are given at the end of this chapter.

1. AUSTRIA -

(a) Airborne Sound Insulation: Single-figure ratings are obtained from a reference contour (Figure 9.6) allowing an average unfavorable deviation* of 2 dB. The STL measurements use either swept frequency-modulated sinusoids with octave-band analysis, or white noise with 1/3-octave band analysis.

(b) Impact Sound Insulation: Single figure ratings are obtained from a reference contour (Figure 9.7) allowing an average unfavorable deviation of 2 dB. 1/1-octave band analysis of impact sound pressure levels, normalized to $A_o = 10m^2$, is made in the receiving room with the ISO type tapping machine operating on the floor above.

Recommendations for both airborne and impact sound insulation are based upon four sound insulation groups, by building types, with criteria for various individual partition functions within each group. In addition there are three reference curves for assessing impact noise reduction (ΔL) achieved by modifying the basic floor-ceiling structures with additional floor or ceiling assemblies. Although this standard is not a legal requirement, it is observed by most planners, builders, customers and housing authorities in Austria.

Reference: Ö NORM B 8115 "Hochbau Schallschutz und Hörsamkeit", April 27, 1959.

2. BELGIUM -

As far as we know, there are no national requirements, however,

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*Generally throughout these capsular descriptions, the "average unfavorable deviation" ($\bar{d}$) is computed as follows:

$$\bar{d} = \frac{\sum_n d_n}{n} = \frac{d_1 + d_2 + \cdots + d_n}{n} \qquad (9.6)$$

where d_n are the deviations from the reference contour. The deviations in the unfavorable sense are entered at their full value and those in the favorable sense are entered with a value of zero.

British, French and German standards are applied in certain areas, and in some cases more stringently than in the countries of origin.

3. BULGARIA -

As far as we know, the Bulgarian requirements are quite similar to those of Czechoslovakia.

4. CANADA

(a) Airborne Sound Insulation: "Construction shall provide a sound transmission class rating* of not less than 45 between dwelling units in the same building and between a dwelling unit and any space common to two or more dwelling units." Quoted from Section 5 "Sound Control" (Residential Standards, Canada, 1965, NRC. No. 8251) Supplement No. 5 to the National Building Code of Canada, 1960, NRC. No. 5800.

(b) Impact Sound Insulation: There are no requirements in current use, but it is understood that a new code is in preparation.

5. CZECHOSLOVAKIA -

(a) Airborne Sound Insulation: Requirements are based upon reference contours (Figure 9.8) with different contours applicable to laboratory and field measurements, allowing an average unfavorable deviation of 2 dB, providing that no single unfavorable deviation may exceed 8 dB, based upon octave bands. STL measurements are conducted in the laboratory and sound level difference measurements which are normalized to ($A_o = 10m^2$) are performed in the field.

Reference: O. Brandt, "Sound Insulation Requirements between Dwellings". An invited paper presented at the Fourth International Congress on Acoustics, Copenhagen, Denmark, 1962.

(b) Impact Sound Insulation: As far as we know, the measurements and the reference contour follow the German standard (DIN 4109); however, the requirements are about 10 dB more stringent.

6. DENMARK -

(a) Airborne Sound Insulation: The requirements are based upon reference contours (Figure 9.6) with a distinction between isolation provided by a partition alone and isolation between two rooms. The sum total of unfavorable deviations may not exceed 16 dB. Measurements are reported as sound pressure level differences normalized to $T_o = 0.5$ second.

(b) Impact Sound Insulation: Similarly, these requirements are based upon a reference contour (Figure 9.9) with the same restriction on unfavorable deviations. 1/3-octave band measurements of impact sound pressure levels, normalized to $T_o = 0.5$ second, are made in the receiving room with the ISO type tapping machine operating on the floor above.

Reference: Bygningsreglement for Købstaederne og landit (Building Regulations) Chapter 9, "Sound Isolation", Copenhagen, Denmark (1961)

7. ENGLAND -

(a) Airborne Sound Insulation: Three grading contours (Figure 9.10) - House Party Wall Grade, Grade I and Grade II are

*As prescribed in ASTM Specification E90-61T "Tentative Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Floors and Walls", 1961.

specified as recommended requirements; a small allowance is permitted which is equal to an average unfavorable deviation of 1 dB. If the mean deficiency exceeds 1 dB of Grade II, the structure is classified as x dB worse than Grade II. This quantity is not defined for structures rating better than Grade II. 1/3-octave band measurements are made in accordance with British Standard 2750: 1956*, and results are reported as STL or sound pressure level differences normalized to $T_o = 0.5$ second for laboratory and field respectively. Frequency-modulated sinusoids or random noise may be used.

(b) Impact Sound Insulation: Likewise, two grading contours, (Figure 9.11) Grade I and Grade II, are specified as recommended requirements with similar allowances as above. Impact sound pressure levels are measured, either in octave or 1/3-octave bands and normalized to $A_o = 10m^2$ in the laboratory or $T_o = 0.5$ second in the field. Measurements are made in the receiving room with an ISO type tapping machine operating on the floor above. If the analysis is made in bands less than a full octave, results are to be "corrected" by adding $10 \log_{10} n$, where 1/n is the bandwidth used.

Although the code represents a standard of good practice, and thus takes the form of recommendations, some local areas require compliance with certain sections of the code; there are indications of the future emergence of regulations throughout the United Kingdom.

Reference: British Standard Code of Practice, CP3: Chapter III, "Sound Insulation and Noise Reduction" (1960).

8. FINLAND -

(a) Airborne Sound Insulation: Contours (Figure 9.12) associated with three sound insulation classes are specified as recommended requirements. The classes are based upon maximum permissible noise levels in a given space, as well as the necessary sound isolation obtainable from a partition or between two rooms. The sum total of the unfavorable deviations may not exceed 16 dB. STL measurements are conducted in the laboratory, and sound pressure level differences normalized to $T_o = 0.5$ second are performed in the field; all data are reported in 1/3-octave bands.

(b) Impact Sound Insulation: Likewise, contours (Figure 9.13) associated with the three sound insulation classes are specified as recommended requirements. These carry the same restriction on unfavorable deviations, as above. 1/3-octave band measurements of impact sound pressure levels are made in the receiving room with the ISO tapping machine in operation on the floor above. Laboratory and field results are normalized to $A_o = 10m^2$ and $T_o = 0.5$ second, respectively.

There is no legislation yet in Finland regarding mandatory requirements of sound insulation; therefore, the above are considerd to be recommendations.

Reference: EHDOTUS ÄÄNENERISTYSMÄÄRÄYSIKSI, "Suggestion for Requirements of Sound Insulation", Valtion Teknillinen Tutkimuslaitos, Tiedotus. Sarja III - Rakennus 42, Helsinki (1960).

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*"Recommendations for Field and Laboratory Measurement of Airborne and Impact Sound Transmission in Buildings", British Standard 2750: 1956, British Standards Institution.

9. FRANCE -

The French have had standards since 1958; however, it is understood that new regulations are being prepared. Single-figure ratings are derived from comparison of measured values with specified average sound pressure level differences normalized to $T_o = 0.5$ second for airborne sound insulation. Similarly, ratings for impact sound insulation are obtained by comparison of measured 1/3-octave band impact sound pressure levels, adjusted to "correspond" to octave band levels, with specified sound pressure levels normalized to $T_o = 0.5$ second. An ISO type tapping machine is used as a source of impact excitation.

10. GERMANY -

(a) Airborne Sound Insulation: Single-figure ratings are obtained from reference contours* (Figure 9.6); separate curves are used for the comparison of field and laboratory data. An average unfavorable deviation of 2 dB is permitted when computed as follows:

$$\bar{d} = \frac{\frac{d_1}{2} + d_2 + \cdots d_{n-1} + \frac{d_n}{2}}{(n-1)} \leq 2 \text{ dB} \qquad (9.7)$$

where d_n are the deviations from the reference contour; deviations in the favorable sense are assumed to lie on the contour and are entered as zero in the computation. n is equal to the number of measured values, usually at sixteen 1/3-octave bands. Measurements are made in accordance with DIN 52210**, and results are reported as R(STL) and R' for laboratory and field measurement respectively.

(b) Impact Sound Insulation: Single-figure ratings are obtained from reference contours (Figure 9.7) in a similar manner as for airborne sound insulation; the average unfavorable deviation is computed analogously. The 1/3-octave band analysis of impact sound pressure levels is made in the receiving room with the ISO tapping machine operating on the floor above. The sound pressure levels are normalized to $A_o = 10m^2$ and "corrected to correspond" with octave band data.

Germany was among the first countries to include provisions for acoustical privacy and noise control in building codes; and the present standard (DIN 4109) is perhaps one of the most comprehensive documents of its kind.

Reference: Schallschutz in Hochbau (Sound Insulation in Buildings), DIN 4109, (5 parts dated September 1962 - April 1963).

11. NETHERLANDS -

(a) Airborne Sound Insulation: There are two quality classes of sound insulation, "fair" and "good", based mainly upon the comparison of measured insulation values with reference values (Figure 9.14).

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*The theory of requirement contours is given by L. Cremer, in "Der Sinn der Sollkurven", Schallschutz von Bauteilen, Berlin, 1960. (Published by Wilhelm Ernst & Son.)

**Messungen zur Bestimmung des Luft - und Trittschallschutzes, (Measurements for the Determination of Airborne and Impact Sound Insulation), DIN 52210, March 1960.

From that comparison, three specific rules are used for obtaining the Insulation Index of a structure. Measurements are made in four octave bands with center frequencies ranging from 250 to 2000 Hz; the laboratory results are reported as STL and field results as sound pressure level differences normalized to $A_o = 10m^2$.

(b) Impact Sound Insulation: Similarly, there are two quality classes of sound insulation and the ratings are based upon comparison with reference values (Figure 9.15) with three specific rules analogous to the airborne sound insulation rating system. Impact sound pressure level measurements are made in the receiving room with an ISO type tapping machine operating on the floor above. The measurements are made in the same four octave bands and are normalized to $A_o = 10m^2$.
Reference: Natuurkundige Grondslagen voor Bouwvoorschriften, Deel III, Geluidwering in Woningen (Noise Control and Sound Insulation in Dwellings), NEN 1070, December 1962, Nederlands Normalisatie-Instituut.

12. NORWAY

(a) Airborne Sound Insulation: Single-figure ratings are obtained by comparison of measured data with reference contours (Figure 9.16) allowing an average unfavorable deviation of 1 dB. Measurements are made in accordance with ISO/R 140-1960*, and results are reported as sound pressure level differences normalized to $T_o = 0.5$ second. The codes are based upon an effective airborne sound insulation number which takes into account the insulation qualities of the partition, its area, the volume and the reverberation time of the receiving room and the estimated degree of flanking transmission.

(b) Impact Sound Insulation: Similarly, single-figure ratings are obtained by comparison with reference contours (Figure 9.17), allowing the same average unfavorable deviation. A 1/3-octave band analysis of impact sound pressure levels, normalized to $T_o = 0.5$ second, is made in the receiving room with the ISO tapping machine operating on the floor above. The codes also are based upon an effective impact sound number system, which yields positive numbers such that the larger values indicate increased impact sound insulation.
Reference: "Proposed Norwegian Building Code for Sound Insulation", Norges Byggforskinngsinstitut Rapport 38, Oslo 1963.

13. SCOTLAND

(a) Airborne Sound Insulation: The Scottish building standards are based upon the "House Party Wall Grade" and "Grade I" contours of the British Standard Code of Practice (Figure 9.10), CP3: Chapter III, "Sound Insulation and Noise Reduction", 1960; the measurements are conducted in accordance with B.S. 2750: 1956, (See 7. ENGLAND).

(b) Impact Sound Insulation: Likewise, the "Grade I" reference contour (Figure 9.11) for impact sound pressure levels is used. The 1/3-octave band analysis is normalized to $T_o = 0.5$ second, and "corrected to correspond" with octave band data.

This differs significantly from the British case because the

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*International Organization for Standardization, ISO Recommendation R140, "Field and Laboratory Measurements of Airborne and Impact Sound Transmission", ISO/R 140-1960 (E).

Scottish building standards constitute a legal requirement, effective June 15, 1964, as opposed to a recommendation. Although not applicable to existing buildings prior to that date, local authorities have the power to require conformation in all new buildings.
Reference: Building Standards (Scotland) Regulations, Part VIII, 1963, as presented by G. Berry in an article entitled "Sound Insulation in Houses and Flats - Effect of New Scottish Building Standards", INSULATION, January 1964.

14. SWEDEN -

(a) Airborne Sound Insulation: There are three grading contours (Figure 9.18) to which measured 1/3-octave band data are compared. The data are reported as sound pressure level differences normalized to $A_o = 10m^2$. The total sum of the unfavorable deviations may not exceed 16 dB. The requirements, which are stated in terms of functional application of the wall structures, thus determine which one of the three contours must be satisfied in a specific case.

(b) Impact Sound Insulation: Two grading contours (Figure 9.19) are specified for the required comparisons; these are based upon a 1/3-octave band analysis of impact sound pressure levels measured in the receiving room with an ISO type tapping machine operating on the floor above. The results are normalized to $A_o = 10m^2$ and are reported as measured, i.e. without the "correction" to octave bands. In this case, the total sum of the unfavorable deviations may not exceed 32 dB.
Reference: Swedish Building Code: BABS 1960. Anvisnigar Till Byggnadsstadgan, Kungl. Byggnadsstyrelsens Publikationer, Stockholm, Sweden (1960).

15. SWITZERLAND -

(a) Airborne Sound Insulation: An unofficial draft recommendation exists, in which "minimum" and "maximum" requirements of average sound transmission loss are specified, which are based upon both laboratory and field measurements according to type of building and wall function. In the case of multifamily dwellings, the following is applicable:

Building Component	Laboratory Min.	Laboratory Max.	Field Min.	Field Max.
Dividing walls and ceilings in flats, staircase wall	52 dB	57 dB	50 dB	55 dB
Dividing walls between flats and restaurant, cinema, garage, workshop and other business premises	57 dB	67 dB	55 dB	65 dB

(b) Impact Sound Insulation: There are no explicit requirements.
Reference: W. Furrer, "Room and Building Acoustics and Noise Abatement", p. 203, English Translation (Butterworth & Co. Ltd., London, 1964).

16. U.S.S.R. -

(a) Airborne Sound Insulation: There are three reference contours (Figure 9.20) with which sound transmission loss measurements are to be compared. In the comparison, unfavorable deviations are computed as follows:

$$\bar{d} = \frac{\frac{d_1}{2} + d_2 + \cdots + d_5 + \frac{d_6}{2}}{6} \leq 2\ \mathrm{dB} \qquad (9.8)$$

where d_n are the deviation from a reference contour based upon the six 1/1-octave bands with center frequencies in the range 100-3200 Hz. In addition, no single unfavorable deviation may exceed 8 dB.

(b) Impact Sound Insulation: Similarly, there are two reference contours (Figure 9.21) which specify maximum impact sound pressure levels permissible in the receiving room with a tapping machine operating on the floor above. Unfavorable deviations from the specification contours are computed analogously, as above, according to equation 9.8.

Reference: Advisory Code for Sound Insulation in Housing and Community Buildings, (CH39-58) State Publishing Office for Building Architecture and Building Materials Literature, Moscow, 1959.

In general, most of the requirements imply minimal sound insulation; however, the foregoing cursory review of codes, standards and recommendations obviously does not include all the information contained in such documents. For example, many codes specify criteria for partitions within dwelling units, maximum sound pressure levels permissible in a given space, criteria for doors and windows, means to minimize flanking transmission and structure-borne noise, and other pertinent information. In fact, some documents approach textbook status on the subject of acoustical privacy and noise control rather than codes.

In summary, the review shows several prevalent techniques for specifying adequate acoustical privacy, which essentially are as follows:

(1) Single-figure rating requirements or recommendations formulated on the basis of a single reference contour or upon a family of reference contours, with accompanying rules for computing such ratings. The code requirements are not necessarily consonant with, or the same as, the values of the reference contour; or in other words, the required insulation, for a given installation, may be x dB more stringent than the values of the reference contour. (This point has been often overlooked in similar studies, of existing codes and criteria, appearing in the literature.)

This system affords the greatest flexibility for the code writer because he can revise the single-figure requirements, if need be, without disrupting the basic rating scheme.

(2) Grading curves for minimum airborne sound insulation and maximum impact sound pressure levels. This system affords the simplicity of a "go or no go" decision on the part of the appropriate authorities; but if revision of the requirements becomes necessary, the change is usually difficult to accomplish.

(3) Requirements based upon the single-figure arithmetic average of sound transmission loss values. Although this system is the simplest, there have been technical questions raised regarding its suitability.

Figure 9.22 shows the range of minimum airborne sound insulation requirements and recommendations of other countries and the range of suggested values* for particular cases requiring better sound insulation performance. Technically speaking, sound transmission loss, STL, and normalized level difference, D_n, values should not be plotted on the same graph; however, for purposes of convenience, they are shown together and labeled "Airborne Sound Insulation". It can be shown that $STL = D_{A_o}$ when the partition area S is approximately 107.6 ft^2; also,

$STL = D_{T_o}$ when $S/V \rightarrow 0.1$ ft^{-1}, where S is the partition area and V is the volume of the receiving room in the English system of units**.

Similarly, the shaded areas in Figure 9.23 show, analogously, the range of minimum impact sound insulation requirements or recommendations of other countries and the range of suggested values for particular cases requiring better sound insulation performance. These values are plotted to be consistent with 1/3-octave band analyses; i.e., reference contours which were established for comparison with octave band data have been lowered 5 dB for comparison with 1/3-octave band data. In addition, reference values for use with data normalized to both $A_o = 10m^2$ and $T_o = 0.5$ second are shown together. It can be shown that the two normalization schemes yield equivalent results for measurements in rooms which have a volume of approximately 1100 ft^3 or 31m^3.

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*These generally pertain to areas where better than minimal sound insulation is usually necessary, such as separation of dwelling units in quiet or suburban locations; separation of dwelling units from small business shops within a building, or from noisy areas such as mechanical equipment rooms, restaurants and for application to hospitals, hotels and so forth.

**In metric units:

$$STL = D_{A_o} \text{ when } S = 10m^2$$

$$STL = D_{T_o} \text{ when } S/V \rightarrow 0.33m^{-1}$$

Figure 9.6

Reference Contours

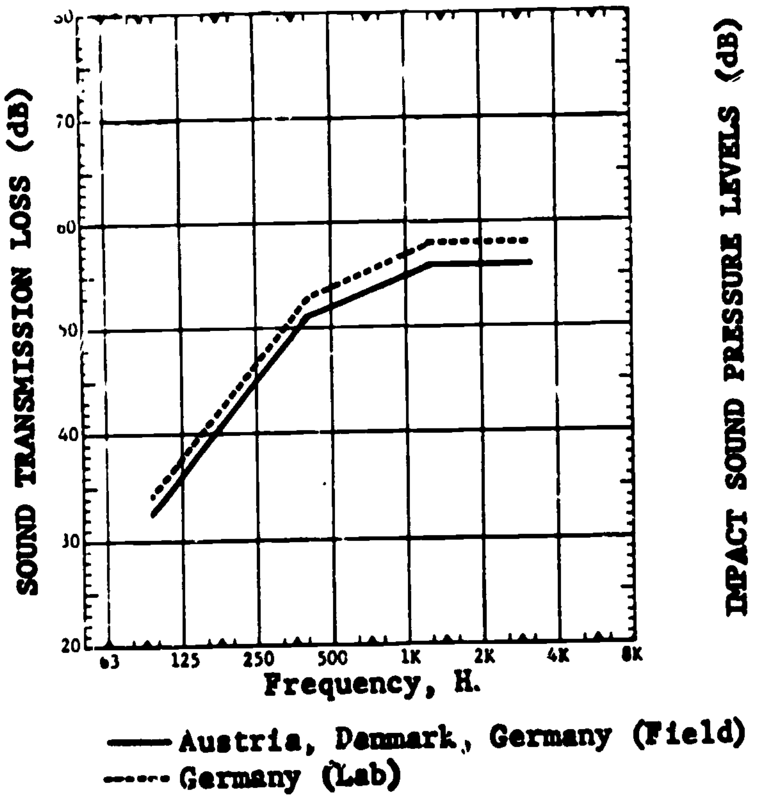


Figure 9.7

Reference Contour

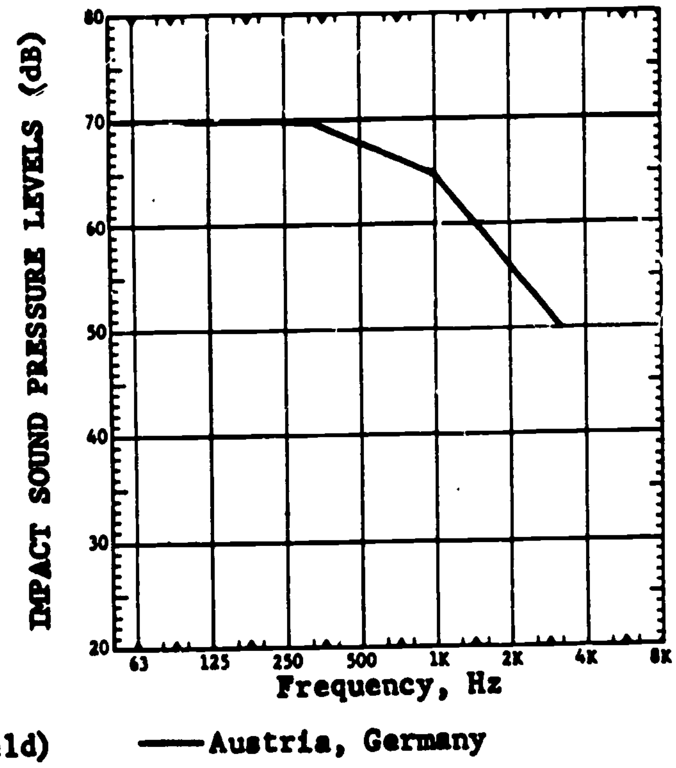


Figure 9.8

Reference Contours

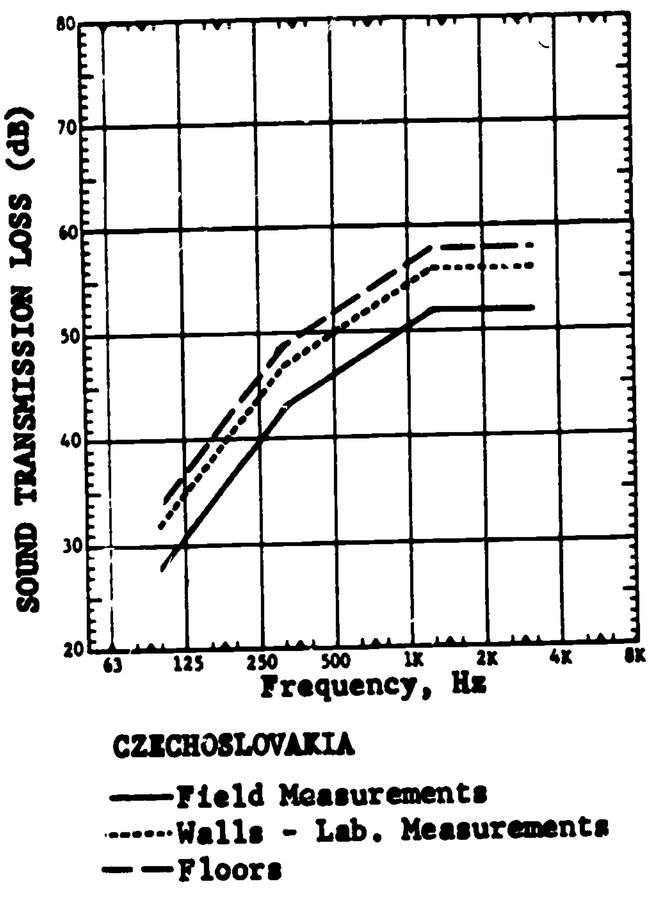


Figure 9.9

Reference Contour

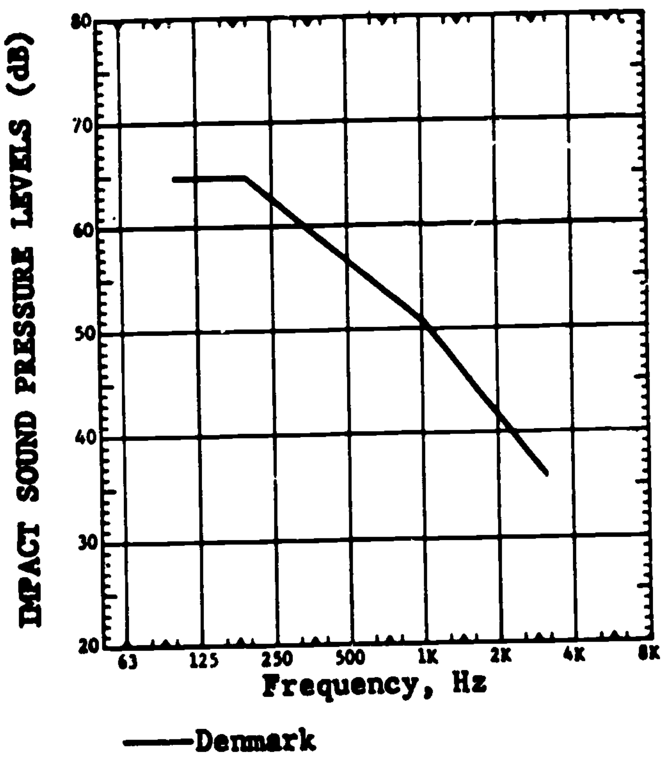
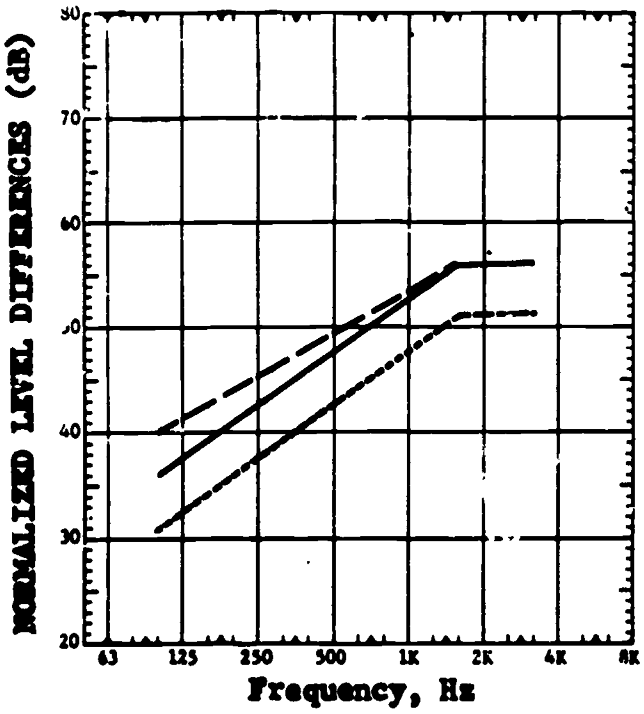


Figure 9.10

Grading Contours

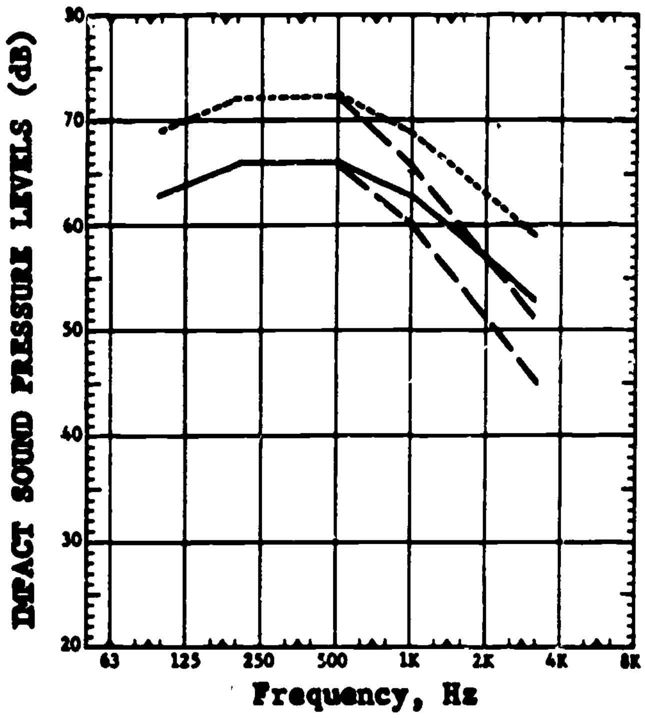


ENGLAND

——Grade I (Flats)
------Grade II (Flats)
— —House Standard (House Party Wall Grade)

Figure 9.11

Grading Contours

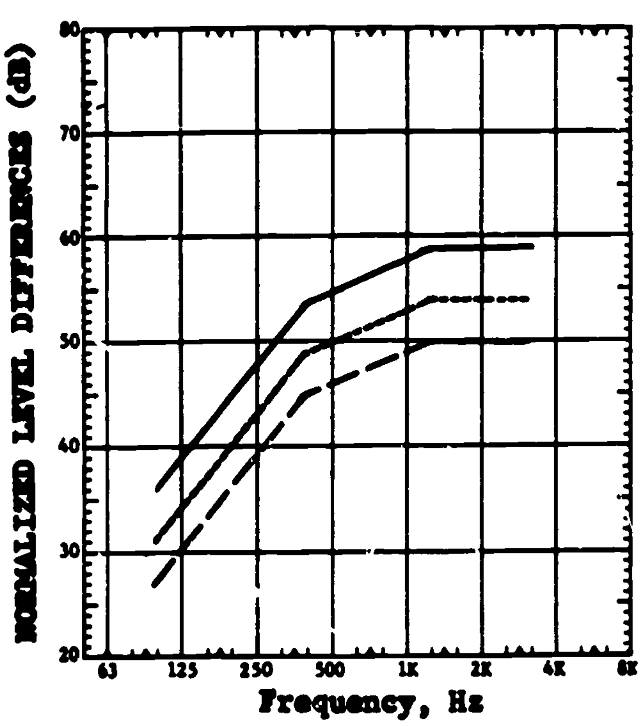


ENGLAND

——Grade I
-----Grade II
— —With linoleum

Figure 9.12

Recommended Contours

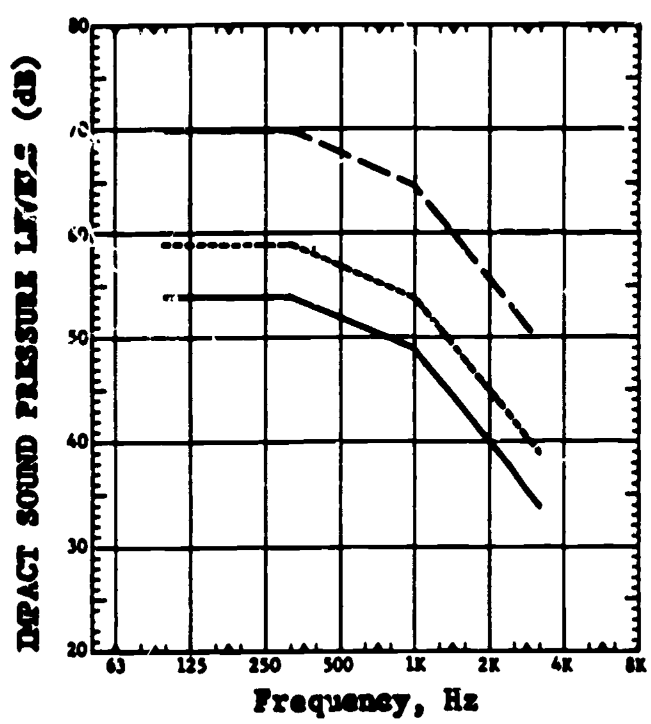


FINLAND (Field Measurements)

——Class I
------Class II
— —Class III

Figure 9.13

Recommended Contours

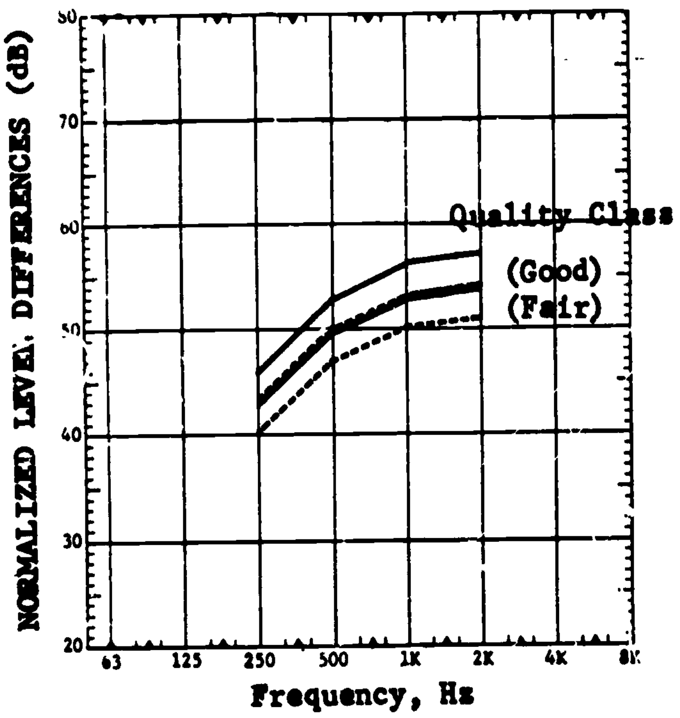


FINLAND

——Class I
------Class II
- — -Class III

Figure 9.14

Reference Values

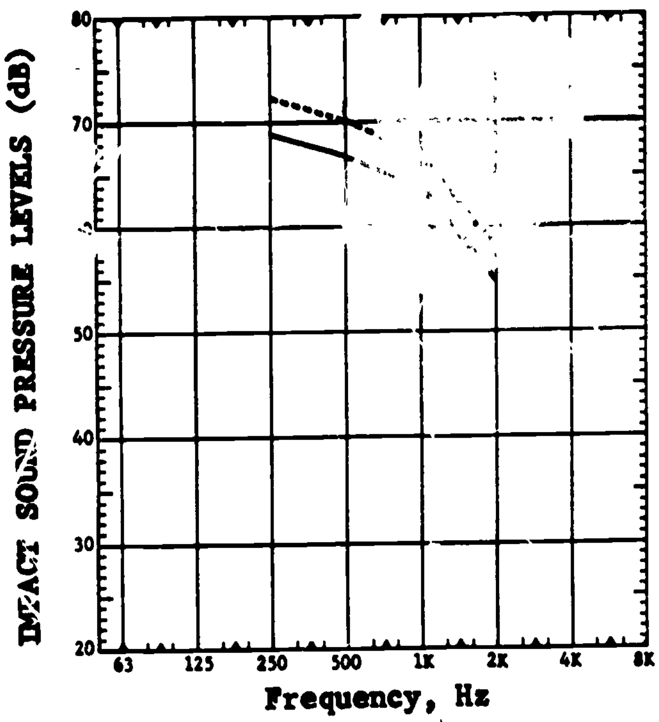


NETHERLANDS

——To Protect Sensitive Room
------To Protect Non-sensitive Room

Figure 9.15

Reference Values

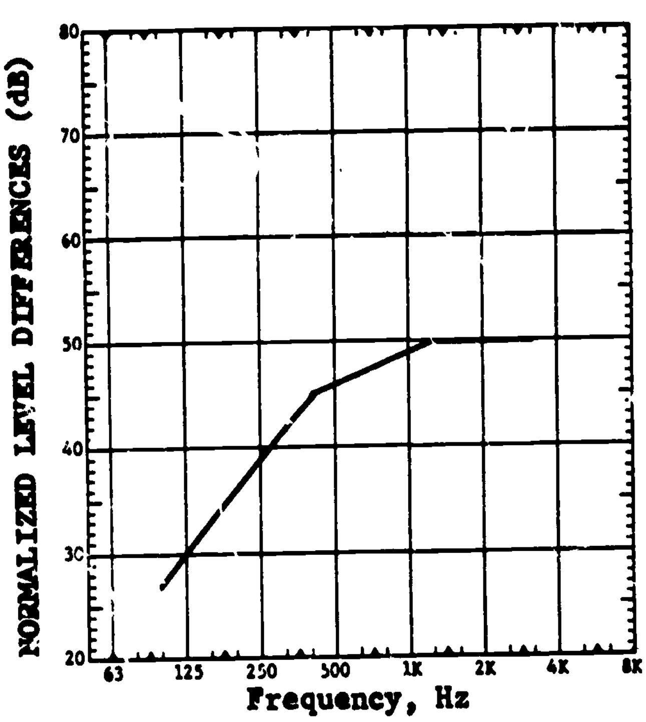


NETHERLANDS

——Quality Class - (Good)
------Quality Class - (Fair)

Figure 9.16

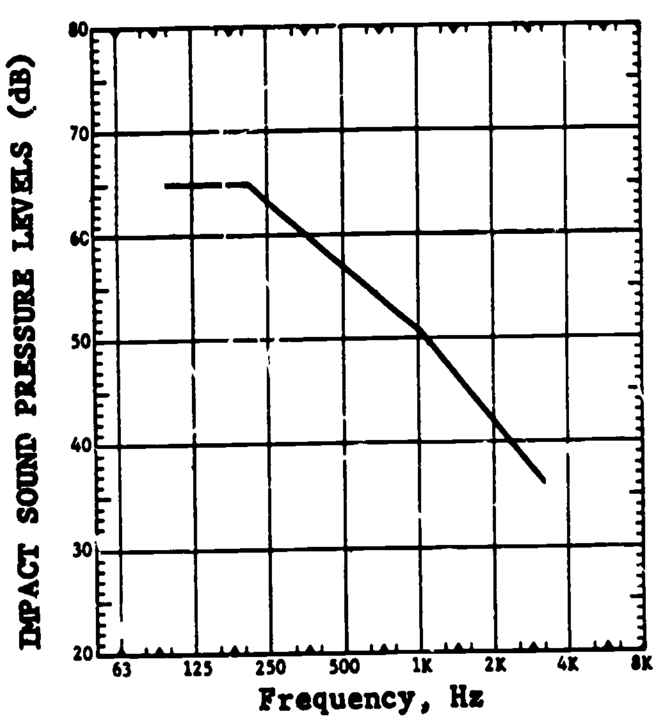
Reference Contour



——Norway

Figure 9.17

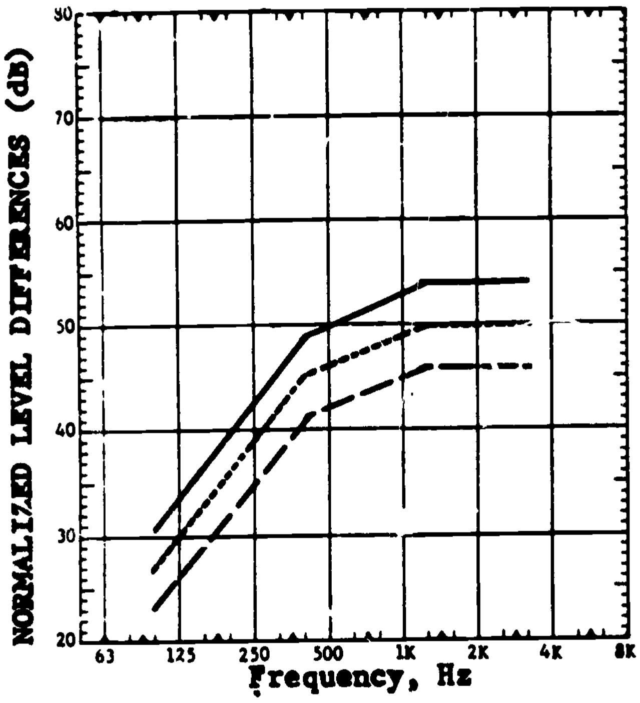
Reference Contour



——Norway

Figure 9.18

Grading Contours

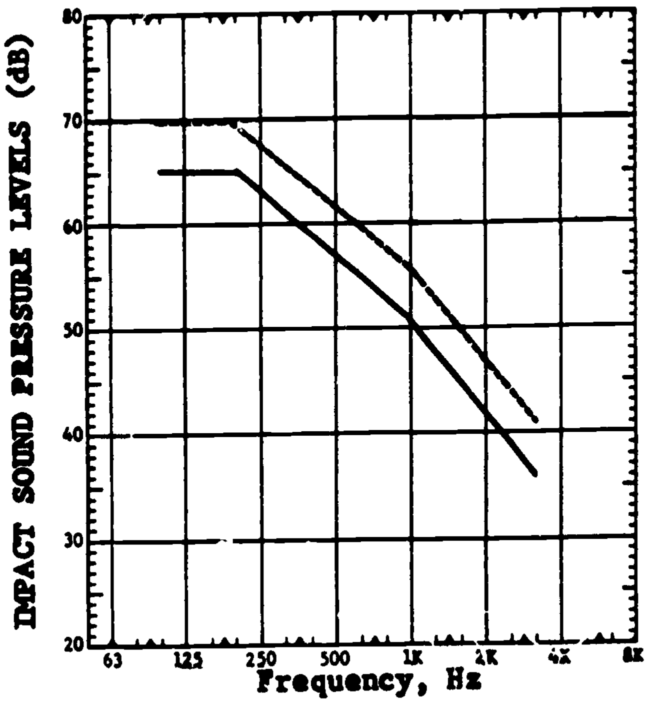


SWEDEN

——Grade I
------Grade II
-—-Grade III

Figure 9.19

Grading Contours

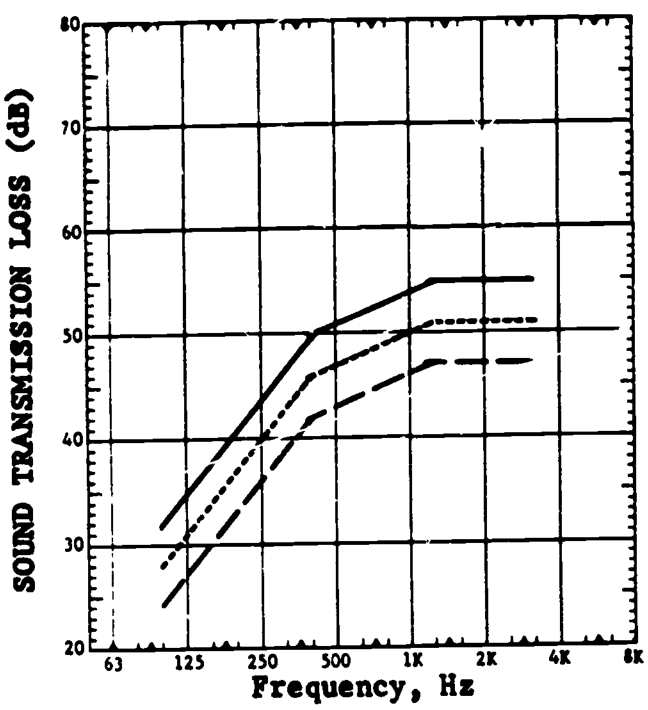


SWEDEN

——Grade I
------Grade II

Figure 9.20

Reference Contours

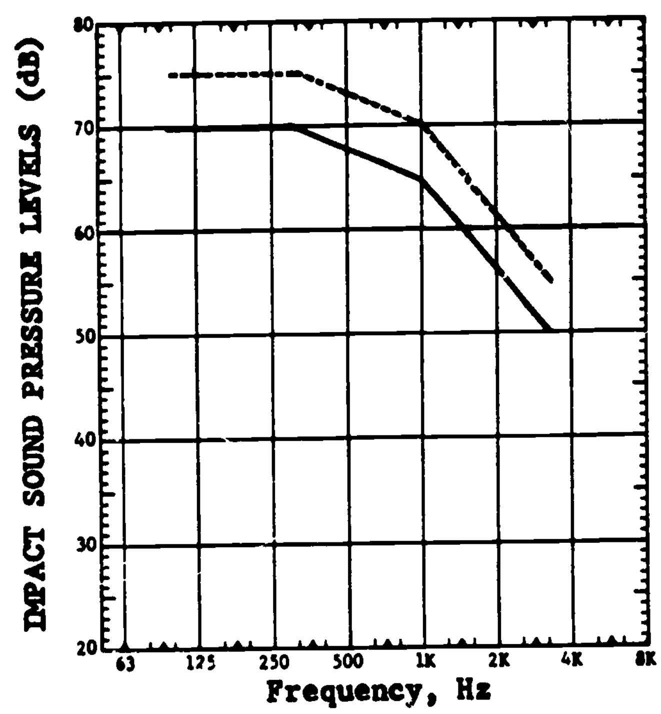


U.S.S.R.

——Standard Curve I
-------Standard Curve II
——Standard Curve III

Figure 9.21

Reference Contours



U.S.S.R.

——Standard Curve IV
------Standard Curve V

GRAPHIC SUMMARY OF FOREIGN CODES

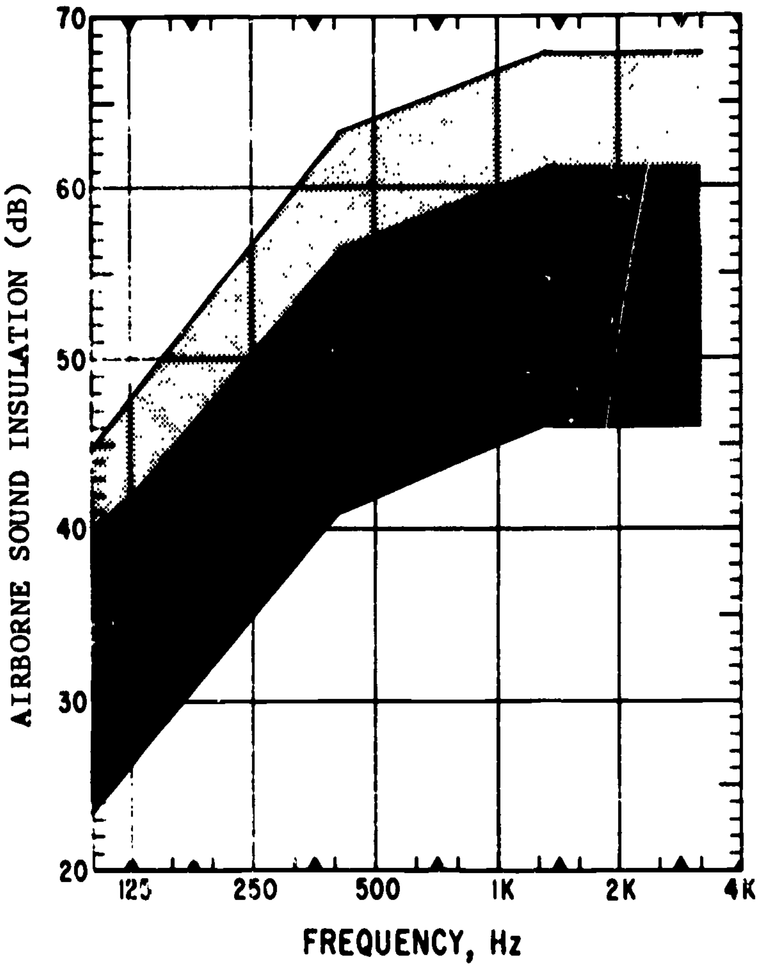


Fig. 9.22. AIRBORNE

Range of minimum airborne sound insulation requirements or recommendations.

Suggested range of values for particular cases where better airborne sound insulation is required.

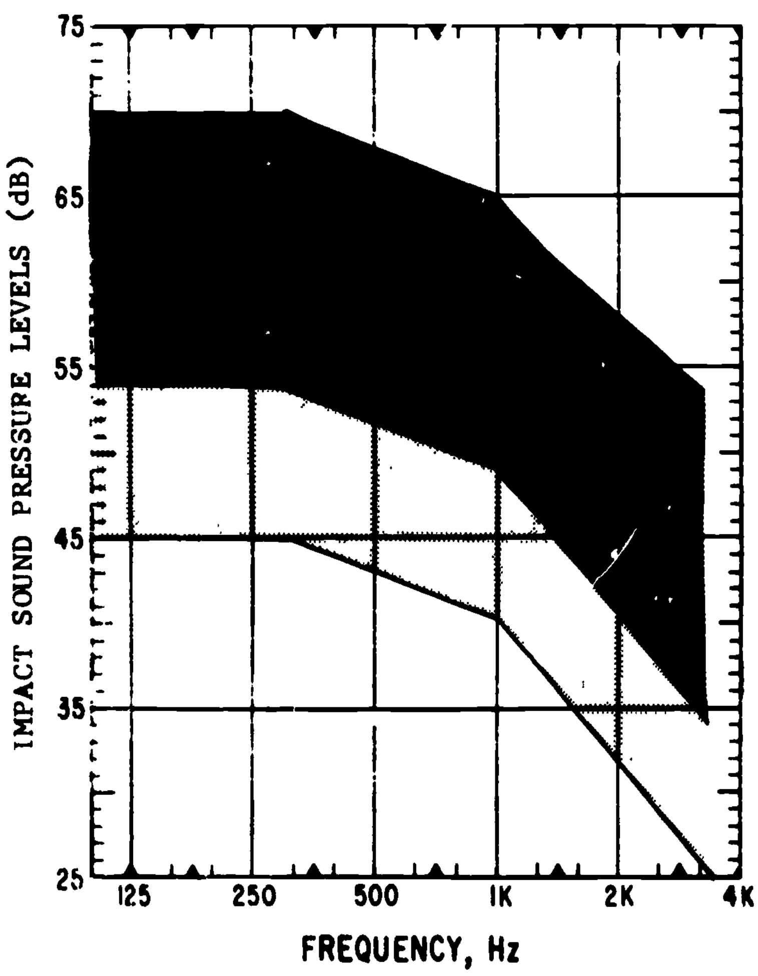


Fig. 9.23. IMPACT

Range of minimum impact sound insulation requirements or recommendations.

Suggested range of values for particular cases where better impact sound insulation is required.

CHAPTER 10

FHA RECOMMENDED CRITERIA

A. INTRODUCTION

The overall objectives of these criteria, as well as this entire Guide, are to provide direction toward the attainment of acoustical privacy and the control of noise in multifamily dwellings. To reach this goal, the system of criteria must be relatively simple in application and administration; it must be based upon meaningful physical measurements; it must be flexible so that it may be revised with ease, in order to maintain currency; and above all, it must be effective.

The plan utilized by the FHA is fundamentally a gradation of single-figure ratings, based upon reference contours. This system affords the greatest opportunity for relating recommendations or requirements to a variety of conditions, such as: ambient background noise usable for masking purposes which may imply urban, suburban or rural locations; minimal, average, or high income housing; and for specific wall or floor-ceiling functions within buildings. In addition, ease of revision of recommendations or requirements is inherent in this system without disrupting the basic scheme for classifying structures as to their acoustical properties.

B. PHYSICAL MEASUREMENTS OF AIRBORNE SOUND INSULATION

Measurements should be performed in conformance with the current methods of test which are endorsed and published by the major standardization committees and associations such as the American Society for Testing and Materials (ASTM), the United States of America Standards Institute (USASI) and the International Organization for Standardization (ISO). The preferred method of test will be that one currently in use at the National Bureau of Standards, which is presently designated as ASTM E90-66T, "Tentative Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions".*

C. SINGLE-FIGURE RATINGS OF AIRBORNE SOUND INSULATION

The only positive method for selecting a construction with the proper sound-insulating properties for a given installation is the study of the entire sound transmission loss curves of a number of constructions. It is difficult to describe completely the acoustical properties of structures with a single value. However, it is commonly acknowledged that single-figure ratings are useful for general categorization and as such may provide a convenient tool for architects, builders, code writers and others.

Over the years, several single-figure rating schemes have been proposed and used with varying degrees of success. However, in recent years, the Sound Transmission Class (STC) has been used in this country with reasonably successful results. The STC relates the sound insulating properties of a structure as a function of frequency more effectively than did the earlier arithmetical average sound transmission loss values.

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*Available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

This single-figure rating appeared initially in ASTM E90-61T* and its foundations and significance are discussed by T.D. Northwood**. A revised STC rating system, which now appears in ASTM E90-66T, conforms with certain technical revisions in the test procedure, and provides a computation scheme which decreases the probability that the STC value of a given partition is determined solely by a single sound transmission loss value at some particular frequency.

The FHA recommended criteria for airborne sound insulation utilize the STC rating system which is given in the above mentioned ASTM E90-66T document. To determine the STC of a test specimen, the sound transmission loss values, as determined in the contiguous sixteen 1/3-octave bands with center frequencies in the range 125-4000 Hz, are compared with the values of the STC reference contours, Figure 10.1, according to the following conditions:

(1) A single unfavorable deviation (i.e. an STL value which falls below the contour) may not exceed 8 dB.

(2) The sum of the unfavorable deviations shall not be greater than 32 dB. Then, the STC for the specimen is the numerical value which corresponds to the STL value at 500 Hz of the highest contour for which the above conditions are fulfilled.

Figure 10.2 illustrates the form of a transparent overlay designed for rapid graphical determinations of STC values. Initially, the sound transmission loss values of a specimen are plotted to the nearest whole dB on graph paper on which the ordinate scale is 2mm/dB and the abscissa scale is 50mm/decade. The transparent overlay is then placed over the graph, matching the frequency scale, and adjusted such that all data points lie on or above the broken-line contour, which assures that single deviations are less than or equal to a maximum of 8 dB. Then the deviations (in dB) falling below the solid-line contour are summed and the total may not exceed 32 dB. If the total is greater than 32 dB, the overlay is adjusted downward until that condition is met. The STC value of the specimen is the STL value indicated by the arrow which leads from the intersection of the reference contour and the 500 Hz ordinate. In addition, a tabular method for determining STC values is given in ASTM E90-66T.

D. PHYSICAL MEASUREMENTS OF IMPACT SOUND PRESSURE LEVELS

As in the case of sound transmission loss measurements, impact sound pressure level measurements should be performed in accordance with the current methods of test which are endorsed by the major standardization organizations. (The only formal document at this time is the ISO

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*ASTM E90-61T, "Tentative Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Walls and Floors" (American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 1961).

**T.D. Northwood, "Sound-Insulation Ratings and the New ASTM Sound-Transmission Class", J. Acoust. Soc. Am., Vol. 34, No. 4, April 1962, pp. 493-501.

Recommendation R140, "Field and Laboratory Measurements of Airborne and Impact Sound Transmission", ISO/R140-1960(E), International Organization for Standardization).

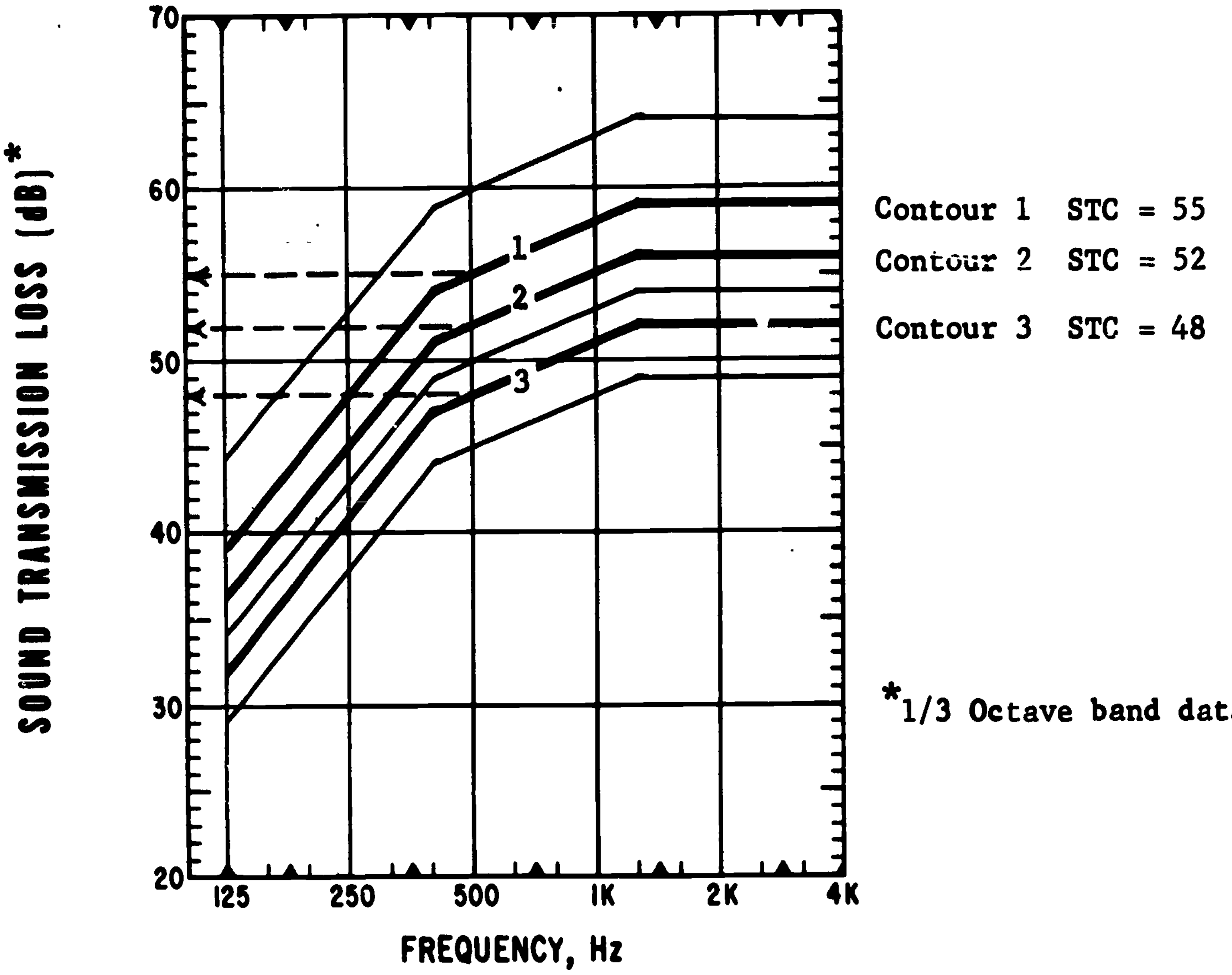
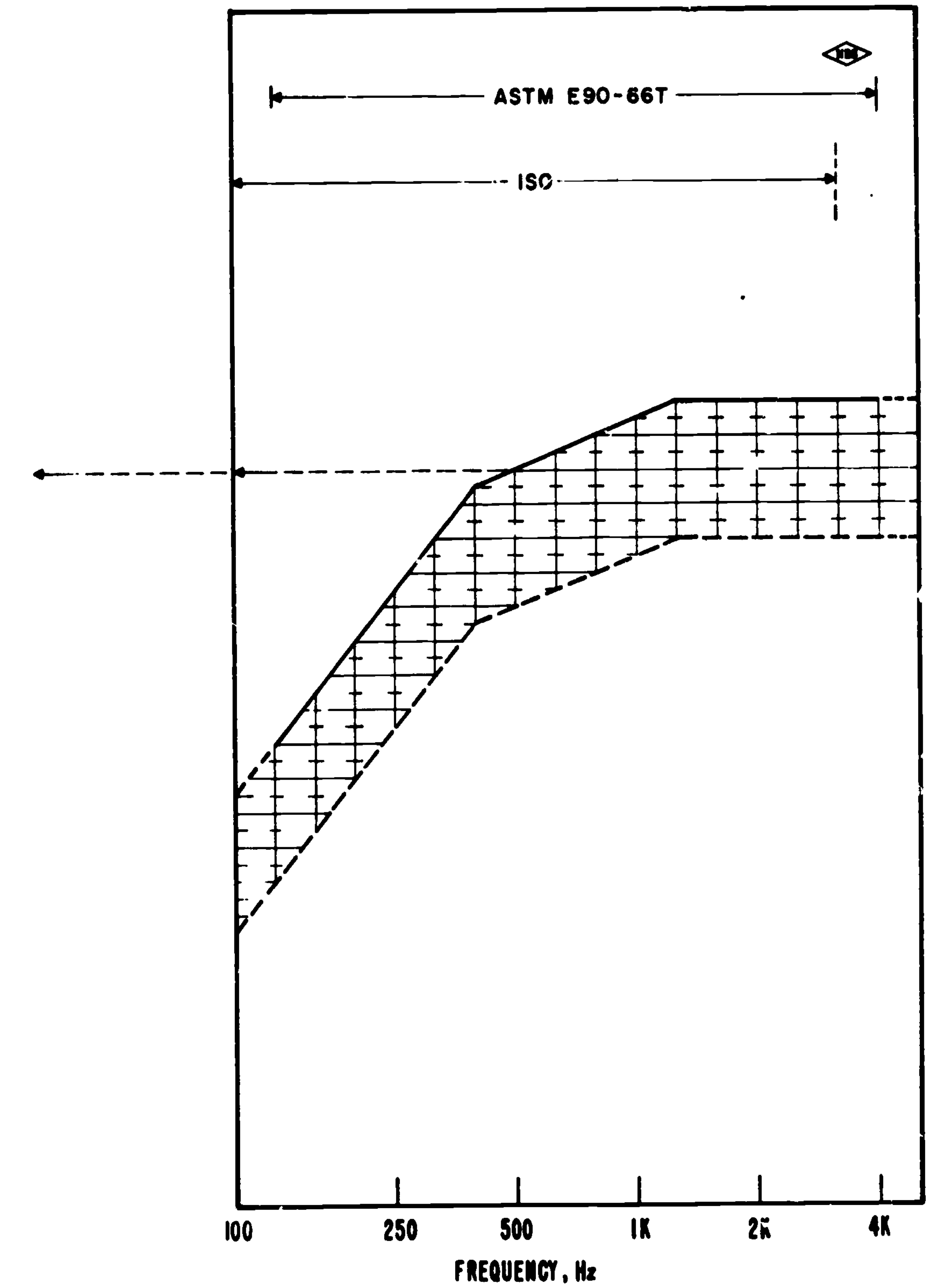


Fig. 10.1. Sound Transmission Class Contours.

Also, the preferred method of test will be that one currently in use at the National Bureau of Standards. There is no formal standard method of test in the United States at this time; however, there is a method presently under consideration in a subcommittee of the ASTM. This proposed method, which is presently in use at NBS, forms the basis of measurement upon which the criteria are founded.

The method of test involves the operation of a "standard" tapping machine* on the floor and the measurement of the resultant sound pressure levels produced in a reverberant room directly below. The sound pressure levels, averaged over time and space, in 16 contiguous 1/3-octave bands with center frequencies in the range 100-3150 Hz, are to be measured at six stationary microphone positions or with a slowly moving microphone in the receiving room with the tapping machine placed successively in at least three specified locations on the floor. The

*Tapping machine specifications are given in ISO/R140.



SOUND TRANSMISSION CLASS, STC

Use with 1/3-octave data; 5cm = 25dB, 5cm = 1 freq. decade
STC = TL value of Reference Curve at 500 Hz

Fig. 10.2. Form of Overlay for STC Determination.

results of the measurements shall be reported as impact sound pressure levels (ISPL), normalized to a reference room absorption of $A_o = 10m^2$ or 107.6 sabins.

E. SINGLE-FIGURE RATINGS OF IMPACT SOUND INSULATION

In choosing the proper floor-ceiling structure to meet the impact sound insulation requirements of a particular installation, it is recommended that the entire impact sound pressure level curves be studied, rather than choosing structures solely on the basis of the single-figure ratings. Experience has shown clearly that single-figure classifications cannot describe completely the acoustical properties of structures. Occasionally the rank order of two structures on the basis of single-figure ratings is reversed when the entire impact sound pressure curves are considered. The one with a lower single-figure rating may provide better sound insulation for a given situation. For these reasons, a certain amount of discretion must be exercised in the use of a single-figure classification system. Nevertheless, this system does serve a useful purpose in categorizing structures with similar impact sound insulating properties and, with some reservations, can be used by architects, builders and code authorities for acoustical design purposes in building construction.

The physical measurement of airborne sound insulation of a building partition is based on differential measurements of the sound pressure levels in two reverberant rooms separated by the test partition, and thus is readily adaptable to a rating system such as the STC in which larger numbers indicate increased sound insulation. However, the impact sound transmission performance of a floor structure is based on measurements of the absolute sound pressure levels produced in a room directly below the test floor on which a "standard" tapping machine is operating. In this case, lower impact sound pressure levels indicate better insulating performance. The fact that airborne sound insulation measurements and ratings differ in principle from those of impact sound insulation has caused some confusion among architects, builders, contractors and others, particularly with respect to the meaning and relationship of the two rating systems.

To remove this confusion and relieve the architect and builder of the burden of reconciling different acoustical rating systems, a new system called the IMPACT INSULATION CLASS (IIC) has been devised. This system which is utilized in the FHA recommended criteria for impact sound insulation, establishes a somewhat analogous parallelism with the more familiar airborne STC rating system. As in the STC system, the IMPACT INSULATION CLASS (IIC) rates floor structures with positive numbers in ascending degrees of impact sound insulation, i.e. the larger the number the greater the insulation. This avoids the confusing practice of dealing with "negative insulation values", which arise from the use of a zero-valued reference contour. Thus, for all practical purposes, the numerical values and significance assigned to the contours of the IIC rating system are about the same in terms of impact sound insulation as the values and significance associated with the contours of the airborne sound insulation STC system. Thus for example, an architect might simply specify an STC = 50 and an IIC = 50 for a particular installation. In addition, there is the inherent versatility which allows all code authorities to establish and revise their own criteria, if necessary, without the awesome task of re-evaluating structures tested previously.

To determine the IIC of a test specimen, the impact sound pressure levels are measured according to section D above, normalized to a reference absorption of $A_o = 10m^2$ or 107.6 sabins, and compared with the values of the IIC reference contours, Figure 10.3, according to the following conditions:

(1) A single unfavorable deviation (i.e. an ISPL value which lies above the contour) may not exceed 8 dB.

(2) The sum of the unfavorable deviations shall not be greater than 32 dB.

Then the IIC for the specimen is the value of the ordinate scale on the right (IIC), corresponding to the ISPL value at 500 Hz of the lowest contour for which the above conditions are fulfilled.

The IIC contour may be constructed as follows: a horizontal line segment in the interval 100 to 315 Hz; a middle line segment decreasing 5 dB in the interval 315 to 1000 Hz; followed by a high frequency line segment decreasing 15 dB in the interval 1000 to 3150 Hz.

On the average, the IIC rating is about 51 points higher (algebraic addition), than the INR rating used in FHA No. 750. However, it would be dangerous to apply an "across the board" adjustment to all INR ratings, for the spread between the two rating systems might be about ± 2 points.

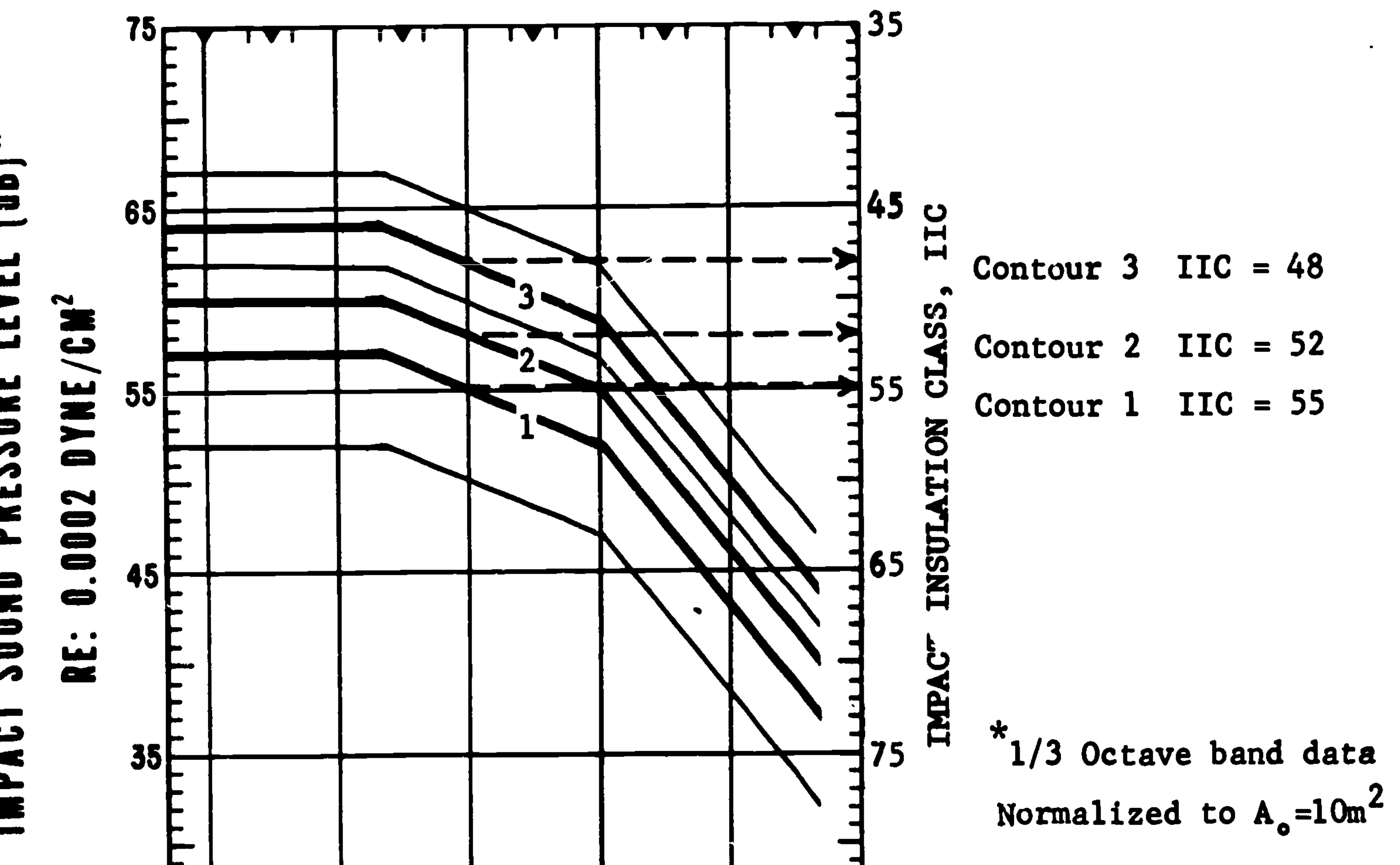
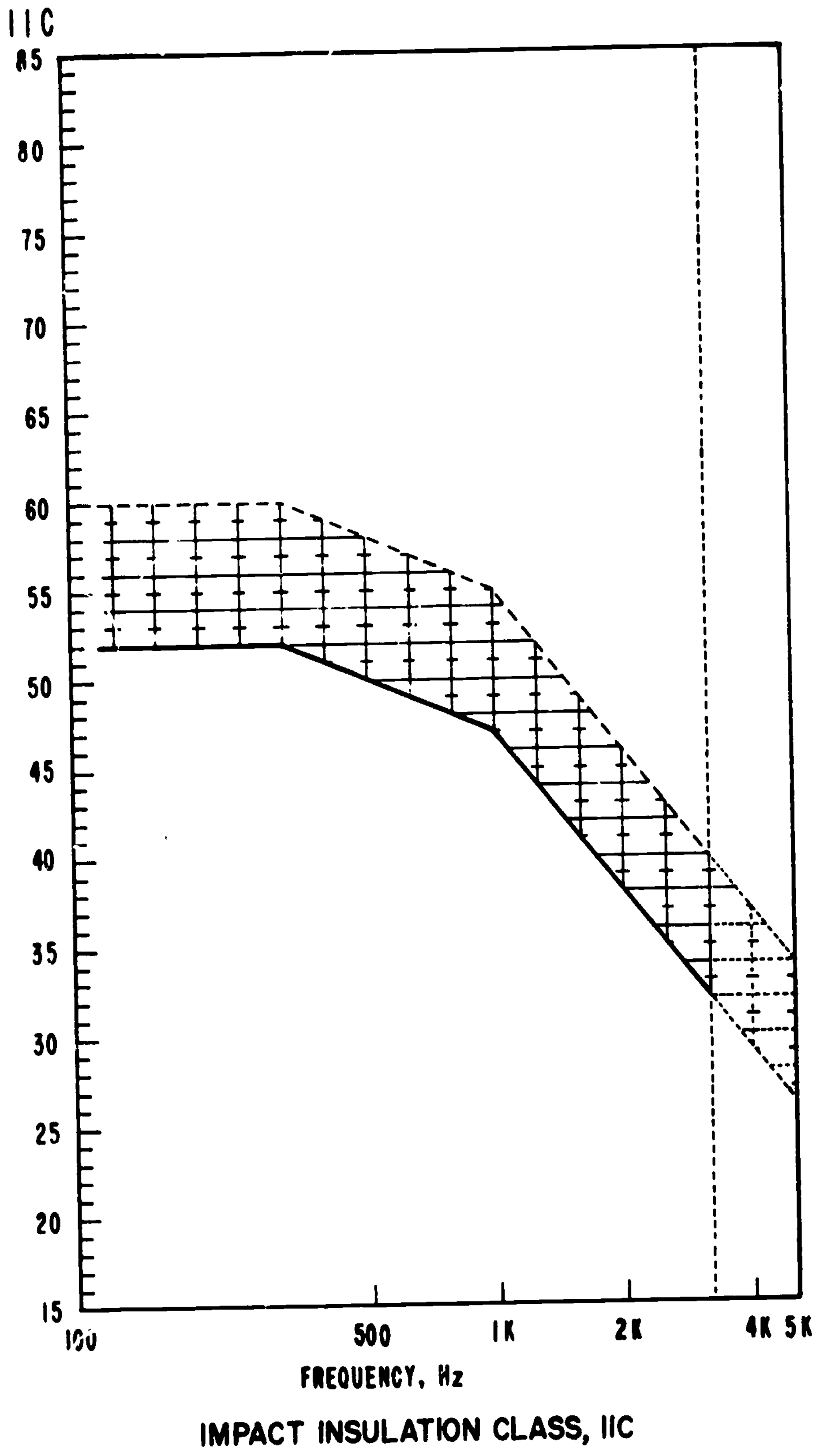


Fig. 10.3. Impact Insulation Class Contours.



Use with 1/3-octave data; 5cm = 25dB, 5cm = 1 freq. decade

Read IIC at ISPL = 60 dB

Fig. 10.4. Form of Overlay for IIC Determination.

Figure 10.4 illustrates the form of a transparent overlay designed for rapid graphical determination of IIC values. Initially, the impact sound pressure levels normalized to $A_o = 10m^2$ are plotted, to the nearest whole dB, on graph paper on which the ordinate scale is 2mm/dB and the abscissa is 50mm/decade. The transparent overlay is then placed over the graph, aligned with the frequency scale, and adjusted so that all data points lie on or below the broken-line contour; this assures initially that single deviations are less than or equal to a maximum of 8 dB; then the deviations above the solid-line contour are summed and the total may not exceed 32 dB. If the total is greater than 32 dB, the overlay is adjusted upward until that condition is met. Then the IIC value, read from the overlay, corresponds to the ISPL value of 60 dB on the graph scale.

F. RECOMMENDED CRITERIA

Descriptive definitions of three grades of acoustic environment are given in order to ascribe criteria suitable to the wide range of urban developments, geographic locations, economic conditions and other factors involved in the areas of concern of the FHA. Constructions which meet the criteria will provide good sound insulation and satisfy most of the occupants in the buildings which fit the conditions of each grade. Emphasis should be placed upon Grade II, as described below, for this category will be applicable to the largest percentage of multifamily dwelling construction and thus should be considered as the fundamental guide.

Grade I is applicable primarily in suburban and peripheral suburban residential areas, which might be considered as the "quiet" locations and as such the nighttime exterior noise levels might be about 35-40 dB(A) or lower, as measured using the "A" weighting network of a sound level meter which meets the current standards. The recommended permissible interior noise environment is characterized by noise criteria of NC20-25*. In addition, the insulation criteria of this grade are applicable in certain special cases such as dwelling units above the eighth floor in high-rise buildings and the better class or "luxury" buildings, regardless of location.

Grade II is the most important category and is applicable primarily in residential urban and suburban areas considered to have the "average" noise environment. The nighttime exterior noise levels might be about 40-45 dB (A); and the permissible interior noise environment should not exceed NC25-30 characteristics.

Grade III criteria should be considered as minimal recommendations and are applicable in some urban areas which generally are considered as "noisy" locations. The nighttime exterior noise levels might be about 55 dB(A) or higher. It is recommended that the interior noise environment should not exceed the NC-35 characteristic.

*Details of NC curves may be found in Chapter 20 of "Noise Reduction", edited by L.L. Beranek, McGraw-Hill Book Company, Inc., 1960.

In all cases, the partition structures should have STC and IIC ratings equal to or greater than the given criterion figures. For floor-ceiling assemblies, the criteria for both airborne and impact sound insulation must be met. A floor-ceiling structure which may provide adequate impact sound insulation but insufficient airborne sound insulation, or vice versa, will not assure freedom from occupant complaints.

The fundamental or key criteria of airborne and impact sound insulation of wall and floor assemblies which separate dwelling units of equivalent function are given in Table 10-1. These criteria are based upon STC and IIC ratings derived from laboratory measurements, since standard methods of test for field measurements have not as yet been formally adopted. Figures 10.5 and 10.6 illustrate the relationship of the fundamental FHA recommended criteria with the range of airborne and impact sound insulation requirements or recommendations of other countries.

TABLE 10-1. Key Criteria of Airborne and Impact Sound Insulation Between Dwelling Units

	GRADE I	GRADE II	GRADE III
Wall Partitions	STC ≥ 55	STC ≥ 52	STC ≥ 48
Floor-Ceiling Assemblies	STC ≥ 55 IIC ≥ 55	STC ≥ 52 IIC ≥ 52	STC ≥ 48 IIC ≥ 48

The following comprehensive tables show the criterion values related to partition function as applied in the separation of dwelling units. Indeed, these tables include most of the typical separation combinations found in multifamily buildings, as well as some which are clearly undesirable for several reasons. The purpose of this detail is to illustrate the importance of the acoustical separation between sensitive and non-sensitive areas. Where the partition between dwelling units is common to several functional spaces, the partition must meet the highest criterion value.

TABLE 10-2. Criteria for Airborne Sound Insulation of Wall Partitions Between Dwelling Units

Partition Function Between Dwellings Apt. A		Apt. B	Grade I STC	Grade II STC	Grade III STC
Bedroom	to	Bedroom	55	52	48
Living room	to	Bedroom[1, 2]	57	54	50
Kitchen[3]	to	Bedroom[1, 2]	58	55	52
Bathroom	to	Bedroom[1, 2]	59	56	52
Corridor	to	Bedroom[2, 4]	55	52	48
Living room	to	Living room	55	52	48
Kitchen[3]	to	Living room[1, 2]	55	52	48
Bathroom	to	Living room[1]	57	54	50
Corridor	to	Living room[2, 4, 5]	55	52	48
Kitchen	to	Kitchen[6, 7]	52	50	46
Bathroom	to	Kitchen[1, 7]	55	52	48
Corridor	to	Kitchen[2, 4, 5]	55	52	48
Bathroom	to	Bathroom[7]	52	50	46
Corridor	to	Bathroom[2, 4]	50	48	46

NOTES, RE: TABLE 10-2

1. The most desirable plan would have the dwelling unit partition separating spaces with equivalent functions, e.g., living room opposite living room, etc.; however, when this arrangement is not feasible, the partition must have greater sound insulating properties.

2. Whenever a partition wall might serve to separate several functional spaces, the highest criterion must prevail.

3. Or dining, or family. or recreation room.

4. It is assumed that there is no entrance door leading from corridor to living unit.

5. A common approach to corridor partition construction correctly assumes the entrance door as the acoustically weakest "link" and then incorrectly assumes that the basic partition wall need be no better acoustically than the door. However, the basic partition wall may separate the corridor from sensitive living areas such as the bedroom and bathroom without entrance doors, and must therefore have adequate insulating properties to assure acoustical privacy in these areas. In areas where entrance doors are used, the integrity of the corridor-living unit partition must be maintained by utilizing solid-core entrance doors, with proper gasketing. The most desirable arrangement has the entrance door leading from the corridor to a partially enclosed vestibule or foyer in the living unit.

6. Double-wall construction is recommended to provide, in addition to airborne sound insulation, isolation from impact noises generated by the placement of articles on pantry shelves and the slamming of cabinet doors. Party walls which utilize resilient spring elements to achieve good sound insulation may be used, providing wall cabinets are not mounted on them. It is not practical to use such walls for mounting of wall cabinets because the sound insulating performance of the walls can be easily short-circuited, unless specialized vibration isolation techniques are used. See text regarding proper installation of cabinets and recommended isolation procedures for appliance installations.

7. See text regarding vibration isolation of plumbing in kitchens and bathrooms and recommended installation of cabinets, medicine chests, etc.

FHA RECOMMENDED SOUND INSULATION CRITERIA

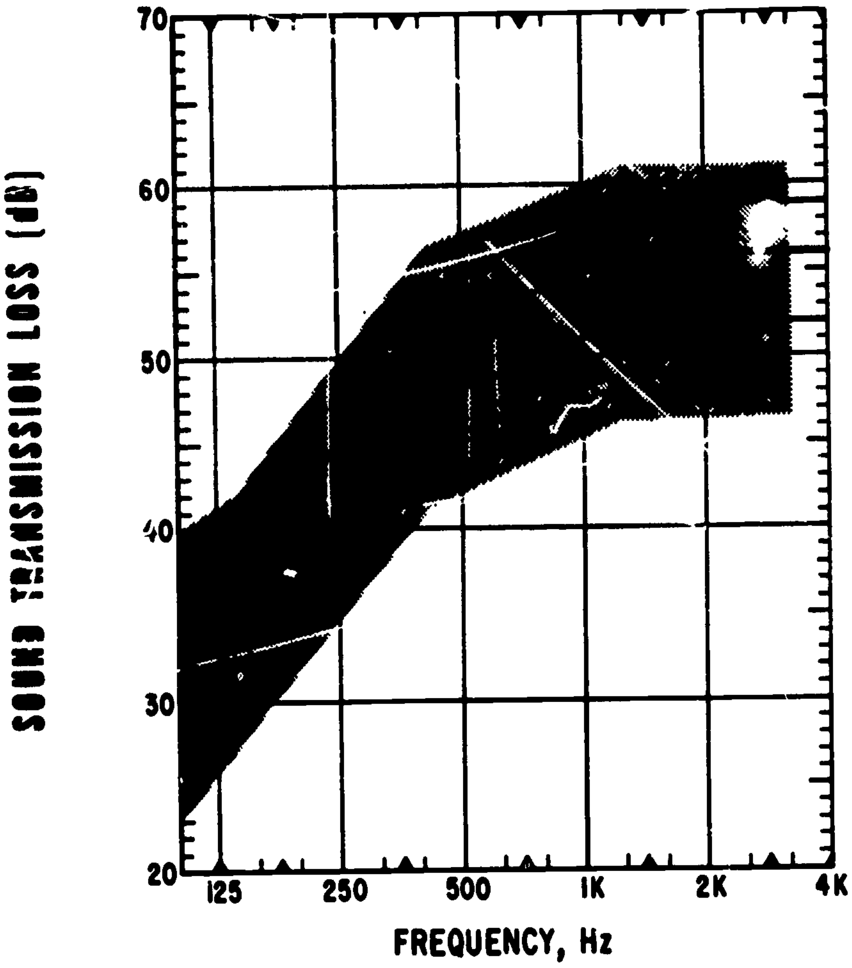


Fig. 10.5. AIRBORNE

Grade I STC = 55

Grade II STC = 52

Grade III STC = 48

Approximate range of airborne sound insulation requirements or recommendations of other countries.

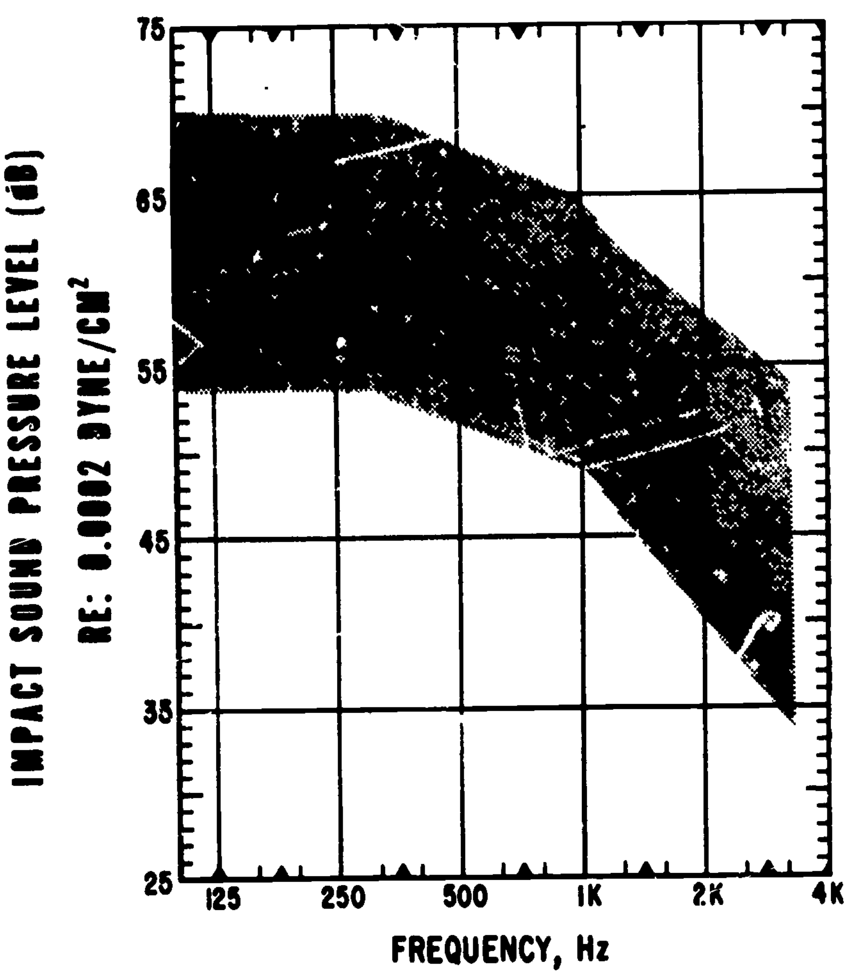


Fig. 10.6. IMPACT

Approximate range of impact sound insulation requirements or recommendations of other countries.

Grade III IIC = 48

Grade II IIC = 52

Grade I IIC = 55

Table 10-3 includes most of the floor-ceiling assembly combinations found in multifamily buildings as well as some which are clearly undesirable for several reasons. In addition, the importance of impact noise insulation is emphasized by giving separate criteria for reciprocal functional relationships.

TABLE 10-3. Criteria for Airborne and Impact Sound Insulation of Floor-Ceiling Assemblies Between Dwelling Units

Partition Function Between Dwellings			Grade I		Grade II		Grade III	
Apt. A		Apt. B	STC	IIC	STC	IIC	STC	IIC
Bedroom	above	Bedroom	55	55	52	52	48	48
Living room	above	Bedroom[1, 2]	57	60	54	57	50	53
Kitchen[3]	above	Bedroom[1, 2, 4]	58	65	55	62	52	58
Family room	above	Bedroom[1, 2, 5]	60	65	56	62	52	58
Corridor	above	Bedroom[1, 2]	55	65	52	62	48	58
Bedroom	above	Living room[6]	57	55	54	52	50	48
Living room	above	Living room	55	55	52	52	48	48
Kitchen	above	Living room[1, 2, 4]	55	60	52	57	48	53
Family room	above	Living room[1, 2, 5]	58	62	54	60	52	56
Corridor	above	Living room[1, 2]	55	60	52	57	48	53
Bedroom	above	Kitchen[1, 4, 6]	58	52	55	50	52	46
Living room	above	Kitchen[1, 4, 6]	55	55	52	52	48	48
Kitchen	above	Kitchen[4]	52	55	50	52	46	48
Bathroom	above	Kitchen[1, 2, 4]	55	55	52	52	48	48
Family room	above	Kitchen[1, 2, 4, 5]	55	60	52	58	48	54
Corridor	above	Kitchen[1, 2, 4]	50	55	48	52	46	48
Bedroom	above	Family room[1, 6]	60	50	56	48	52	46
Living room	above	Family room[1, 6]	58	52	54	50	52	48
Kitchen	above	Family room[1, 6]	55	55	52	52	48	50
Bathroom	above	Bathroom[4]	52	52	50	50	48	48
Corridor	above	Corridor[7]	50	50	48	48	46	46

NOTES; RE: TABLE 10-3

1. The most desirable plan would have the floor-ceiling assembly separating spaces with equivalent functions, e.g. living room above living room etc.; however when this arrangement is not feasible the assembly must have greater acoustical insulating properties.
2. This arrangement requires greater impact sound insulation than the converse, where a sensitive area is above a less sensitive area.
3. Or dining, or family, or recreation room.
4. See text for proper vibration isolation of plumbing fixtures and appliances.
5. The airborne STC criteria in this table apply as well to vertical partitions between these two spaces.
6. This arrangement requires equivalent airborne sound insulation and perhaps less impact sound insulation than the converse.
7. See text for proper treatment of staircase halls and corridors.

The sound insulation between living units and other spaces within the building requires special considerations. Placement of living units vertically or horizontally adjacent to mechanical equipment rooms should be avoided whenever possible. If such cases arise, the following is applicable. Generally the recommended airborne sound insulation criteria between mechanical equipment rooms and sensitive areas in dwellings are STC $\geq$ 65, STC $\geq$ 62 and STC $\geq$ 58 for grades I, II, and III, respectively. Mechanical equipment rooms include furnace-boiler rooms, elevator shafts, trash chutes, cooling towers, garages, and the like. Sensitive areas include bedrooms and living rooms. Similarly, the recommended criteria between mechanical equipment rooms and less sensitive areas in dwellings are STC $\geq$ 60, STC $\geq$ 58 and STC $\geq$ 54 for grades I, II, III, respectively, where less sensitive areas include kitchens and family or recreation rooms. Double-wall construction is usually necessary to achieve adequate acoustical privacy. Where living units are above noisy areas, the airborne sound insulation is important and impact insulation becomes a moot point as long as structure-borne vibration is minimal. However, where mechanical equipment rooms are above living areas, the airborne sound insulation must be maintained, but in addition the impact insulation becomes extremely important and elaborate steps must be taken to assure freedom from intruding vibrations and impact noise. It is not advisable to ascribe impact insulation criteria values to this case, but rather as discussed in Chapter 7, such structures should be designed to assure quiet living spaces.

Placement of dwelling units vertically or horizontally adjacent to business areas such as restaurants, bars, community laundries and the like should be avoided whenever possible. If such situations arise, the recommended airborne sound insulation criteria between business areas and sensitive living areas are STC $\geq$ 60, STC $\geq$ 58 and STC $\geq$ 56 for grades I, II, III, respectively. If the living areas are situated above business areas, impact insulation criteria of IIC $\geq$ 60, IIC $\geq$ 58 and IIC $\geq$ 56 should be adequate; however, if the relative locations are reversed, i.e. business areas above living areas, the impact insulation criteria values should be increased at least by 5 points.

If noise levels in mechanical equipment rooms or business areas exceed 100 dB, as measured using the "linear" or the "C" scale of a standard sound level meter, the airborne insulation criteria given above must be raised 5 points.

Table 10-4 lists suggested criteria for airborne sound insulation of partitions separating rooms within a given dwelling unit.

TABLE 10-4. Criteria for Airborne Sound Insulation within a Dwelling Unit

Partition Function Between Rooms			Grade I STC	Grade II STC	Grade III STC
Bedroom	to	Bedroom [1, 2]	48	44	40
Living room	to	Bedroom [1, 2]	50	46	42
Bathroom	to	Bedroom [1, 2, 3]	52	48	45
Kitchen	to	Bedroom [1, 2, 3]	52	48	45
Bathroom	to	Living room [2, 3]	52	48	45

NOTES: RE: TABLE 10-4

1. Closets may be profitably used as "buffer" zones, providing unlouvered doors are used.
2. Doors leading to bedrooms and bathrooms preferably should be of solid-core construction and gasketed to assure a comfortable degree of privacy.
3. See text for proper vibration isolation of plumbing fixtures and appliances.

Townhouses and row-houses where the living unit occupies more than one story should be separated by a double-wall construction with a rating of STC = 60 or greater. Suggested criteria between rooms in a given dwelling are the same as listed in Table 10-4 and in addition, the floor-ceiling structures should have IIC ratings which are at least numerically equivalent to or greater than the listed STC criteria.

Roof-top or indoor swimming pools, bowling alleys, ballrooms, tennis courts, gymnasiums and the like require extremely specialized acoustical considerations.

Constructions which meet the above recommended criteria should provide adequate acoustical privacy in most cases. However, after sufficient data are obtained which may relate occupant subjective satisfaction with objective measurements of the acoustical properties of structures, it may become apparent that revision is necessary and desirable. Such subsequent revisions might be in the more stringent direction or indeed, perhaps in the less stringent direction to effect a desirable balance between acoustical privacy and economic feasibility. Nevertheless, the inherent flexibility of the system provides for ease of revision and a basis upon which subsequent incremental changes might be made by code authorities and architects.

CHAPTER 11

DISCUSSION AND PRESENTATION OF DATA

A. GENERAL DISCUSSION

To enhance the usefulness of this guide, the results of airborne and impact sound insulation measurements of a large number of wall and floor structures were obtained from many sources and are presented at the end of this chapter. The types of structures range from those rated as excellent sound insulators to those which are admittedly poor. There are two purposes for including this wide variety of construction, one is to present some structures which meet or exceed the FHA criteria and the other is to illustrate some of the structures used commonly which do not provide adequate sound insulation.

In general, most of the airborne sound insulation data presented were obtained from measurements made in accordance with ASTM E90 methods or equivalent, i.e. STL measurements in reverberant rooms. In the case of some European data, which were originally presented as normalized level differences, appropriate adjustments were made in order to present the data as sound transmission loss results and thus, maintain some consistency. Similarly, the impact sound pressure level data reported were obtained from measurements using the tapping machine specified in ISO R140. However, wherever possible, the 1/3-octave data were presented as measured, i.e. without the arbitrary 5 dB adjustment to correspond with octave band data. In fact, in cases where that adjustment had been made previously, 5 dB were subtracted from the levels so that they could be presented as originally measured. Some octave band* results are presented as measured and the accompanying IIC ratings are approximately those which might have been obtained from 1/3-octave band analyses.

The sound transmission loss and impact sound pressure level data presented were obtained from laboratory measurements unless otherwise specified. Those data which were obtained from field measurements are indicated as such in the remarks on the data sheets. In all cases, the reported results are applicable only to the individual specimen tested and therefore do not necessarily apply to all structures of a similar type. In a few instances, results from a sufficient number of tests conducted on nominally identical structures were obtained so that the average values could be presented along with the spread of the results which is indicated by the shaded areas on the graph sheets.

A significant problem arises in presenting data obtained from field measurements because there are no standard methods of field measurement of airborne and impact sound insulation in the United States. (The American Society for Testing and Materials is presently drafting a much-needed standard for determining airborne sound insulation in field installations, which may soon alleviate part of this problem.) Some investigators claim that good agreement between laboratory and field measurements may be obtained when special precautions are taken to avoid

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*1/3-octave band data are preferred and all future results should be presented in this manner.

flanking transmission paths in buildings, and when the measurements are conducted as closely as possible in accordance with ASTM E90-61T. In such cases the test specimens are full scale partitions in an actual building where reverberant, though not necessarily diffuse, sound fields exist in the test rooms. Some of the results of such field measurements are presented in this chapter.

An attempt was made to relate the results of laboratory measurements of walls with those of field measurements which were conducted without special precautions to eliminate flanking paths. The rather tenuous conclusion drawn was that the STC rating based upon such field measurements might be on the average about 4 or 5 points lower than that obtained from "nominally identical" structures tested in the laboratory. See Appendix B for a more complete discussion of the comparison of laboratory and field sound insulation measurements.

Another point which warrants some discussion is that the recommended criteria given in Chapter 10 are based on the STC rating system specified in ASTM E90-66T, while the STC ratings given on the data sheets are based upon the older STC system of ASTM E90-61T. As mentioned previously, the STC rating system given in the newer document is a revised version of that given in E90-61T, relative to contour shape and method of computation. Although, in some cases, the resultant STC ratings obtained for the same structure may differ slightly, this should not be troublesome because it is generally acknowledged that a difference of 1 or 2 in the STC rating of a given partition will not spell the difference between occupant satisfaction or dissatisfaction. A statistical check using limited numbers of structures for which both STC_{61} and STC_{66} ratings could be obtained shows that the STC_{66} rating is about 1.5 to 2 points higher, on the average, than the STC_{61} rating for a given construction. However, it would be dangerous to apply an "across the board" adjustment to all STC_{61} ratings, for the spread between the rating systems is about -2 to +4. The primary reason for recommending criteria based on the STC_{66} system is simply to provide currency to the guide. Unfortunately, there is an insufficient quantity of data based on this system to present at this time. Consequently, E90-61T data are reported and should prove to be quite useful, since the given detailed sound transmission loss spectra are more important than any single-figure rating.

B. DATA SHEETS

Although the data sheets should be self-explanatory, a brief supplementary explanation might be helpful. The sound transmission loss data of wall structures are given on data sheets W-1 through W-87; then the STL and the impact sound pressure level data of floor-ceiling structures follow on data sheets F-1 through F-61. Many data sheets include information of more than one structure, e.g. the same basic structure with modifications. Data are presented for 137 wall constructions and 111 floor-ceiling structures.

The data sheets include the following information:

(1) TYPE - identifies the basic structure

(2) TEST REF. - identifies the source of the data presented. The first number refers to the item in the "List of References of Test Data" which follows the data section. The next number refers to the "test or job number" assigned by the investigator. For example, TEST REF: 3-(727)

refers to item 3 on the list which is "Sound Insulation of Wall, Floor, and Door Constructions", NBS Monograph 77 and (727) is the number assigned to the test specimen by the National Bureau of Standards.

(3) DESCRIPTION - the components are described in generic terms, i.e. trade-marked names are excluded, and dimensions are given where they were available. In addition, the total nominal thickness and the area weight, in lbs/ft^2, are given for each structure. A drawing of each structure, with the scale usually internally consistent, supplements the written description.

(4) Graphs which illustrate the detailed STL and ISPL spectra are presented. The grid pattern of these graphs is approximately 25 dB = frequency decade. In some cases the ordinate scale has been shifted appropriately in order to plot the curve on the graph.

(5) The STC and IIC ratings as well as the fire ratings are given. Pertinent information and the reference sources of fire ratings are given in Appendix A.

(6) In some cases, self-explanatory remarks are included on the data sheets.

C. INDICES

Three indices are included to aid in the selection of constructions and are described as follows:

(a) Index I - Sound Transmission Class of Wall Constructions is arranged in descending order of STC ratings and includes a brief coded description of constructional elements and the appropriate data sheet number.

(b) Index II - Sound Transmission Class of Floor-Ceiling Constructions is arranged as above for floor-ceiling assemblies and includes the IIC ratings.

(c) Index III - Impact Insulation Class of Floor-Ceiling Constructions is arranged in descending order of IIC ratings and includes the STC ratings.

AIRBORNE SOUND INSULATION DATA
OF WALL CONSTRUCTIONS

TYPE: SOLID CONCRETE

TEST REF: 3-(807), 10, 7-(TL 59-1)

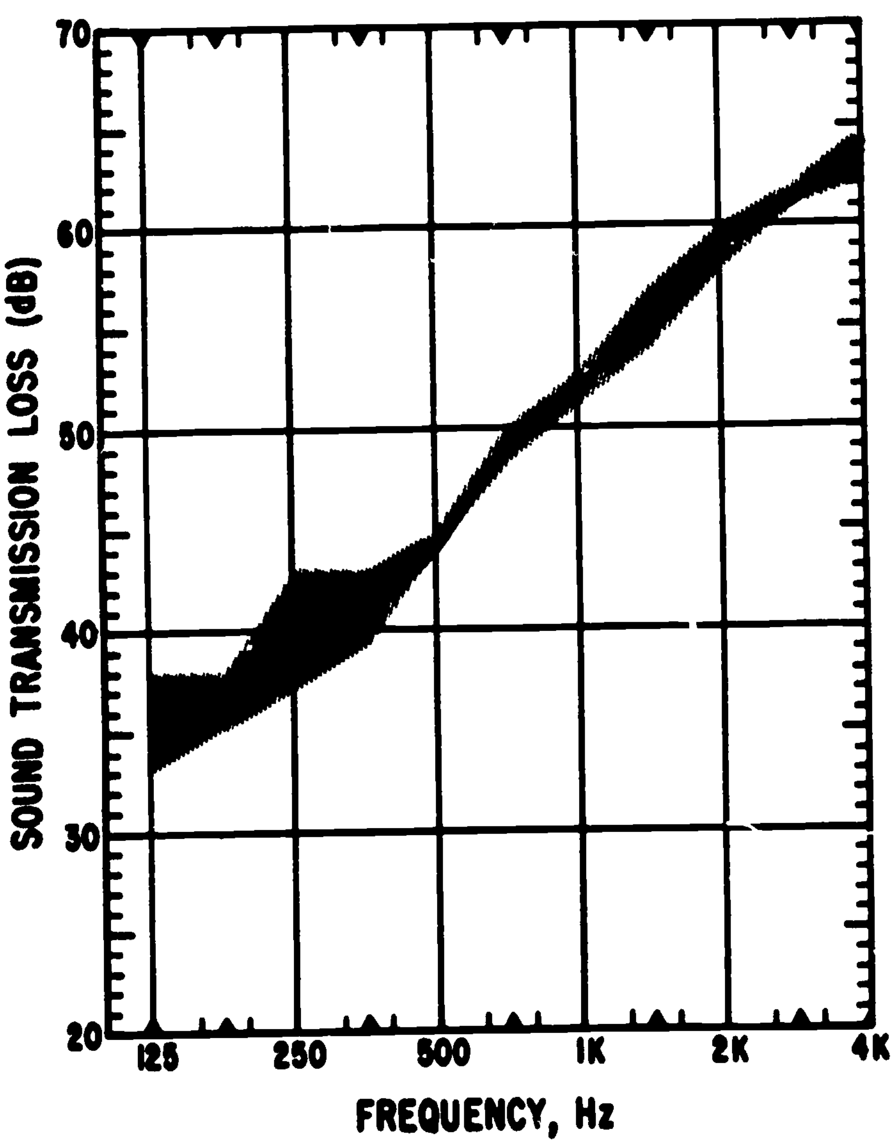
DESCRIPTION: 3-in.-thick solid concrete wall poured in situ in test opening. All surface cavities were sealed with thin mortar mix. 1- to 2-in. slump concrete mixture consisted of 611 lb cement, 1480 lb sand, 1603 lb gravel, and 38 gal water per cubic yard.

Total thickness: 3 in.

Area weight: approximately 39 lb/ft^2

STC = 47; Fire Rating: approximately 30 min. (est.)

REMARKS: Three nominally identical structures tested in three different laboratories. The plotted curve is the average value and the shaded area indicates the spread of the measurements.



TYPE: CONCRETE

TEST REF: 1-(S202-3, 4; S203-1, 2)

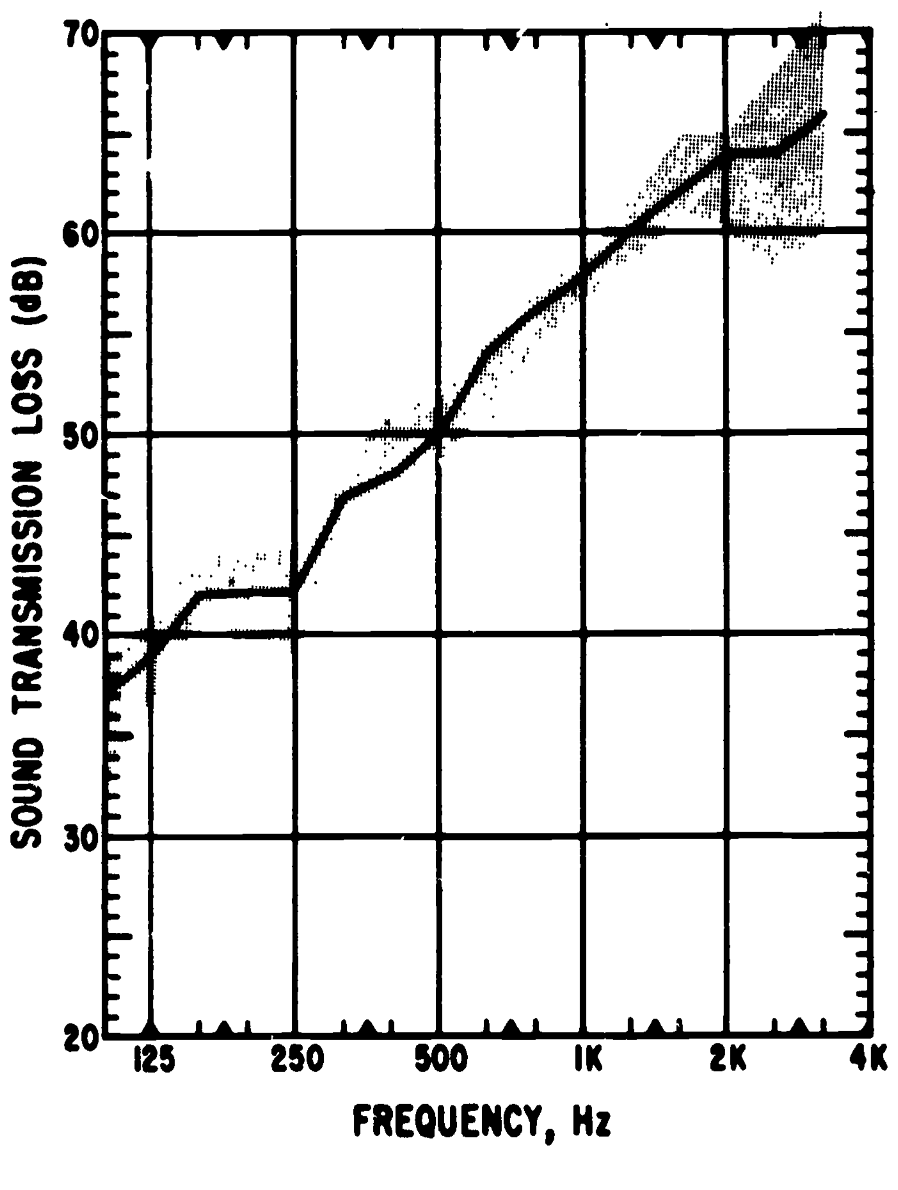
DESCRIPTION: 6-in.-thick concrete wall with a 1/2-in.-thick layer of plaster on both sides.

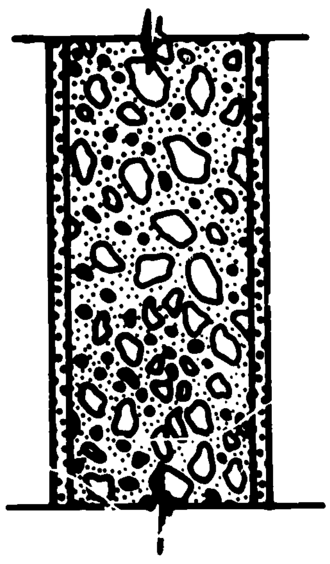
Total thickness: 7 in.

Area weight: 80 lb/ft^2

REMARKS: The plotted curve is the average of field measurements of four nominally identical structures. The shaded area indicates the spread of the measurements.

STC = 53; Fire Rating: 3 hrs. (est.)





TYPE: CONCRETE WALL - WOOD-WOOL AND PLASTER ON FURRING

TEST REF: 1-(S212, S213, S214)

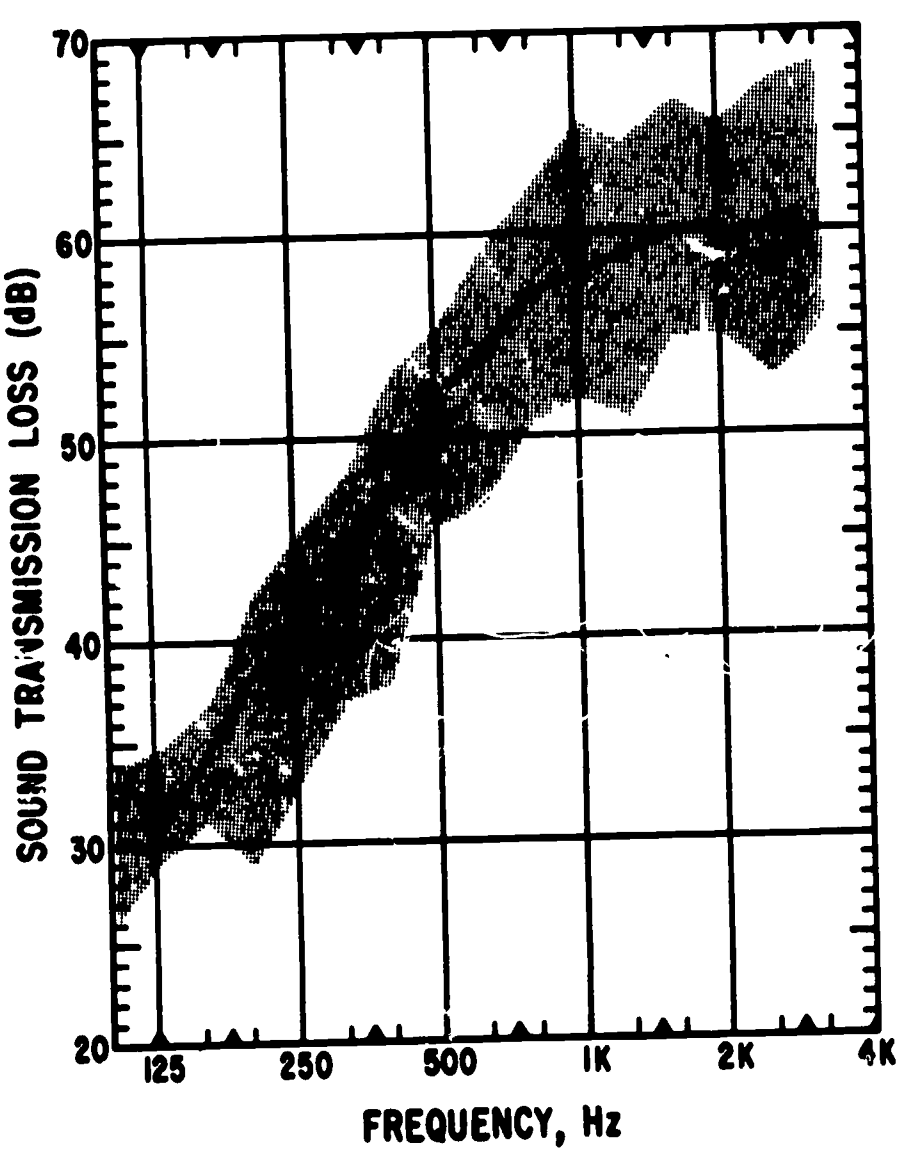
DESCRIPTION: Wall consisted of precast concrete posts spaced about 5 ft on centers with 6-in.-thick "in situ" concrete between posts. On each side, 1/2- by 2-in. furring strips (spacing not specified) with 1-in.-thick wood-wool slabs attached and plastered to a thickness of 1/2 in.

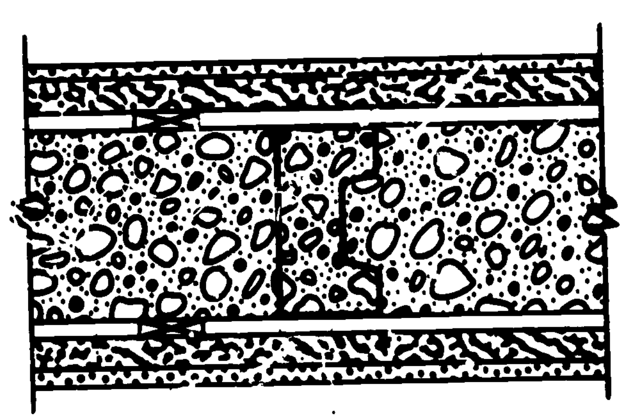
Total thickness: 10 in.

Area weight: 62 lb/ft^2

REMARKS: The plotted curve is the average of field measurements of seven nominally identical structures. The shaded area indicates the spread of the measurements.

STC = 52; Fire Rating: over 3 hrs. (est.)





TYPE: SOLID CONCRETE BLOCK

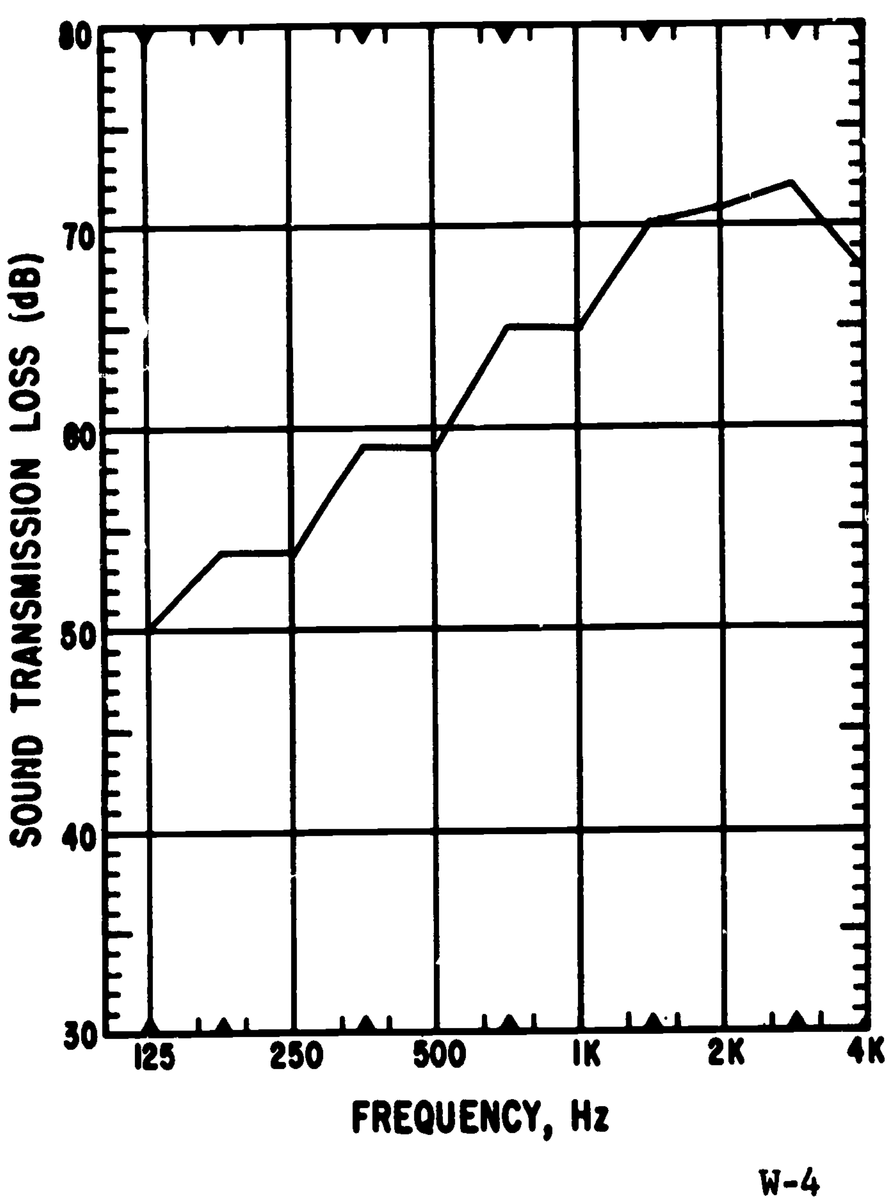
TEST REF: 7-(TL 59-11)

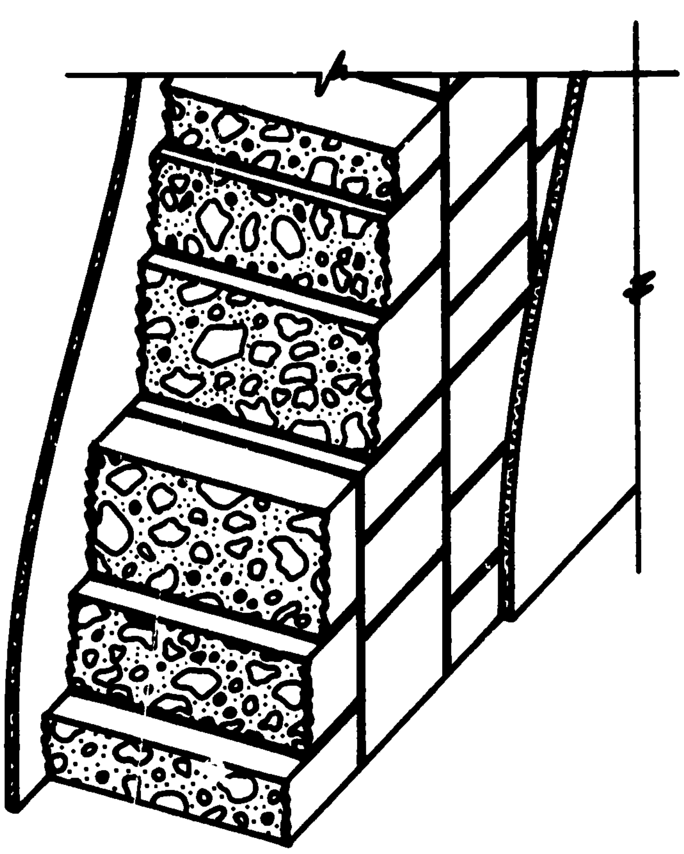
DESCRIPTION: Wall of 4-, 6-, and 8- by 8- by 16-in. sand and gravel aggregate solid concrete blocks; on each side, 1/4-in. to 1/2-in.-thick layer of cement gypsum plaster and sand.

Total thickness: approximately 16 in.

Area weight: 184 lb/ft^2

STC = 63; Fire Rating: over 4 hrs.





TYPE: BRICK

TEST REF: 1-(S170)

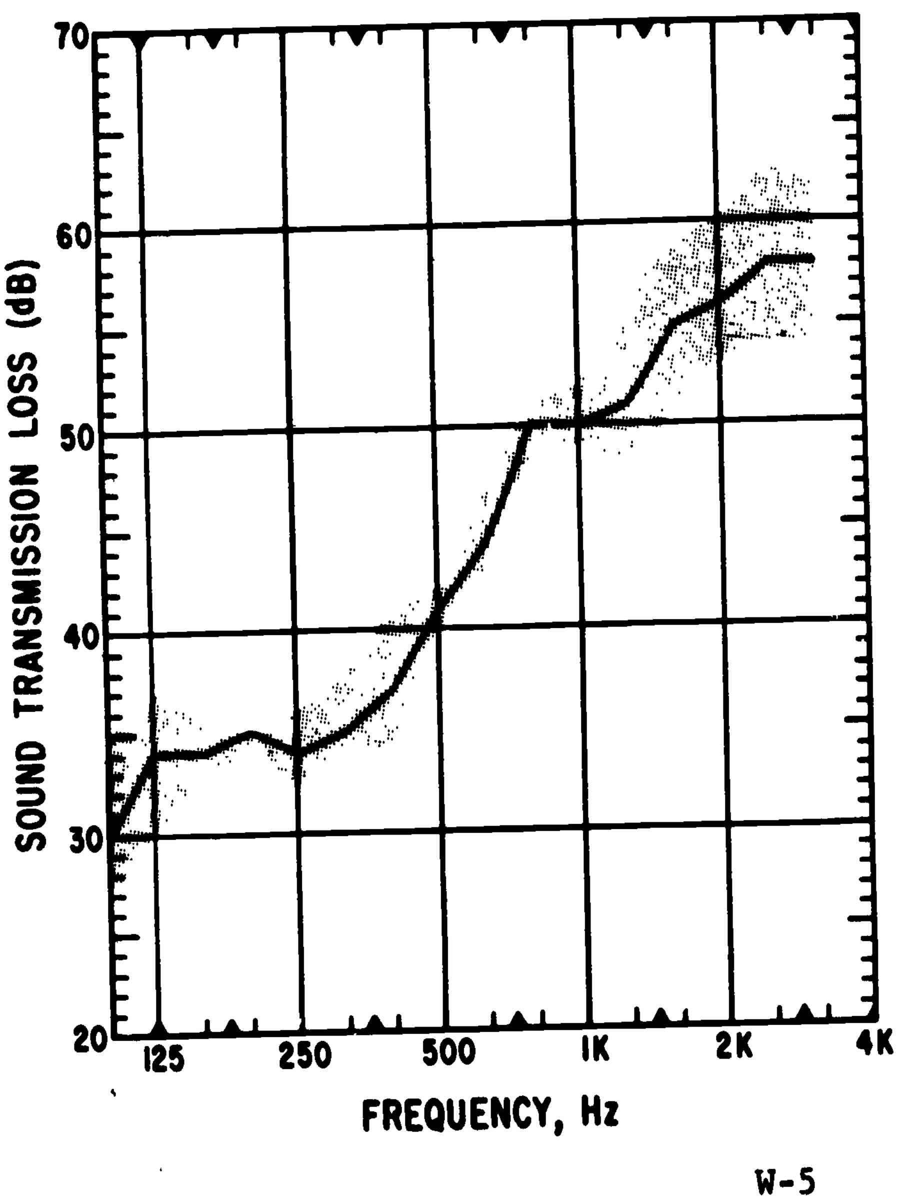
DESCRIPTION: 4 1/2-in.-thick brick wall with a 1/2-in.-thick layer of plaster on each side.

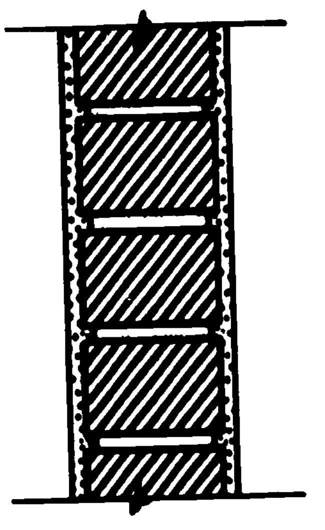
Total thickness: 5 1/2 in.

Area weight: 55 lb/ft^2

REMARKS: The plotted curve is the average of field measurements of three nominally identical structures. The shaded area indicates the spread of the measurements.

STC = 42; Fire Rating: 2 1/2 hrs.





TYPE: BRICK

TEST REF: 1-(S173, S175-2, S182, S183, S184, S185, S186, S189, S195, S196)

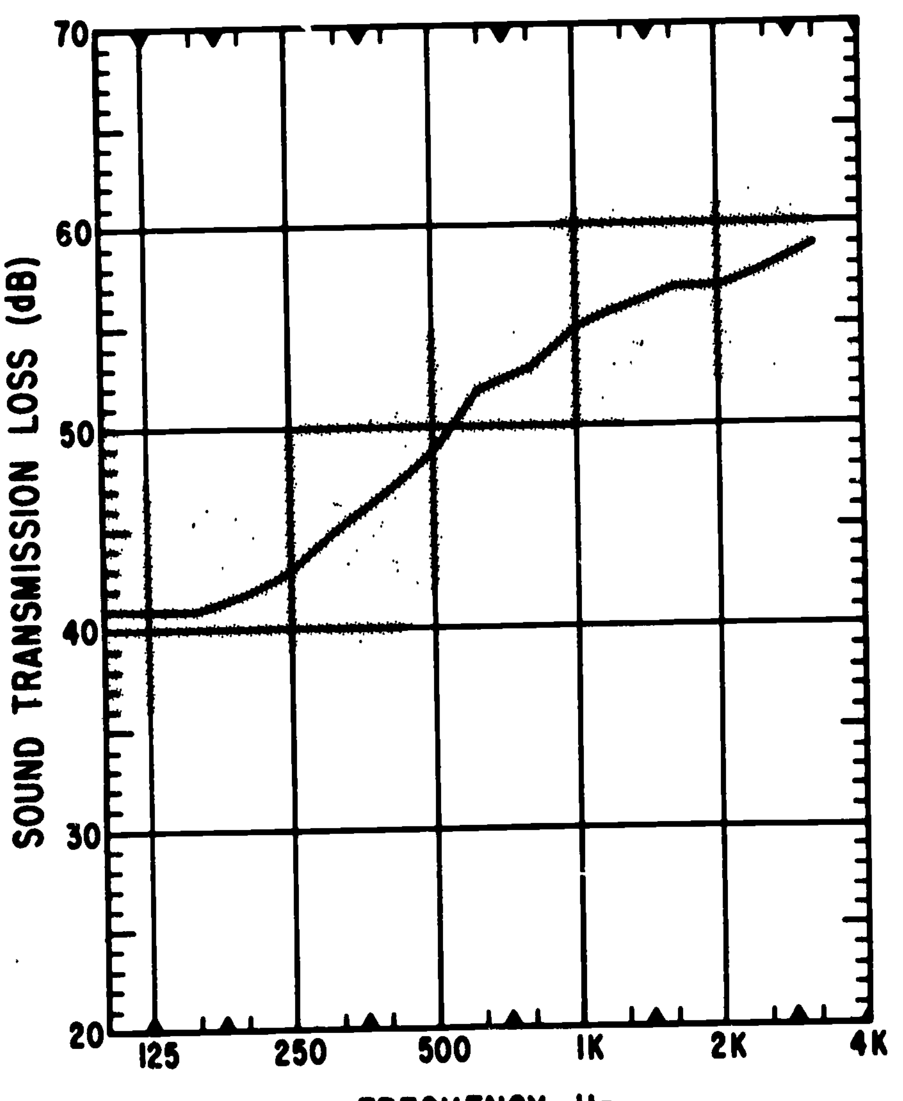
DESCRIPTION: 9-in.-thick brick wall with a 1/2-in.-thick layer of plaster on each side.

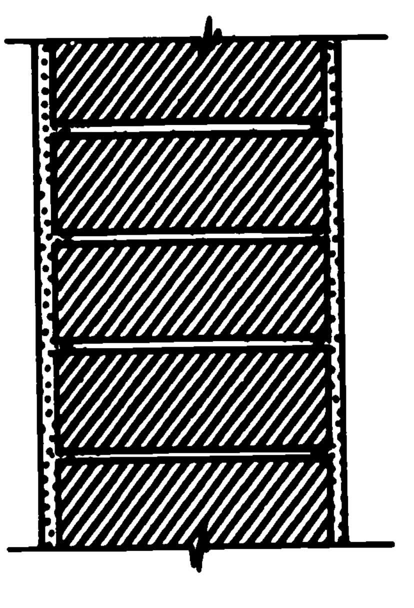
Total thickness: 10 in.

Area weight: 100 lb/ft^2

REMARKS: The plotted curve is the average of field measurements of seventeen nominally identical partition walls. The shaded area shows the spread of the measurements.

STC = 52; Fire Rating: over 4 hrs.





TYPE: BRICK

TEST REF: 2-(307)

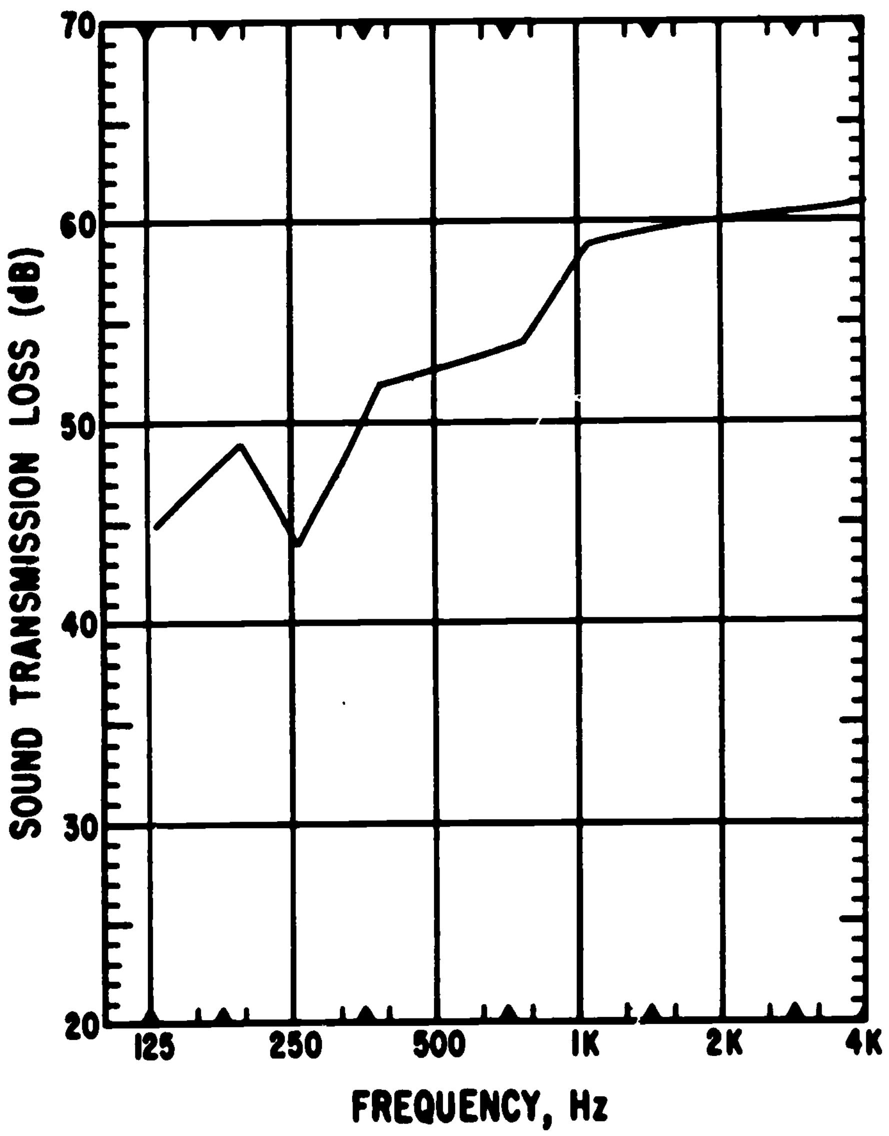
DESCRIPTION: 12-in.-thick brick wall.

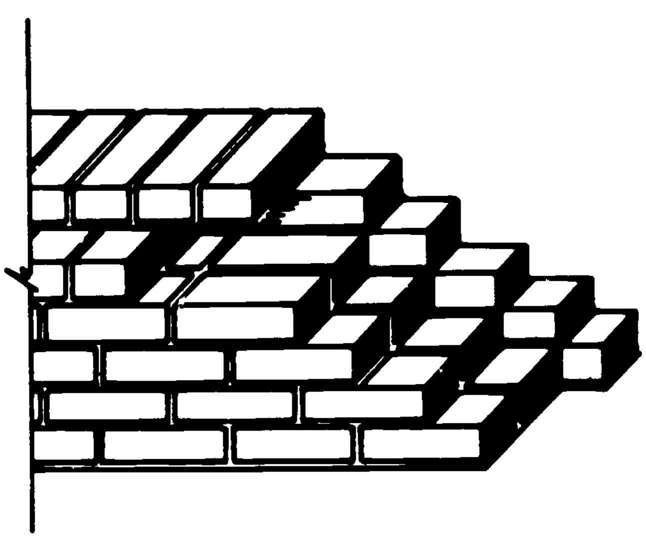
Total thickness: 12 in.

Area weight: 121 lb/ft^2

REMARKS: The STC value is based upon nine test frequencies.

STC = 56; Fire Rating: over 4 hrs.





TYPE: STONE

TEST REF: 1-(S200)

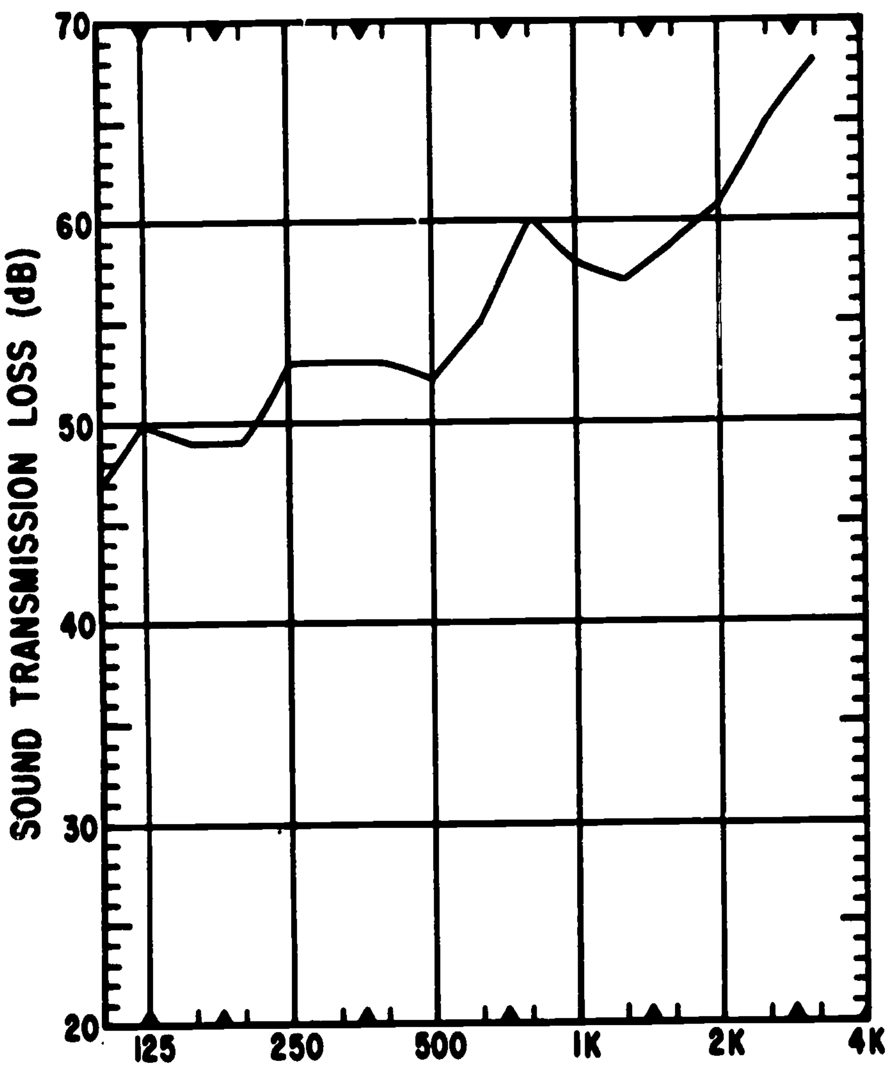
DESCRIPTION: 24-in.-thick stone wall with a 1/2-in.-thick layer of plaster on both sides.

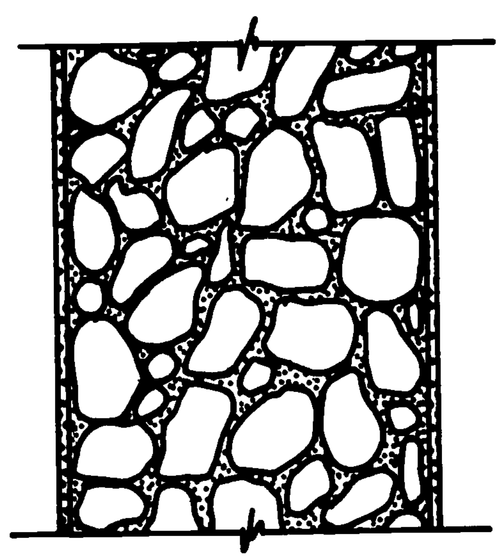
Total thickness: 25 in.

Area weight: 280 lb/ft^2

REMARKS: These measurements were conducted in the field.

STC = 56; Fire Rating: over 4 hrs.





TYPE: HOLLOW CONCRETE BLOCK

TEST REF: 2-(308)

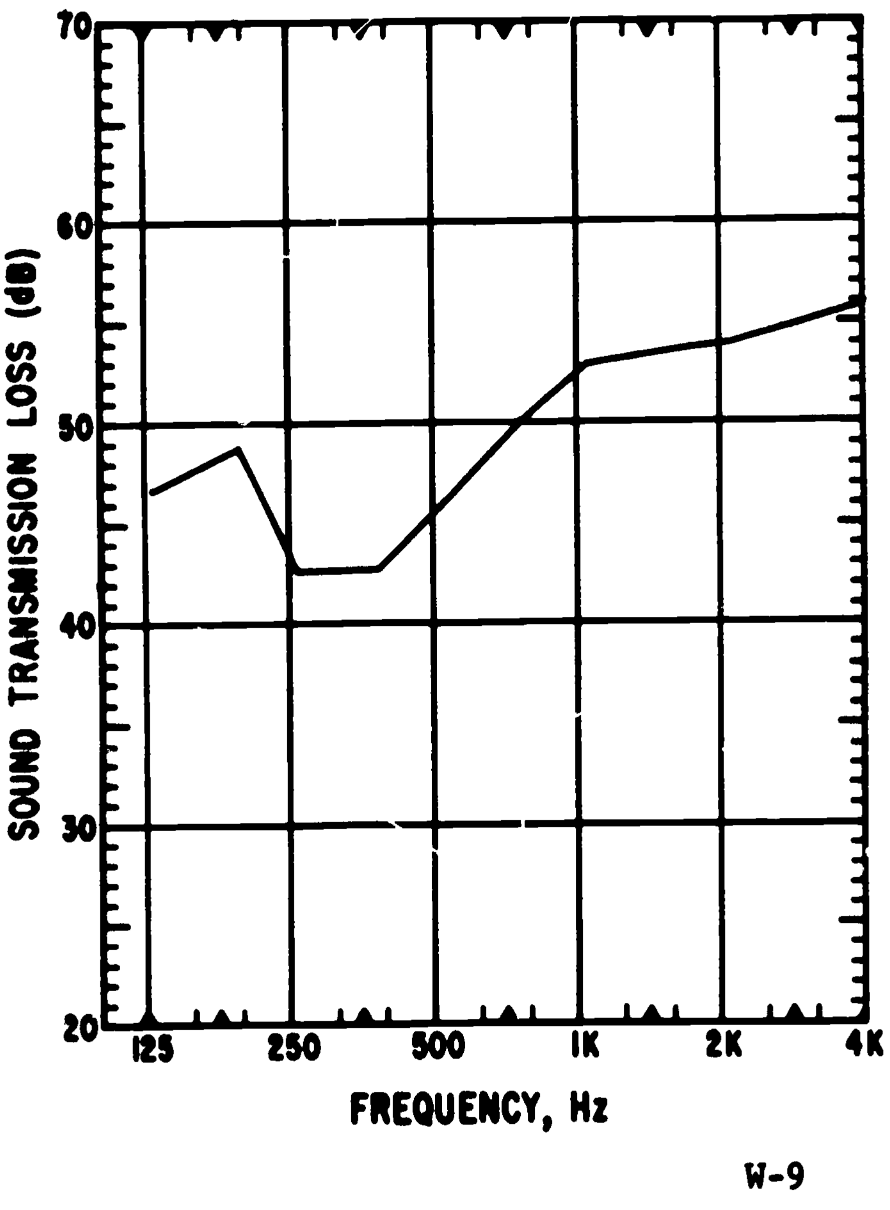
DESCRIPTION: 12-in. wall made of hollow 8- by 8- by 12-in. and 8- by 4- by 16-in. concrete blocks.

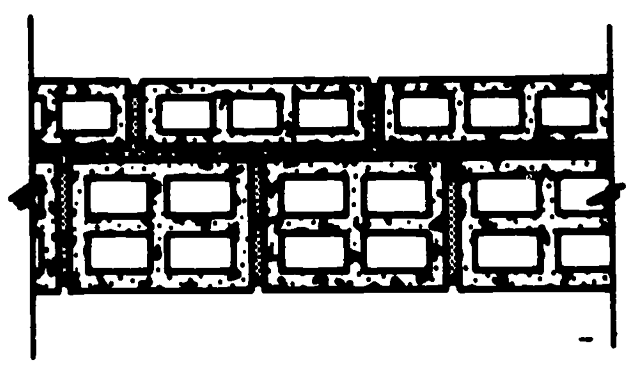
Total thickness: 12 in.

Area weight: 79 lb/ft^2

REMARKS: The STC value is based upon nine test frequencies.

STC = 48; Fire Rating: 4 hrs.





TYPE: HOLLOW CONCRETE BLOCK

TEST REF: (a) 6-(17TR); (b) 6-(18TR)

DESCRIPTION: (a) 6-in. hollow concrete blocks constructed with vertical mortar joints staggered.

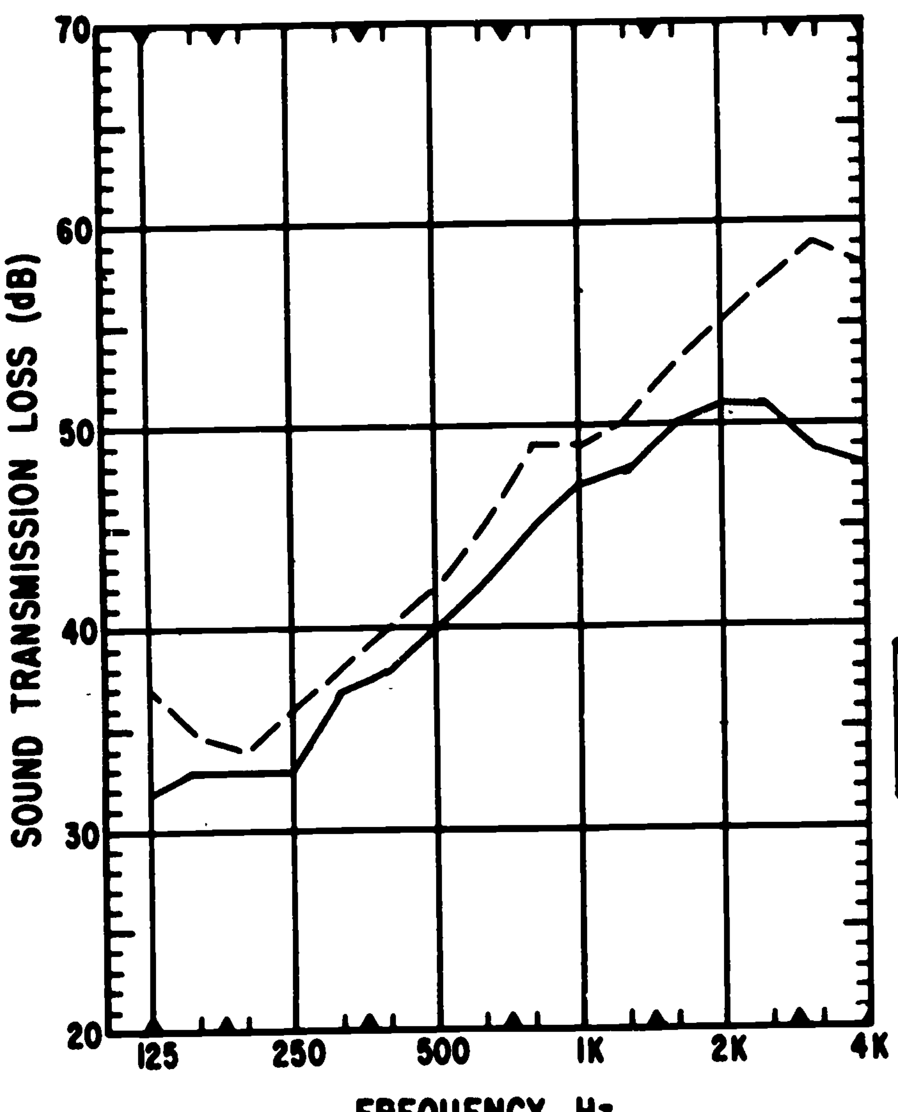
(b) Similar to (a) except wall was painted.

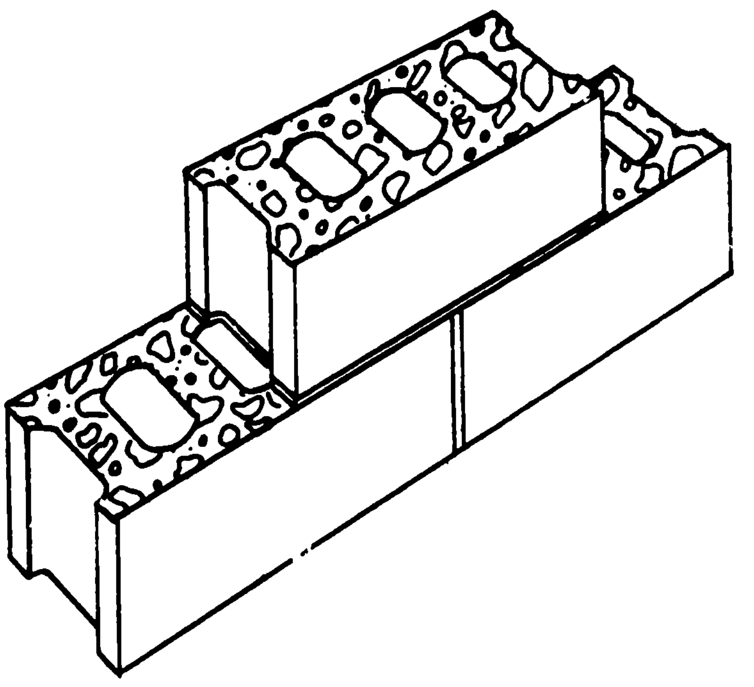
Total thickness: 6 in.

Area weight: 34 lb/ft^2

(a)————STC = 43; Fire Rating: 1 hr. (est.)

(b) – – – – -STC = 45; Fire Rating: 1 hr. (est.)





TYPE: CINDER BLOCK

TEST REF: (a) 2-(144); (b) 2-(145)

DESCRIPTION: (a) 4- by 8- by 16-in. hollow cinder blocks; on each side 5/8 in. of sanded gypsum plaster.

Total thickness: 5 1/4 in.

Area weight: 35.8 lb/ft^2

(b) Similar to (a) except the blocks were 3 in. thick.

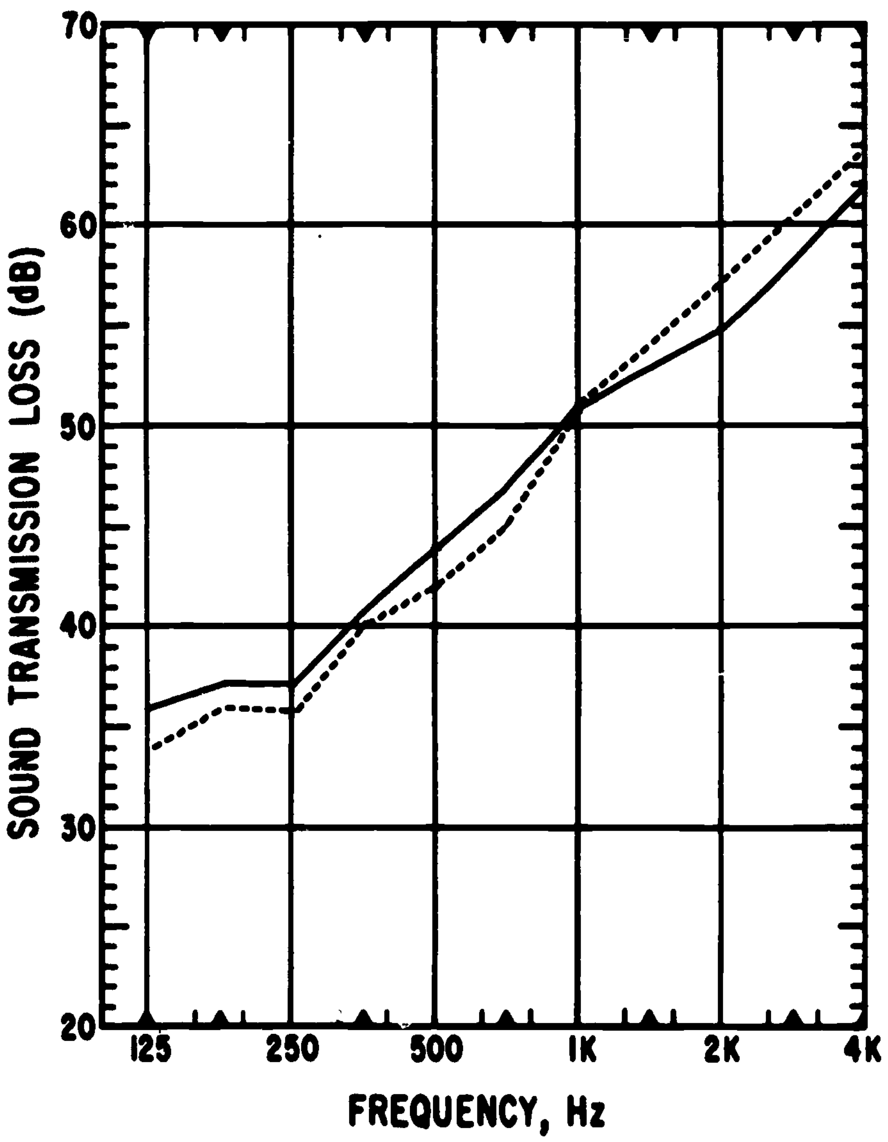
Total thickness: 4 1/4 in.

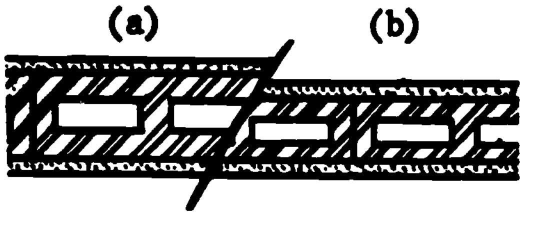
Area weight: 32.2 lb/ft^2

(a) ———— STC = 46; Fire Rating: 2 hrs.

(b) ·········· STC = 45; Fire Rating: 1 1/2 hrs.

REMARKS: The STC values are based upon nine test frequencies.





TYPE: CEMENT BLOCK

TEST REF: (a) 16-(Fig. 10); (b) 16-(Fig. 10)

DESCRIPTION: (a) 3 5/8- by 7 3/4- by 13 1/2-in. lightweight-aggregate cement blocks with 1/2-in. mortar joints; three coats of masonry paint applied to each side of partition.

Total thickness: approximately 3 3/4 in.

Area weight: 26.1 lb/ft^2

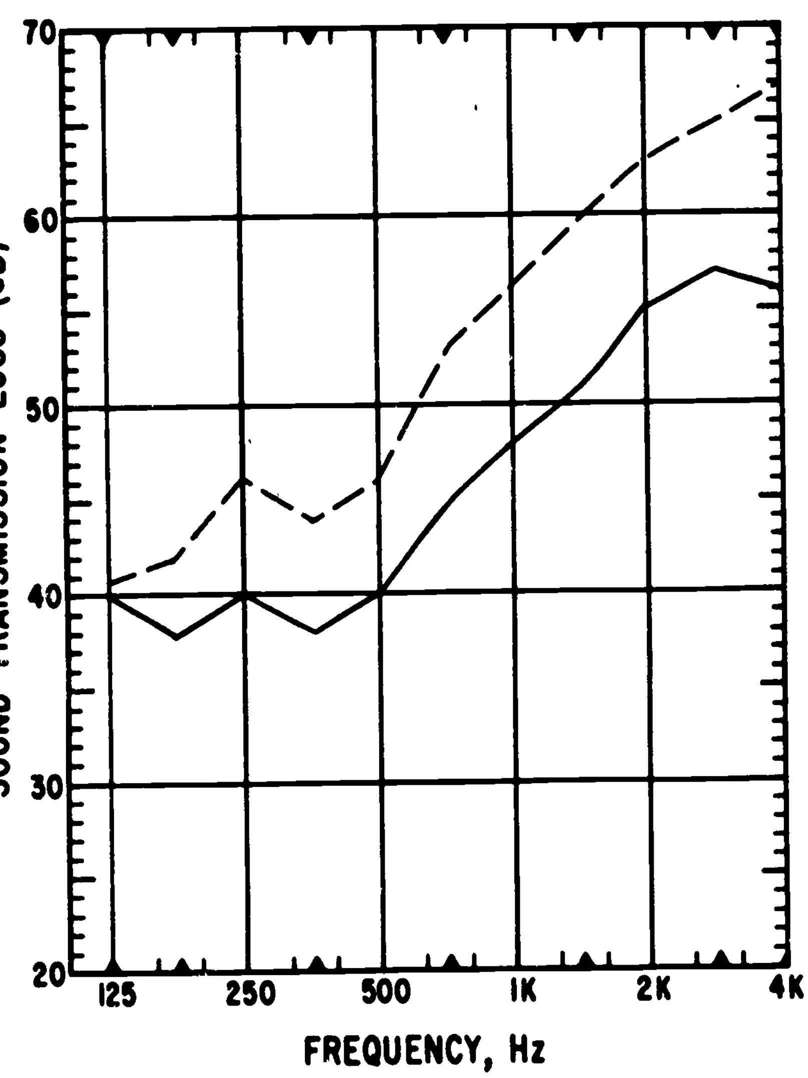
(b) Same as (a) except 1- by 2-in. furring strips were nailed vertically to partition on one side; 1/16-in. layer of lead, 3.94 lb/ft^2, nailed to furring strips, 1/4-in. plywood covered lead with joints caulked.

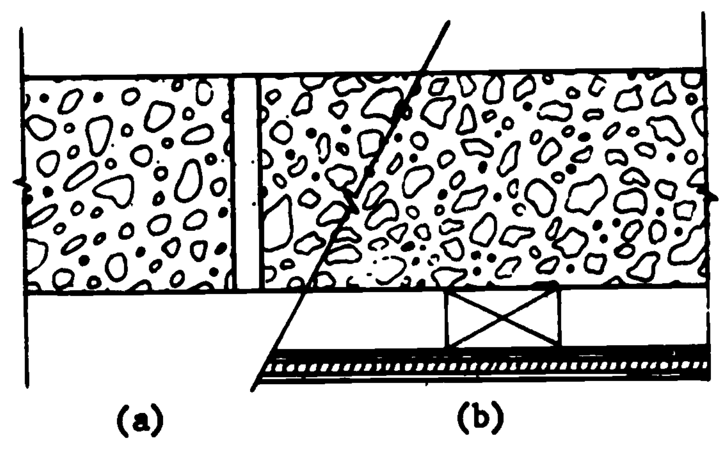
Total thickness: approximately 5 in.

Area weight: approximately 31 lb/ft^2 (Not specified in reference)

(a)———————STC = 44; Fire Rating: 1 1/2 hrs. (est.)

(b)- — — — — —STC = 50; Fire Rating: 1 1/2 hrs. (est.)





TYPE: HOLLOW GYPSUM BLOCK

TEST REF: 2-(304, 309)

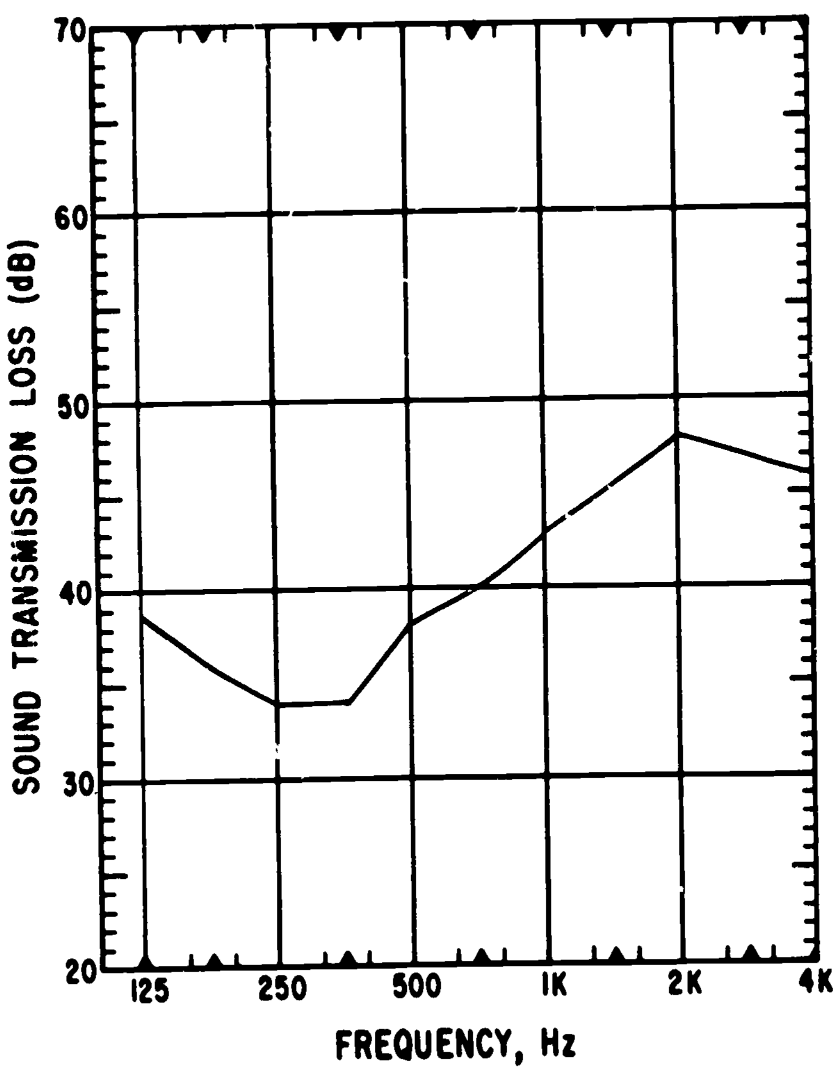
DESCRIPTION: 3-in. hollow gypsum blocks cemented together with 3/8-in. mortar joints; on each side, 1/2-in. sanded gypsum plaster.

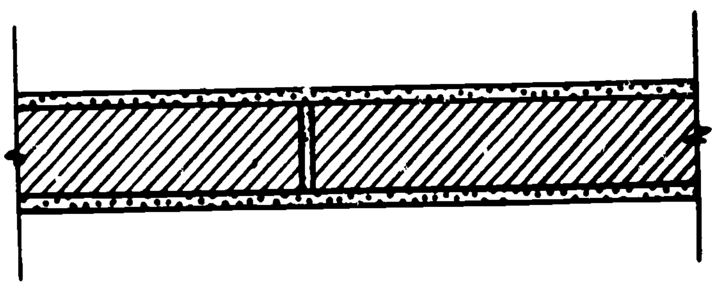
Total thickness: 4 in.

Area weight: approximately 21.5 lb/ft^2

STC = 40; Fire Rating: 3 hrs.

REMARKS: The plotted curve represents the average of laboratory measurements of two nominally identical structures. The STC value is based upon nine test frequencies.





TYPE: HOLLOW GYPSUM BLOCK

TEST REF: (a) 2-(305); (b) 4-(Fig. 13.38)

DESCRIPTION: (a) 4-in. hollow gypsum blocks cemented together with 3/8-in. mortar joints; on each side, 1/2-in. sanded gypsum plaster.

Total thickness: 5 in.

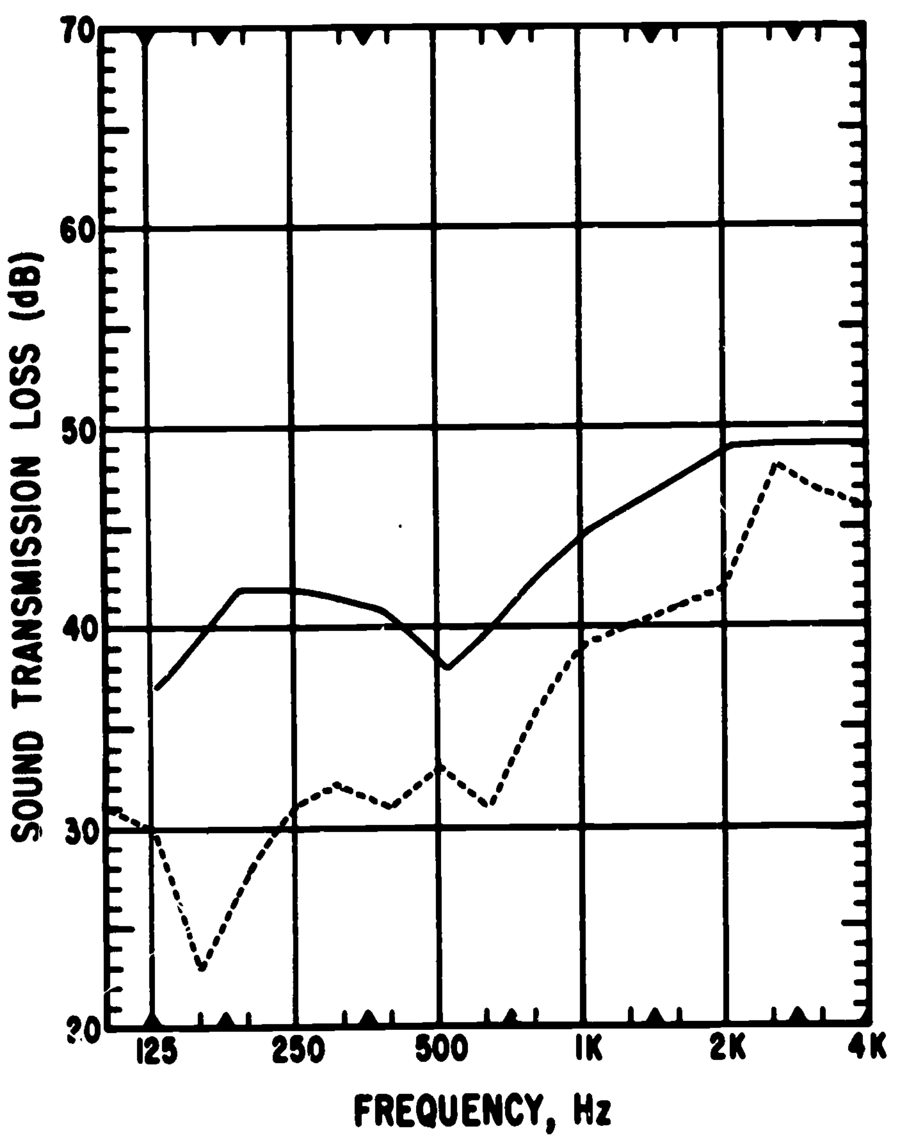
Area weight: 23.4 lb/ft^2

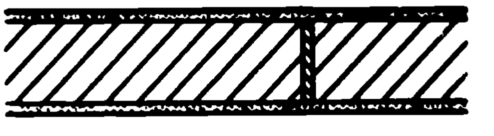
(b) Similar to (a) except plaster coat was 5/8 in. thick.

(a)———————STC = 42; Fire Rating: 4 hrs.

(b)··············· STC = 34

REMARKS: Curve (a) illustrates the results obtained from laboratory measurements and curve (b) the results of field measurements of the sound transmission loss of a similar structure. The STC value of (a) is based upon nine test frequencies.





TYPE: HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES

TEST REF: (a) 3-(313); (b) 3-(317)

DESCRIPTION: (a) 3- by 12- by 30-in. hollow gypsum blocks with 1/2-in. mortar joints. On one side 7/16-in. sanded gypsum plaster; on the other side resilient clips, spaced 18 in. on centers vertically and 16 in. on centers horizontally, held 3/4-in. metal channels 16 in. on centers, to which expanded metal lath was wire-tied; 11/16-in. sanded gypsum plaster. 1/16-in. white-coat finish applied to both sides.

Total thickness: 5 in.

Area weight: 27 lb/ft^2

(b) Similar to (a), except 4- by 12- by 30-in. gypsum blocks were used.

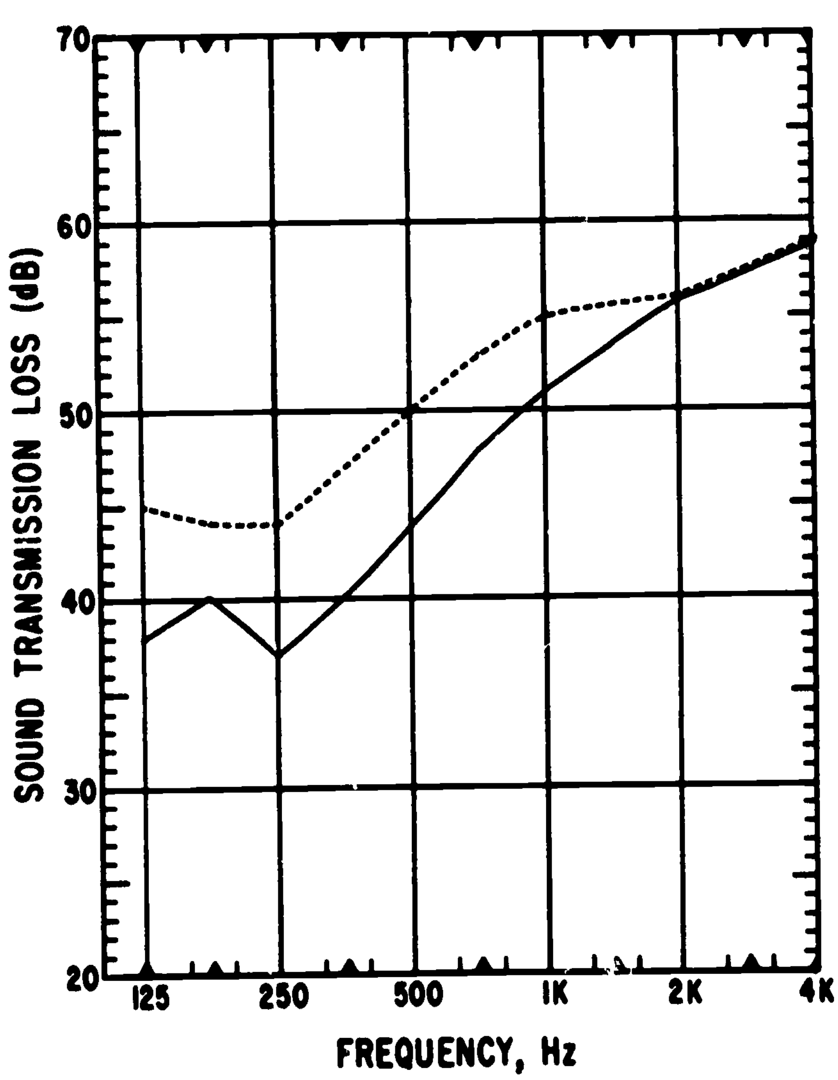
Total thickness: 6 in.

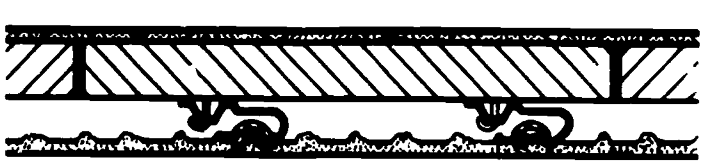
Area weight: 31 lb/ft^2

REMARKS: The STC values are based upon nine test frequencies.

(a) ———————— STC = 46; Fire Rating: 3 hrs.

(b) ---------------- STC = 53; Fire Rating: 4 hrs.





TYPE: HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES

TEST REF: 3-(315)

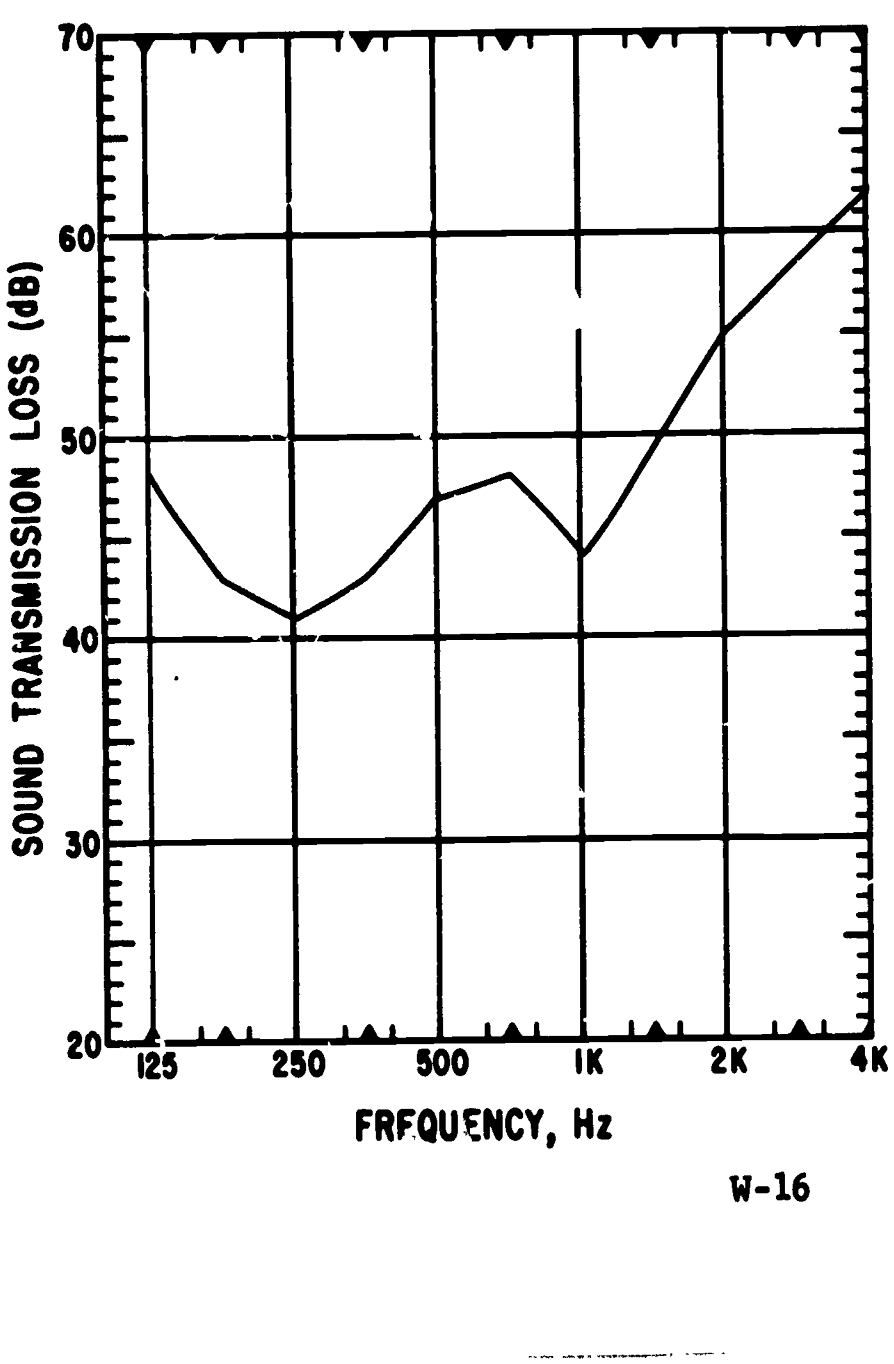
DESCRIPTION: 3- by 12- by 30-in. hollow gypsum blocks with 1/2-in. mortar joints. On one side 7/16-in. sanded gypsum plaster; on the other side resilient clips, attached with 2-in. staples placed 24 in. on centers horizontally and 28 1/4 in. on centers vertically, held 3/4-in. horizontal metal channels wire-tied 28 1/4 in. on centers to clips, 1/2-in. "V" edge long-length gypsum lath wire-tied to channels, and 11/16-in. sanded gypsum plaster; 1/16-in. white-coat finish applied to both sides.

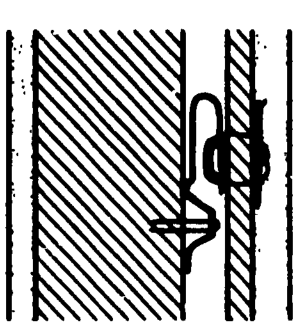
Total thickness: approximately 5 1/2 in.

Area weight: 27 lb/ft^2

REMARKS: The STC value is based upon nine test frequencies.

STC = 45; Fire Rating: 3 hrs.





TYPE: HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES

TEST REF: (a) 3-(316); (b) 3-(319)

DESCRIPTION: (a) 3- by 12- by 30-in. hollow gypsum blocks with 1/2-in. mortar joints. On one side 7/16-in. sanded gypsum plaster; on the other side, slotted resilient metal furring runners placed 25 in. on centers, nailed to mortar joints 12 in. on centers, 1/2-in. long-length gypsum lath wire-tied to the runners, and 11/16 in. of sanded gypsum plaster; 1/16-in. white-coat finish applied to both sides.

Total thickness: 5 1/4 in.

Area weight: 26 lb/ft^2

(b) Similar to (a), except 4- by 12- by 30-in. gypsum blocks were used.

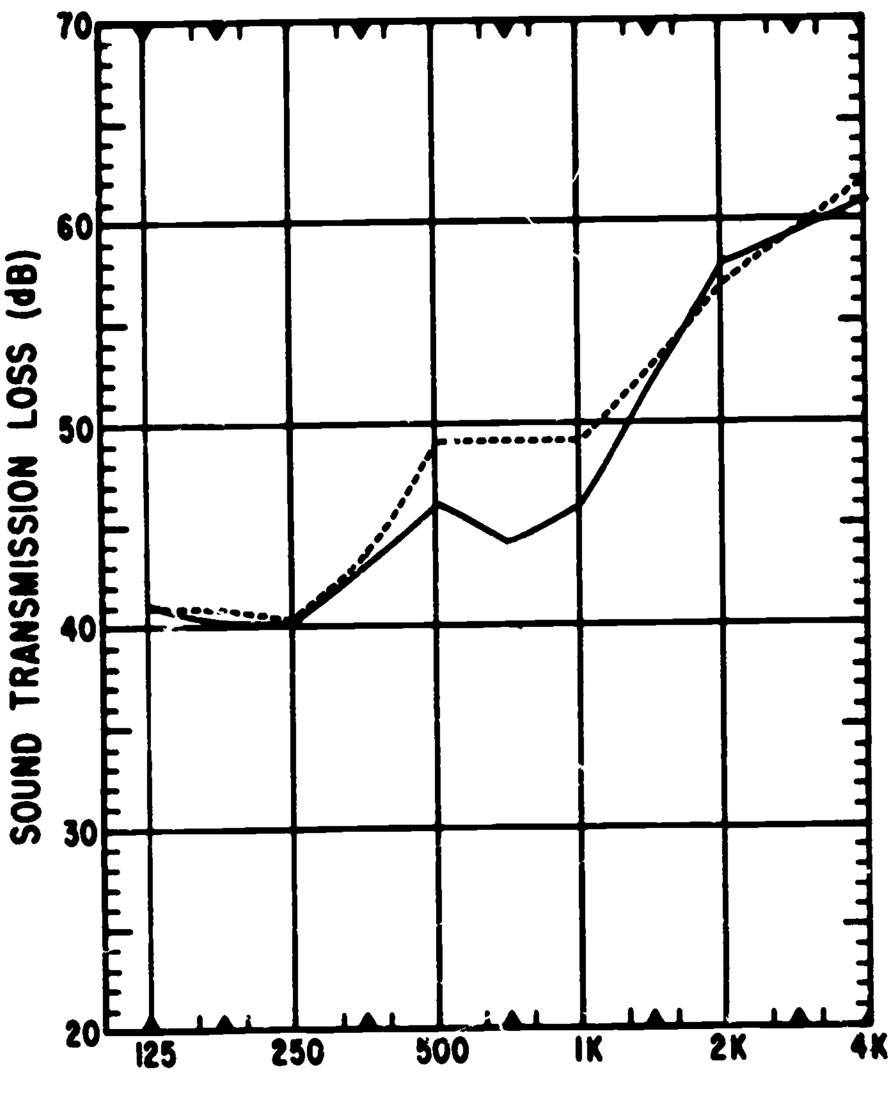
Total thickness: 6 1/4 in.

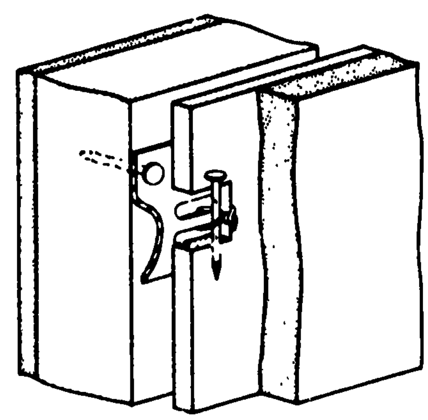
Area weight: 26 lb/ft^2

REMARKS: The STC values are based upon nine test frequencies.

(a) ———— STC = 47; Fire Rating: 3 hrs.

(b) ------------ STC = 49; Fire Rating: 4 hrs.





TYPE: HOLLOW GYPSUM BLOCK, RESILIENT ONE SIDE, PLASTER BOTH SIDES

TEST REF: (a) 7-(TL 60-127); (b) 3-(314); (c) 5-(Fig. 6)

DESCRIPTION: (a) 3- by 12- by 30-in. hollow gypsum blocks with 1/2-in. mortar joints. On one side, 3/8-in. gypsum lath attached with resilient clips stapled 16 in. on centers to blocks, 1/2-in. sanded gypsum plaster with white-coat finish; on the other side, 5/8-in. sanded gypsum plaster with white-coat finish.

Total thickness: approximately 5 1/4 in.

Area weight: 21.7 lb/ft^2

(b) Similar to (a) except plaster on non-resilient side was 1/2 in. thick.

Total thickness: approximately 5 1/8 in.

Area weight: 24 lb/ft^2

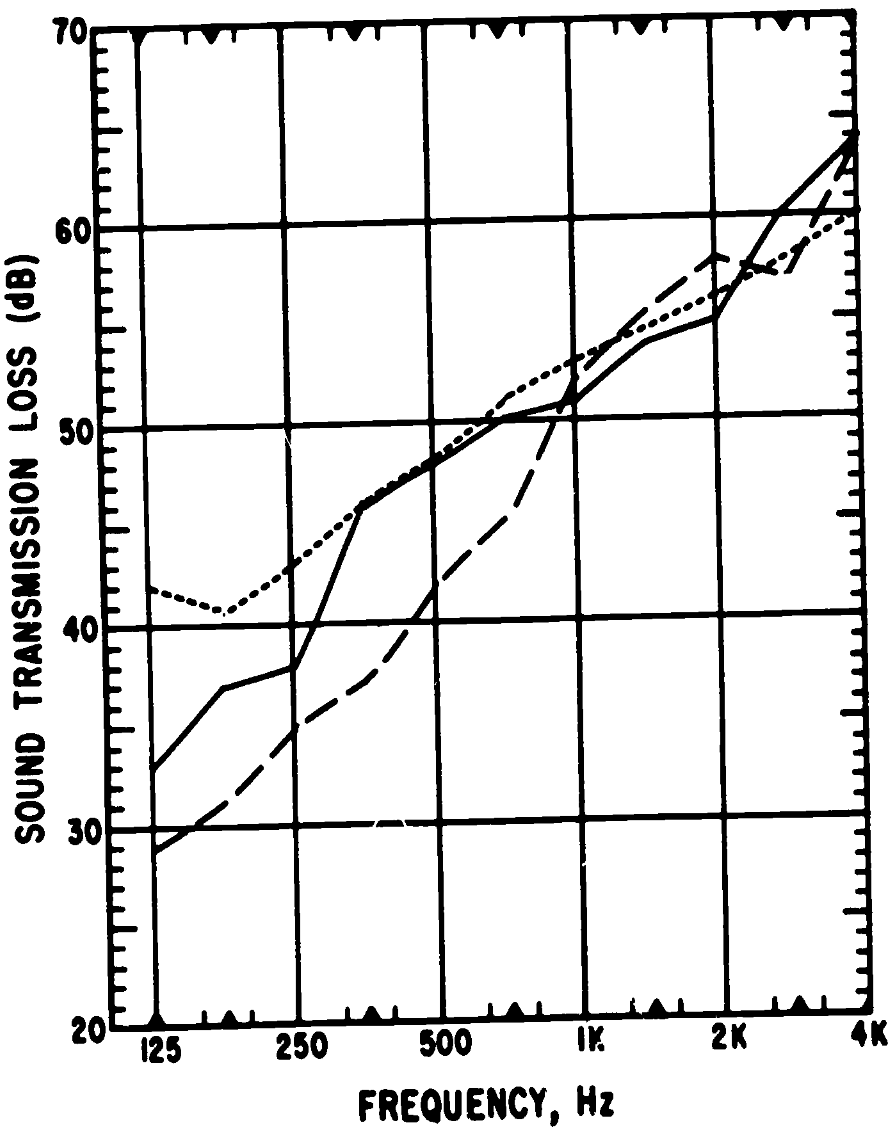
(c) Similar to (b) except measurements were conducted in the field.

Total thickness: approximately 5 1/8 in.

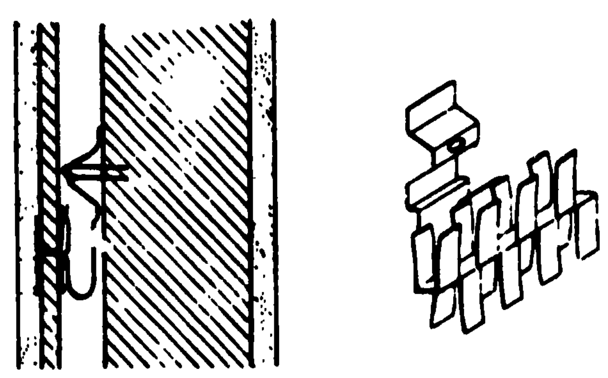
Area weight: approximately 24 lb/ft^2 (Not specified in reference)

REMARKS: The STC value of panel (b) is based upon nine test frequencies.

(a) ———— STC = 51 (b) .... STC = 52 (c) — — — — STC = 43



Fire Rating: 3 hrs.



TYPE: HOLLOW GYPSUM BLOCK, GYPSUM LATH AND RESILIENT CLIPS ONE SIDE

TEST REF: 9-(8-1090072e)

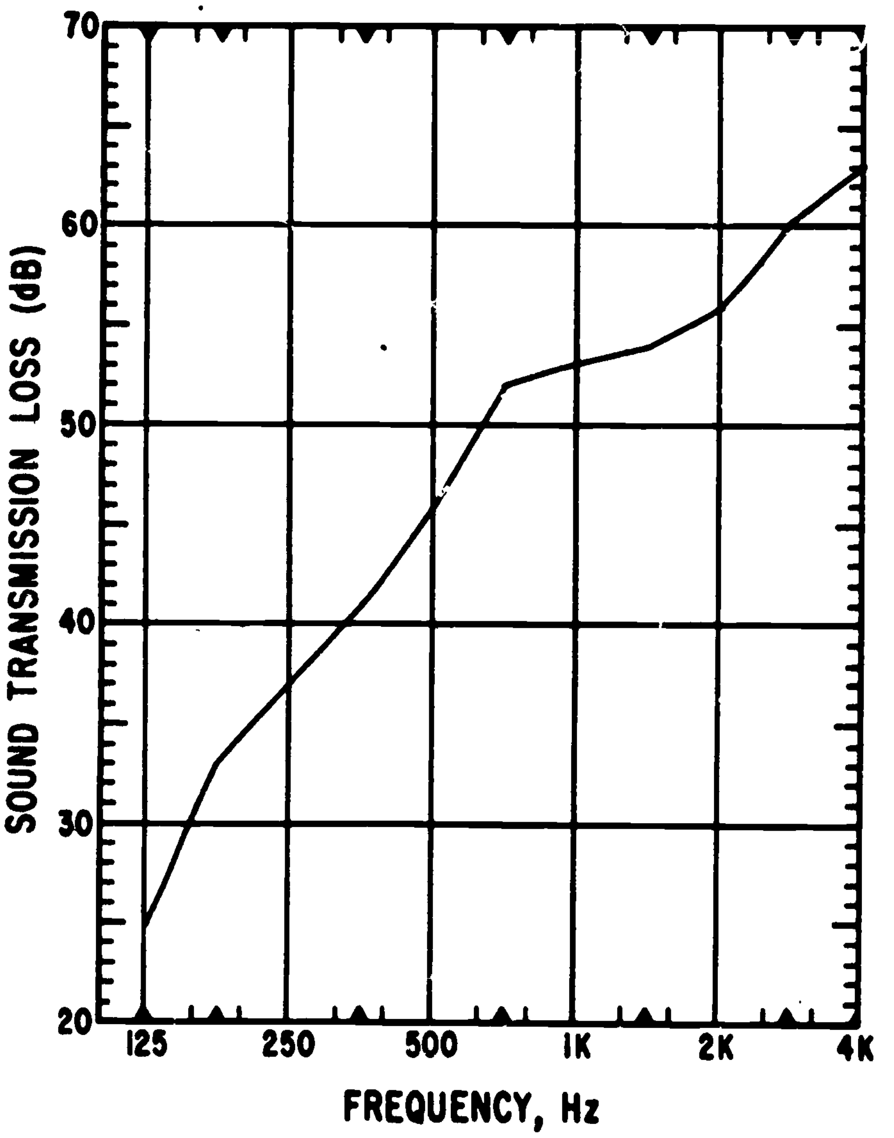
DESCRIPTION: 4- by 12- by 30-in. hollow gypsum blocks isolated around perimeter with 1/2-in.-thick continuous resilient gaskets. On one side, 3/8-in. gypsum lath attached with resilient clips 16 in. on centers, 1/2-in. sanded gypsum plaster with white-coat finish applied to lath; on the other side, 5/8-in. sanded gypsum plaster with white-coat finish applied directly to gypsum blocks. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound.

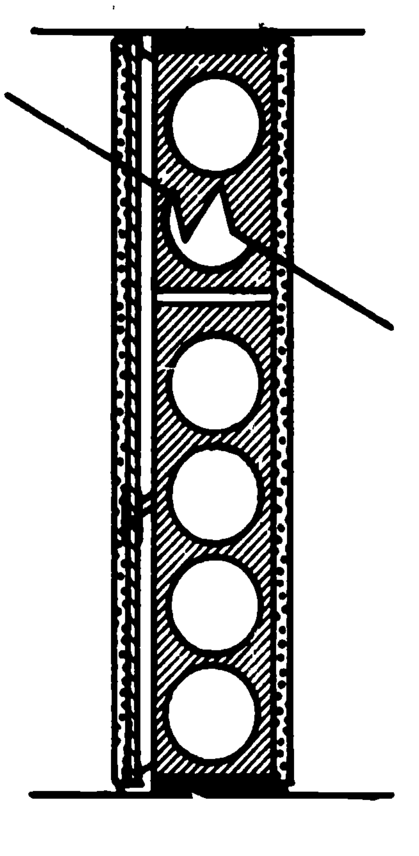
Total thickness: 6 in.

Area weight: 24.1 lb/ft^2

STC = 47; Fire Rating: 4 hrs.

REMARKS: The above test was conducted in the field. One adjoining wall was plastered masonry and the other was a stud wall with 1/2-in. gypsum lath and 1/16-in. plaster finish coat.





TYPE: HOLLOW GYPSUM BLOCK, FURRING STRIPS AND RESILIENT CLIPS ONE SIDE

TEST REF: 9-(8-1090072f)

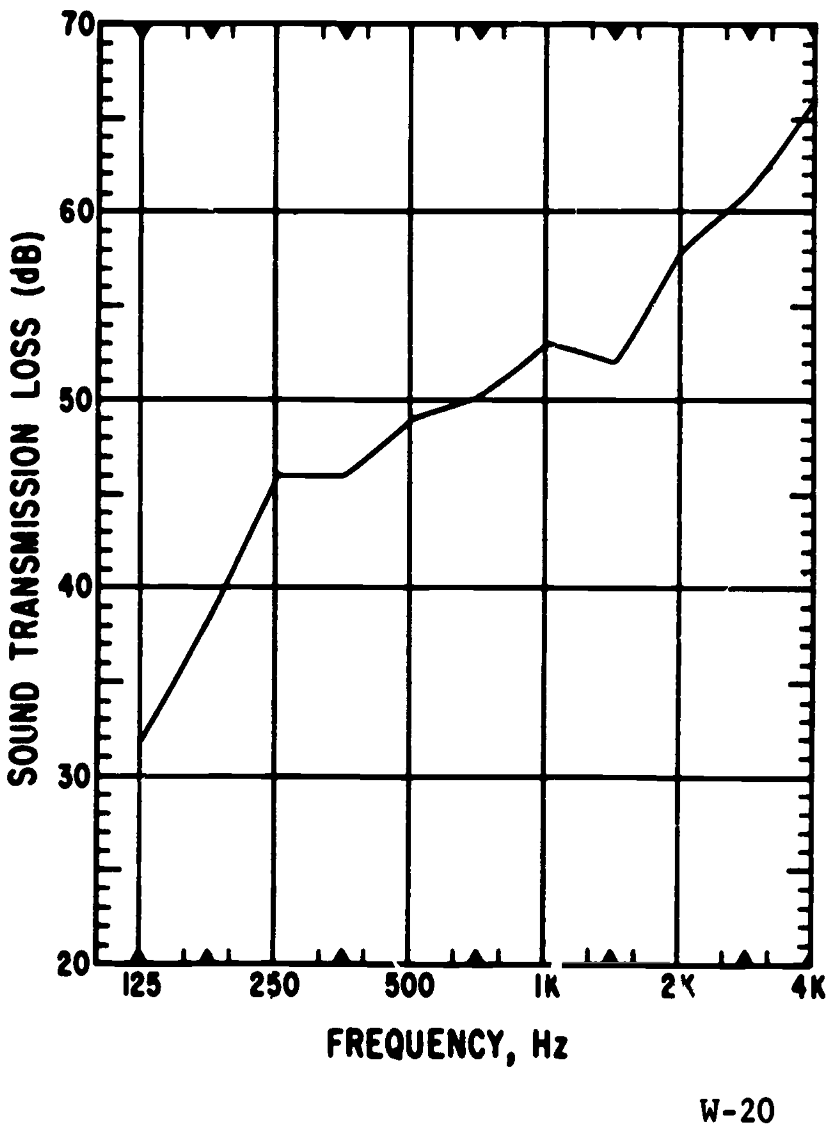
DESCRIPTION: 3- by 12- by 30-in. hollow gypsum blocks isolated around perimeter with 1/2-in.-thick continuous resilient gaskets. On one side, 2- by 2-in. wooden furring strips wire-tied horizontally 16 in. on centers to gypsum blocks. 1 1/2-in.-thick mineral fiber blankets stapled between furring strips. 3/8-in. plain gypsum lath held by resilient clips nailed to the furring strips; 1/2-in. sanded gypsum plaster with white-coat finish applied to lath. On other side, 5/8-in. sanded gypsum plaster with white-coat finish applied directly to gypsum blocks. The 1/4-in. clearance around perimeter closed with a non-setting resilient caulking compound.

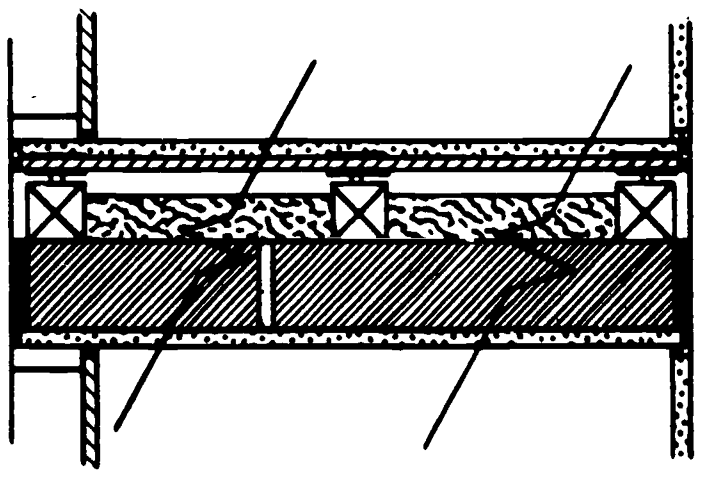
Total thickness: 7 in.

Area weight: 22.9 lb/ft^2

STC = 52; Fire Rating: 3 hrs. (est.)

REMARKS: This test was conducted in the field. One adjoining wall was plastered masonry and the other was a stud wall with 1/2-in. gypsum lath and 1/16-in. plaster finish coat.





TYPE: HOLLOW CONCRETE

TEST REF: 1-(S280)

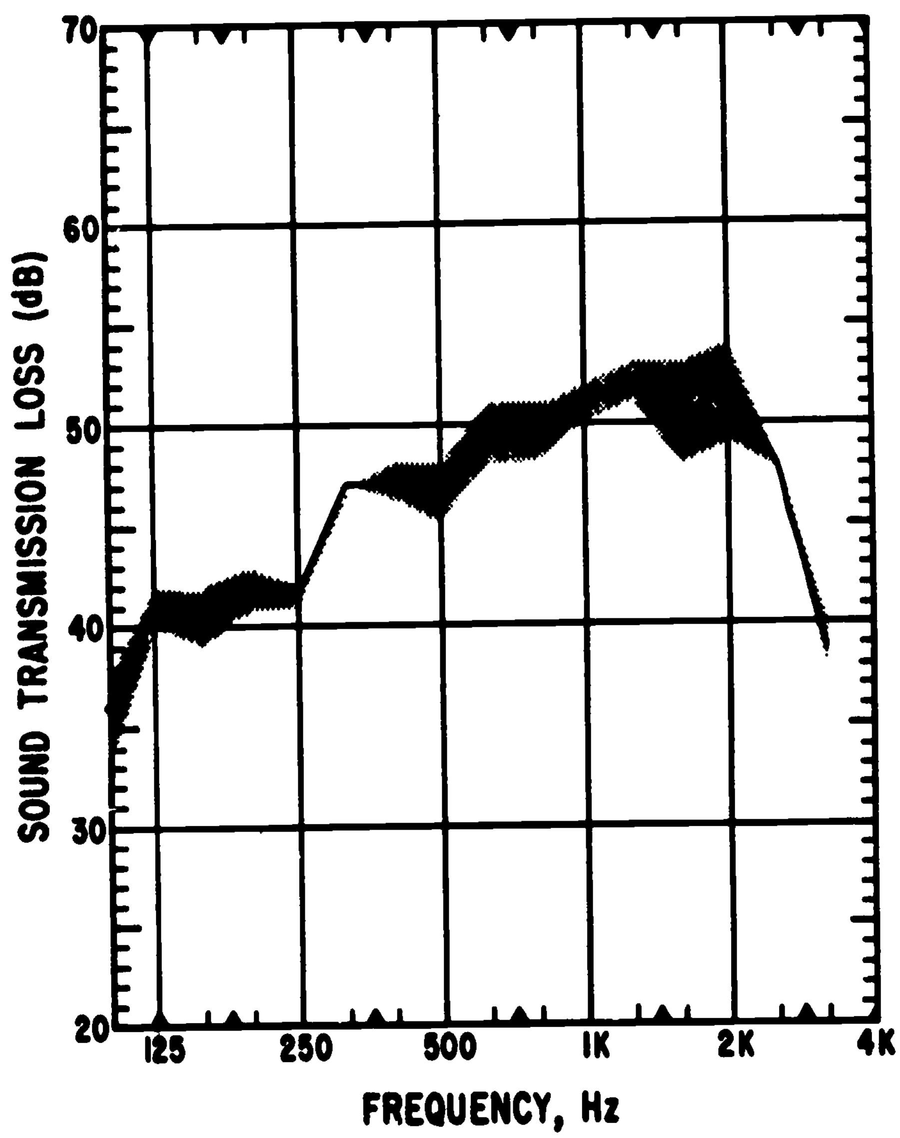
DESCRIPTION: Precast concrete hollow wall panels with in situ concrete posts and beams. The panels have 1 1/2-in.-thick concrete shells with a 6 1/4-in. airspace between them. A 1/2-in.-thick layer of fiberboard is adhered to the exposed surfaces of the panel.

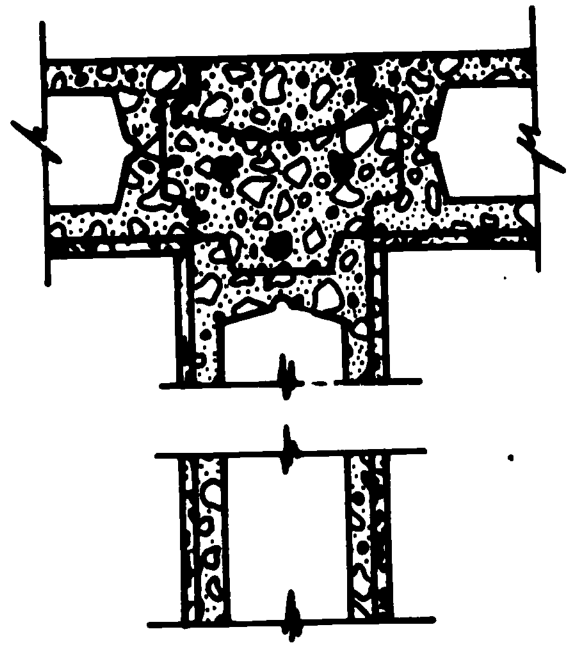
Total thickness: approximately 10 1/4 in.

Area weight: 37 lb/ft^2

REMARKS: The plotted curve is the average of results of field measurements of two nominally identical structures. The shaded area indicates the spread of the measurements.

STC = 43; Fire Rating: Not available





TYPE: DOUBLE BRICK WALL - 2-in. CAVITY

TEST REF: (a) 1-(S219, S220); (b) 1-(S221)

DESCRIPTION: (a) Double wall with 4 1/2-in.-thick brick leaves separated by a 2-in. cavity (wire ties between leaves); 1/2-in. plaster on exposed sides.

(b) Similar to (a), without wire ties between the leaves.

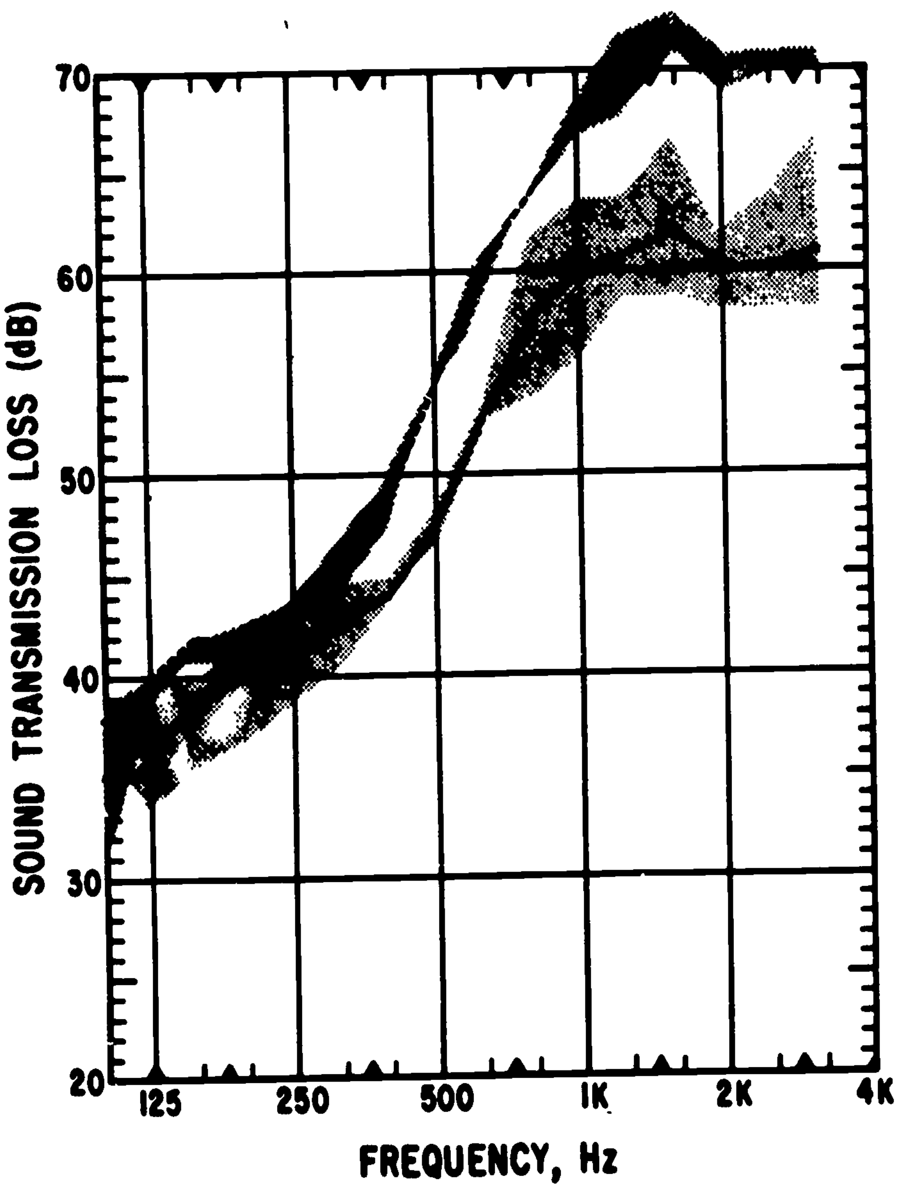
Total thickness: 12 in.

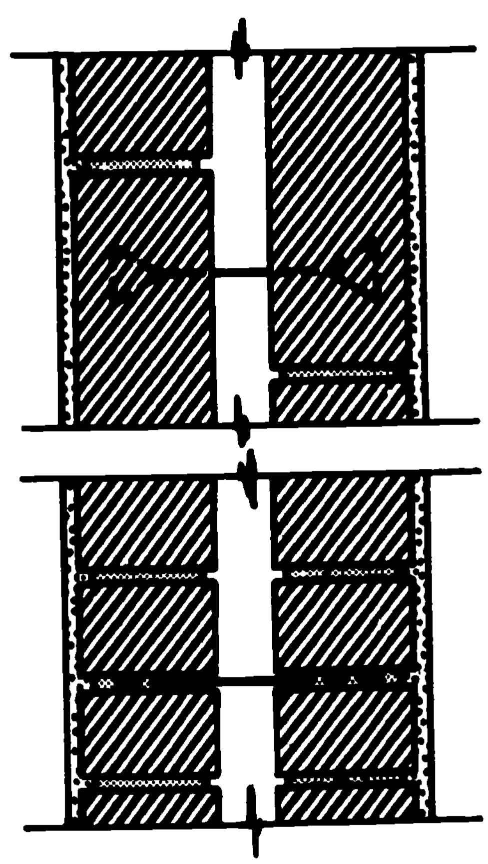
Area weight: 100 lb/ft^2

REMARKS: The plotted curves are the average values of field measurements of three nominally identical structures of type (a) and two structures of type (b). The shaded areas indicate the spread of the measurements.

(a) STC = 49; Fire rating: over 4 hrs.

(b) STC = 54





TYPE: DOUBLE BRICK WALL - 6-in. CAVITY

TEST REF: 1-(S287)

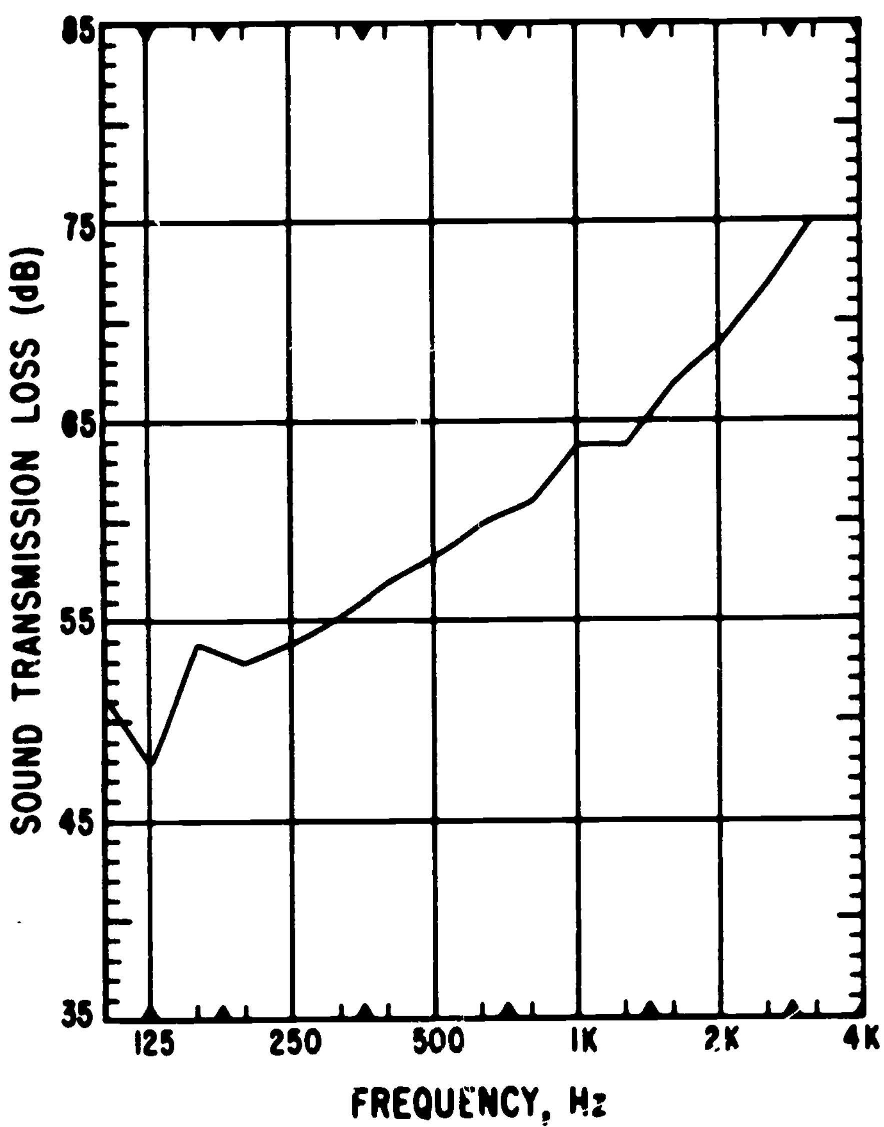
DESCRIPTION: Double wall with 4 1/2-in.-thick brick leaves, 6-in. cavity (no ties); on exposed sides, 1/2-in. plaster on 1-in.-thick wood-wool slabs mortared to the brick walls.

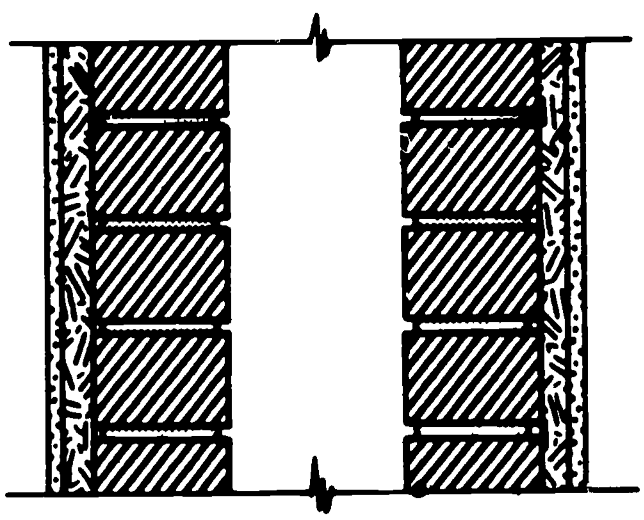
Total thickness: 18 in.

Area weight: 120 lb/ft^2

REMARKS: The plotted curve is the result of field measurements on one structure.

STC = 62; Fire Rating: over 4 hrs.





TYPE: DOUBLE CLAY BLOCK WALL - 2 1/2-in. CAVITY

TEST REF: 1-(S273)

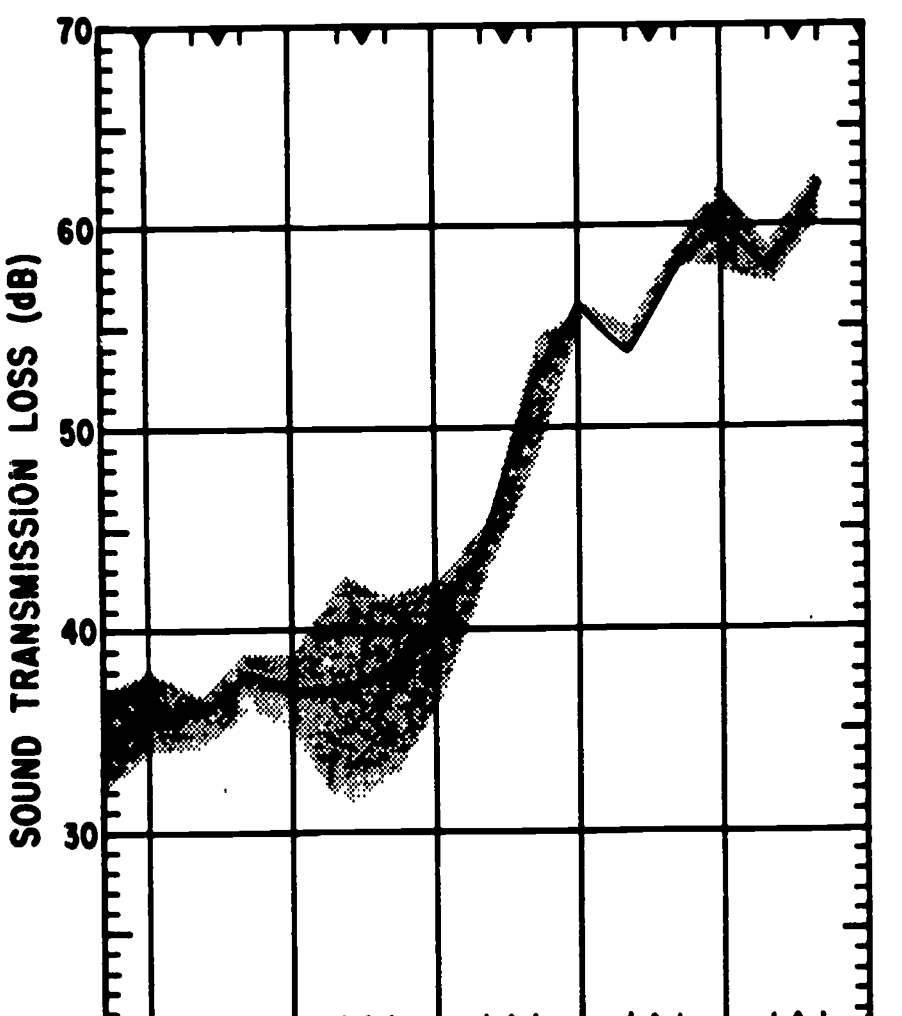
DESCRIPTION: Double wall: 4 1/4-in.-thick hollow clay block leaves, 2 1/2-in. cavity, (wire ties between leaves); 1/2-in. plaster on each side.

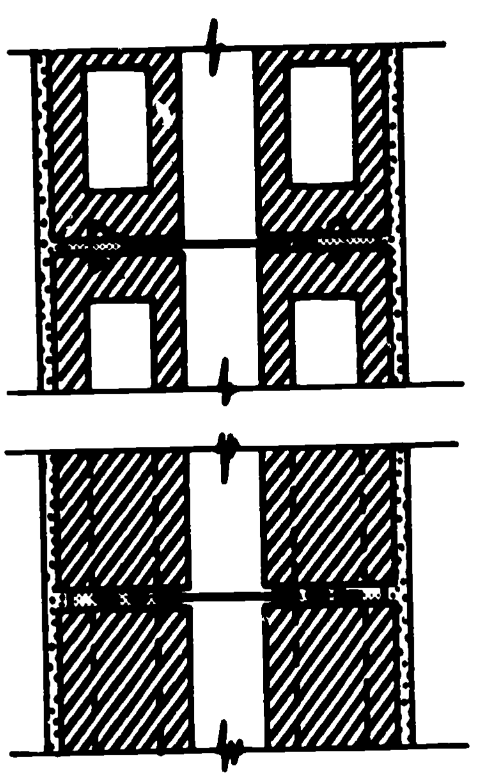
Total thickness: 12 in.

Area weight: 50 lb/ft^2

REMARKS: The plotted curve is average of the results of field measurements of two nominally identical structures. The shaded area indicates the spread of the measurements.

STC = 43; Fire Rating: 3 hrs. (est.)





TYPE: DOUBLE CLINKER BLOCK WALL - 2-in. CAVITY

TEST REF: 1-(S245)

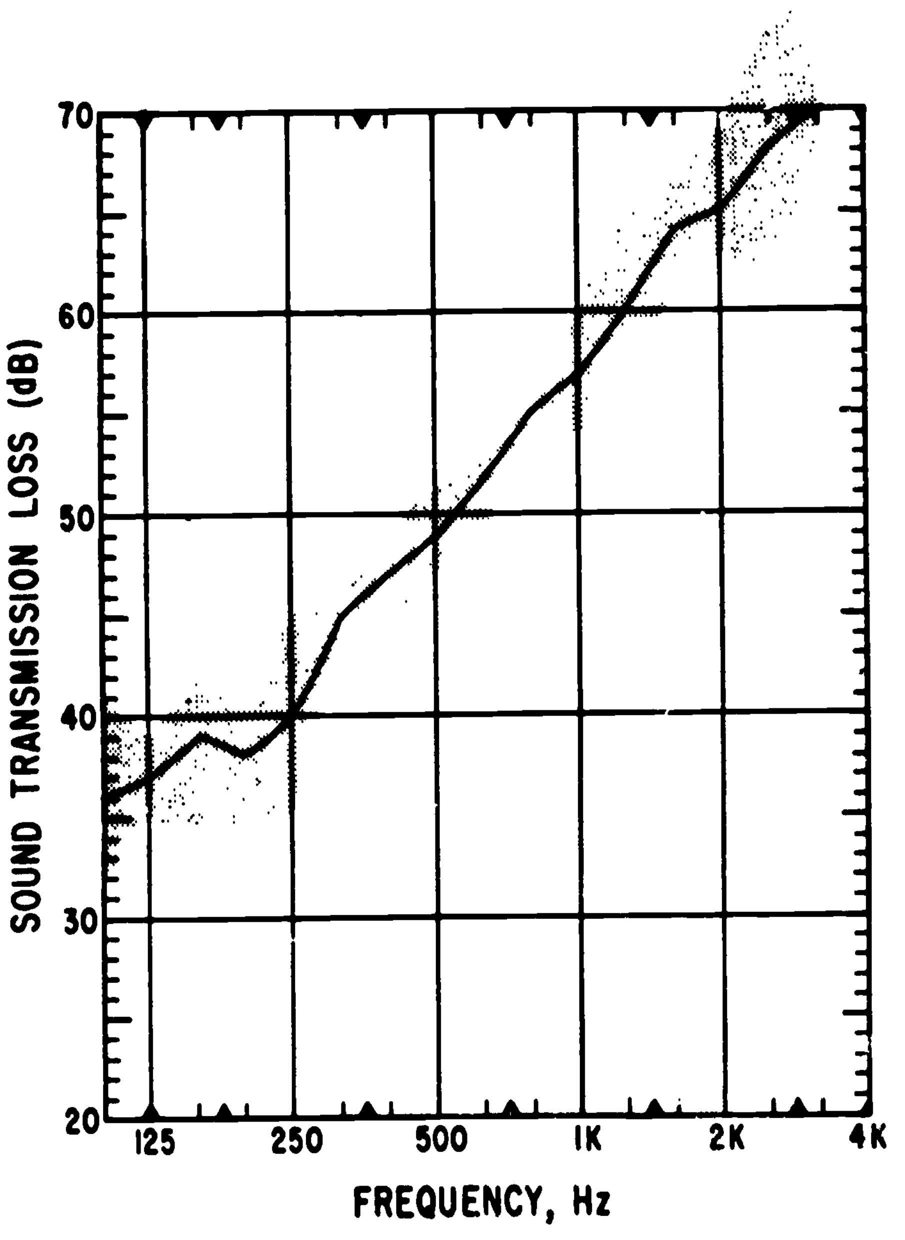
DESCRIPTION: Double wall with 4-in.-thick clinker block leaves, 2-in. cavity, (no ties between leaves) 1/2-in. plaster on exposed sides.

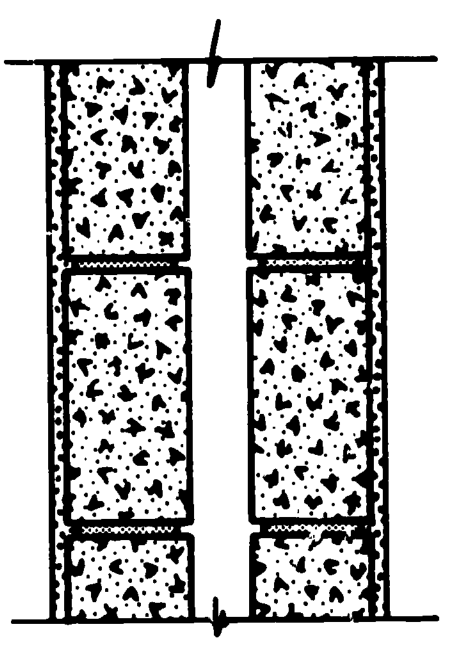
Total thickness: 11 in.

Area weight: 70 lb/ft^2

REMARKS: The plotted curve is the average result of field measurements of four nominally identical structures. The shaded area indicates the spread of the data.

STC = 52; Fire Rating: over 4 hrs.





TYPE: DOUBLE WALL - CONCRETE PANEL AND CLINKER BLOCK

TEST REF: 1-(S282)

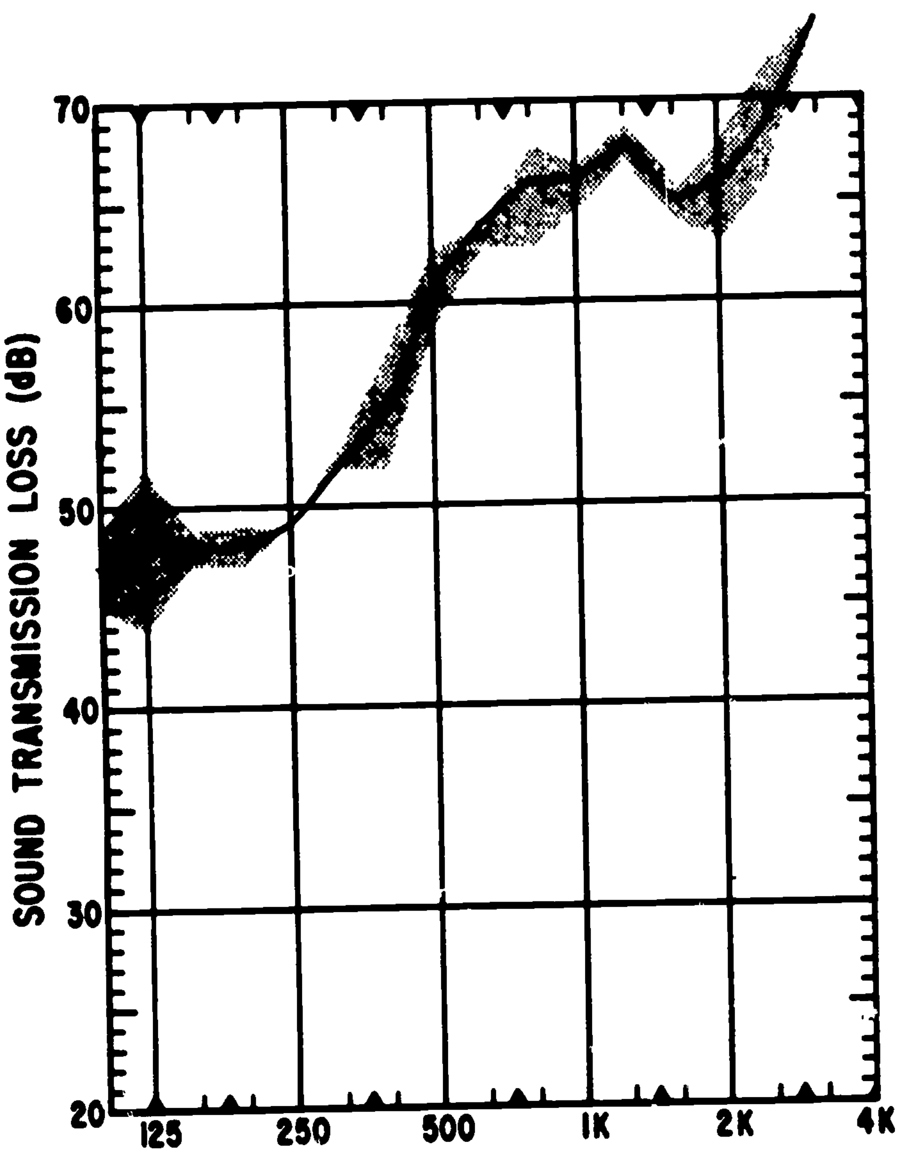
DESCRIPTION: Double wall consisting of approximately 2-in.-thick concrete panels mounted on 2- by 4-in. reinforced concrete posts spaced 18 in. on centers with inner leaves of 2-in.-thick clinker block; a 2-3-in. cavity between inner leaves. 1/2-in.-thick plaster coat on the exposed surfaces.

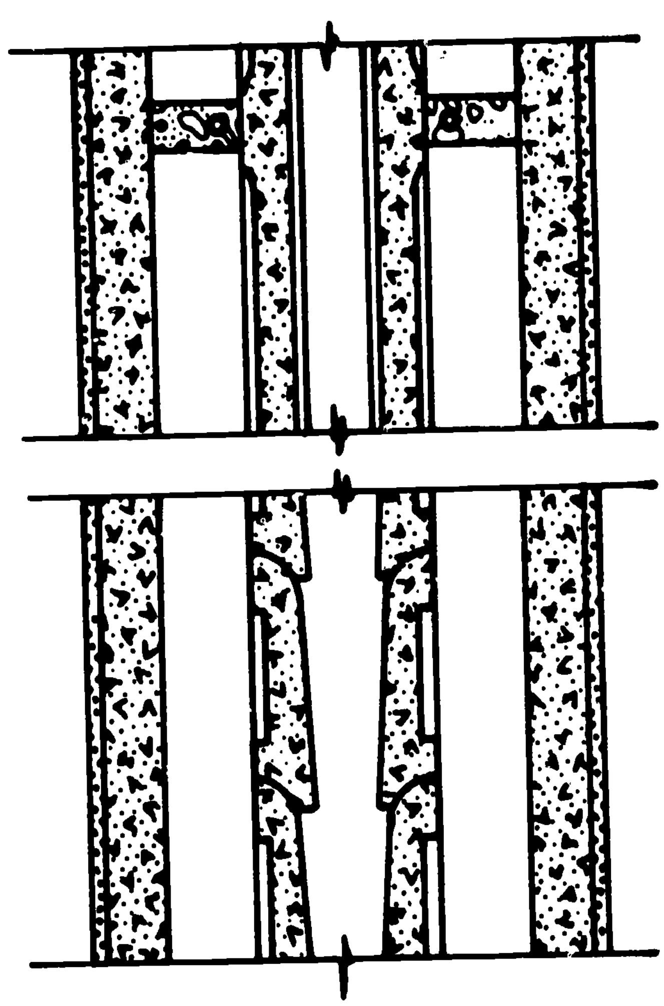
Total thickness: 19 in.

Area weight: 80 lb/ft^2

STC = 60; Fire Rating: over 2 hrs. (est.)

REMARKS: The plotted curve represents the average of field measurements of two nominally identical structures. The shaded area indicates the spread of the measurements.





TYPE: WOODEN STUD, GYPSUM WALLBOARD

TEST REF: 12-(Fig. 8.2); 2-(224, 234)

DESCRIPTION: 2- by 4-in. wooden studs 16 in. on centers; on each side 1/2-in. gypsum wallboard nailed to studs; all joints taped and finished.

Total thickness: approximately 5 in.

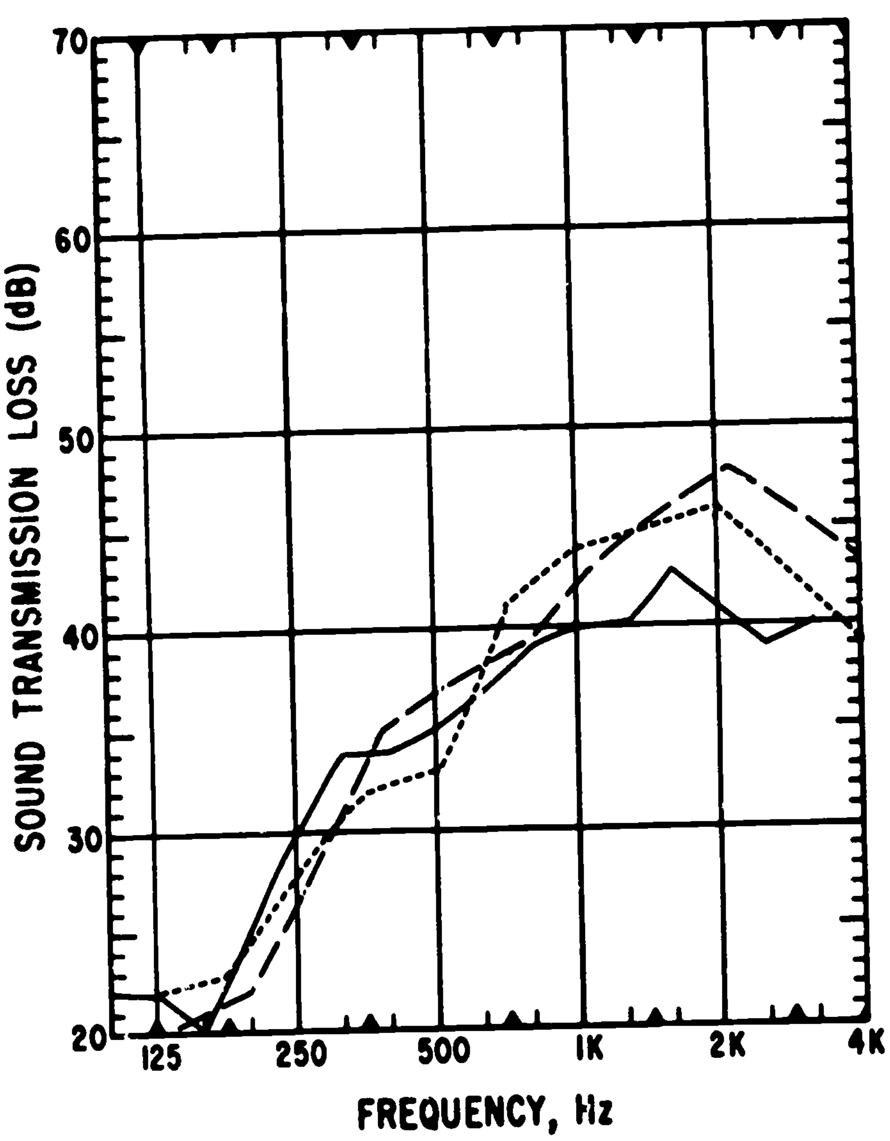
Area weight: approximately 6 lb/ft^2

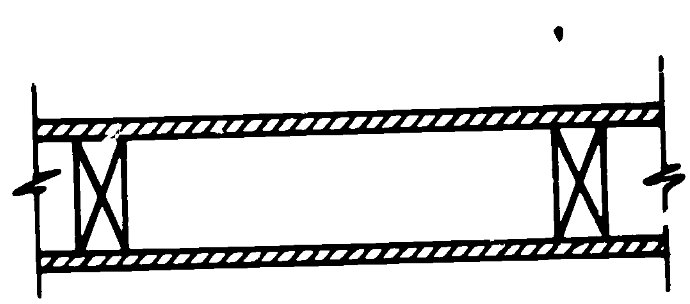
——————— STC = 39; Fire Rating: 1/2 hr. - combustible

– – – – – – STC = 38

.... STC = 37

REMARKS: The STC values for structures from reference No. 2 are based upon nine test frequencies.





TYPE: WOODEN STUD, GYPSUM BOARD WITH LEAD

TEST REF: (a) 12-(Fig. 8.2), 2-(224, 234); (b) 16-(Fig. 4); (c) 16-(Fig. 4)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers, 1/2-in. gypsum wallboard nailed to each side. All joints taped and finished.

Total thickness: 5 in.

Area weight: approximately 6 lb/ft^2

(b) Similar to (a) except a layer of lead, 2.95 lb/ft^2, was laminated to each side of panel.

(c) Similar to (a) except a layer of lead, 6.74 lb/ft^2, was laminated to one side of panel.

Total thickness: approximately 5 1/8 in.

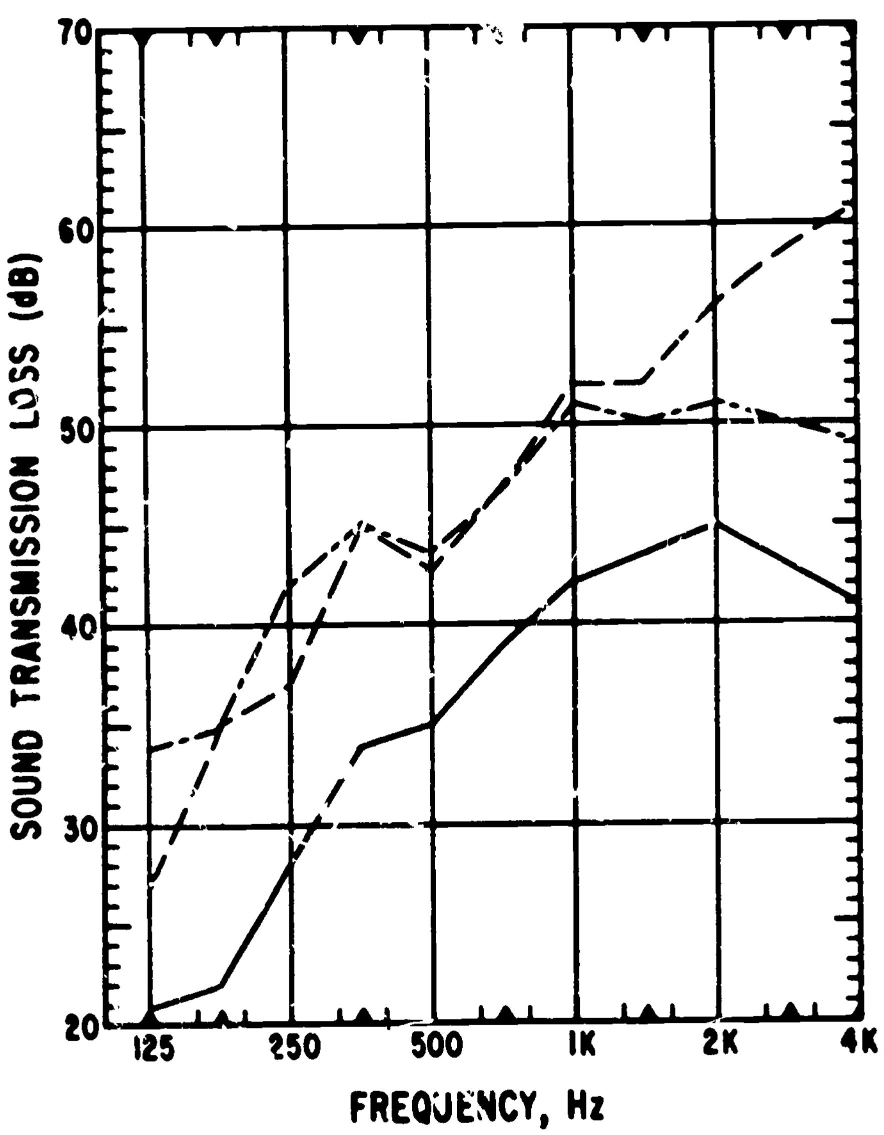
Area weight: approximately 12.5 lb/ft^2

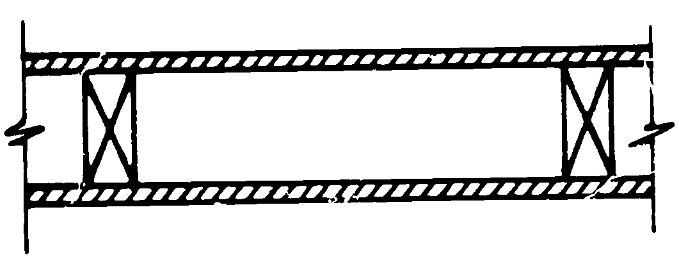
(a)———————STC = 39; Fire Rating: 1/2 hr. - combustible

(b)— — — — — -STC = 47; Fire Rating: 1/2 hr. - combustible

(c)--—-—-—-—--STC = 48; Fire Rating: 1/2 hr. - combustible

REMARKS: The STC value for structure (a) is based upon STL levels at nine frequencies.





TYPE: WOODEN STUD, GYPSUM BOARD

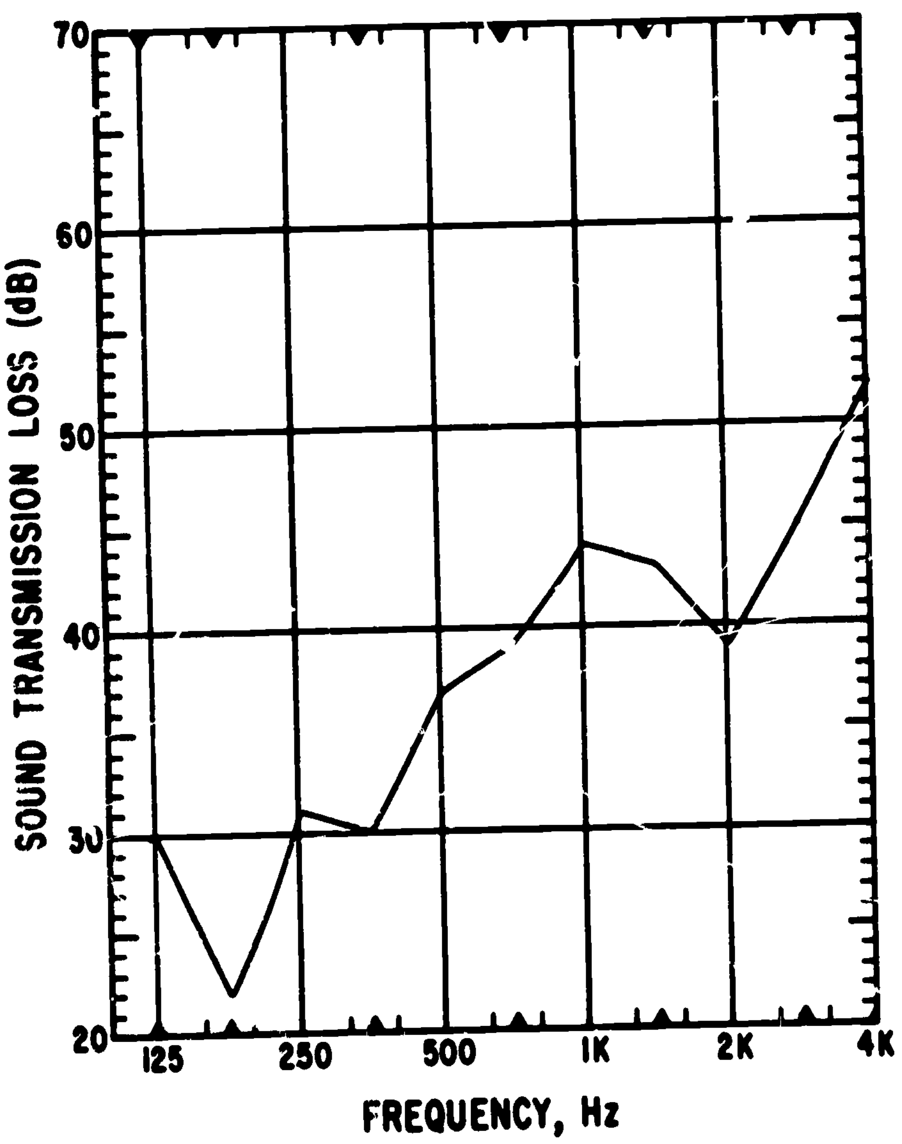
TEST REF: 3-(240)

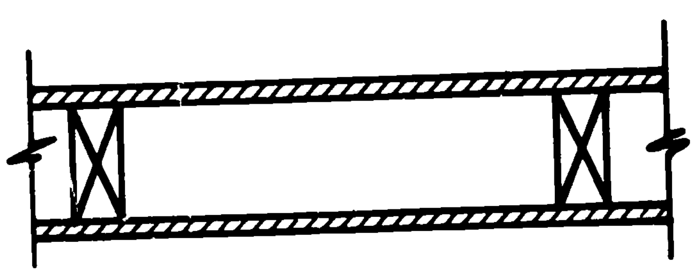
DESCRIPTION: 2- by 4-in. wooden studs 16 in. on centers attached to 2- by 4-in. wooden floor and ceiling plates, 5/8-in. tapered-edge gypsum wallboard nailed 7 in. on centers to both sides of studs. All joints taped and finished.

Total thickness: 5 1/4 in.

Area weight: 7.2 lb/ft^2

STC = 36; Fire Rating: 1 hr. - combustible





TYPE: WOODEN STUD, GYPSUM LATH AND PLASTER

TEST REF: (a) 2-(148, 149) 3-(251); (b) 3-(239)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers attached to 2- by 4-in. wooden floor and ceiling plates, 3/8-in. gypsum lath nailed to studs on both sides, 1/2-in. sanded plaster with white-coat finish.

Total thickness: 5 3/4 in.

Area weight: 13.4-15.7 lb/ft^2

(b) Similar to (a) except the gypsum lath was perforated.

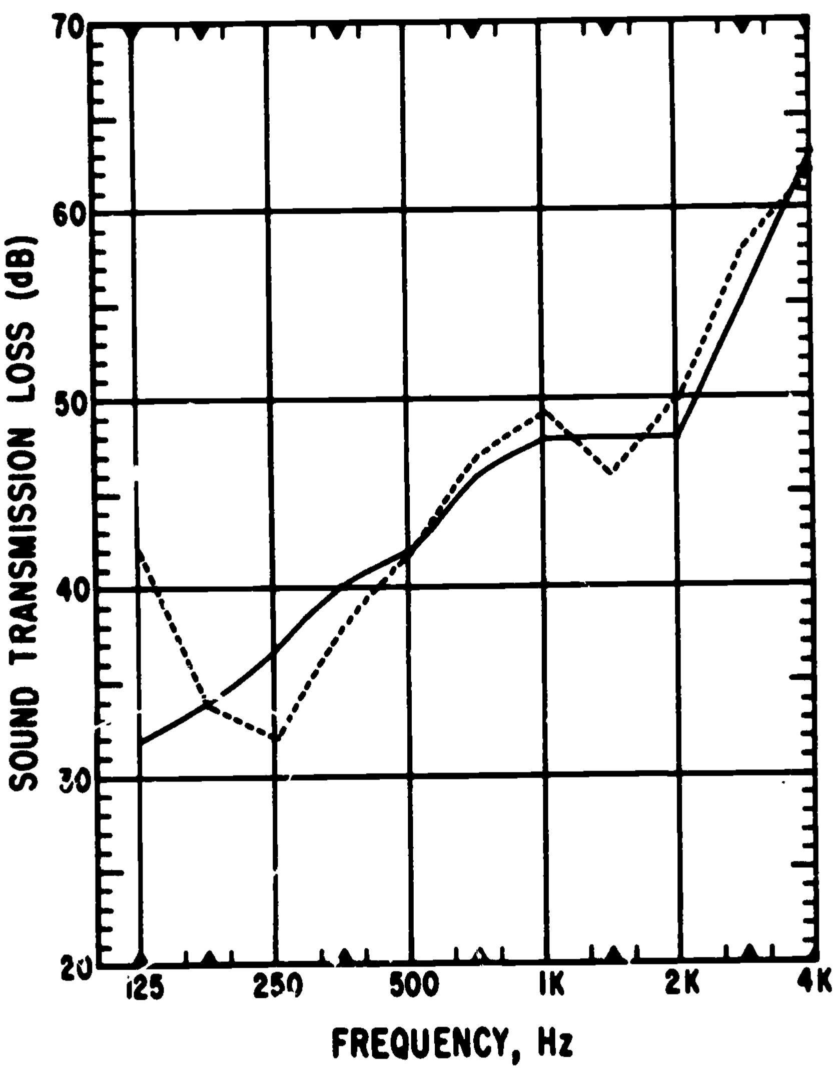
Total thickness: 5 3/4 in.

Area weight: 14.2 lb/ft^2

(a) ———— STC = 46; Fire Rating: 45 min. - combustible

(b) - - - - - - STC = 44; Fire Rating: 1 hr. - combustible

REMARKS: The plotted curve (a) is the average of tests of three nominally identical walls. The STC value of curve (a) is based upon nine test frequencies.



TYPE: WOODEN STUD, LATH AND PLASTER WITH LEAD

TEST REF: (a) 2-(148, 149), 3-(251); (b) 16-(Fig. 6); (c) 16-(Fig. 6)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers, 3/8-in. gypsum lath nailed to studs on both sides, 1/2-in. sanded plaster with white-coat finish.

Total thickness: 5 3/4 in.

Area weight: 13.4-15.7 lb/ft^2

(b) Similar to (a) except a 0.065-in.-thick layer of lead weighing 3.85 lb/ft^2 was laminated to each side of panel.

(c) Similar to (a) except a 0.13-in.-thick layer of lead weighing 7.9 lb/ft^2 was laminated to one side of panel.

Total thickness: approximately 5 7/8 in.

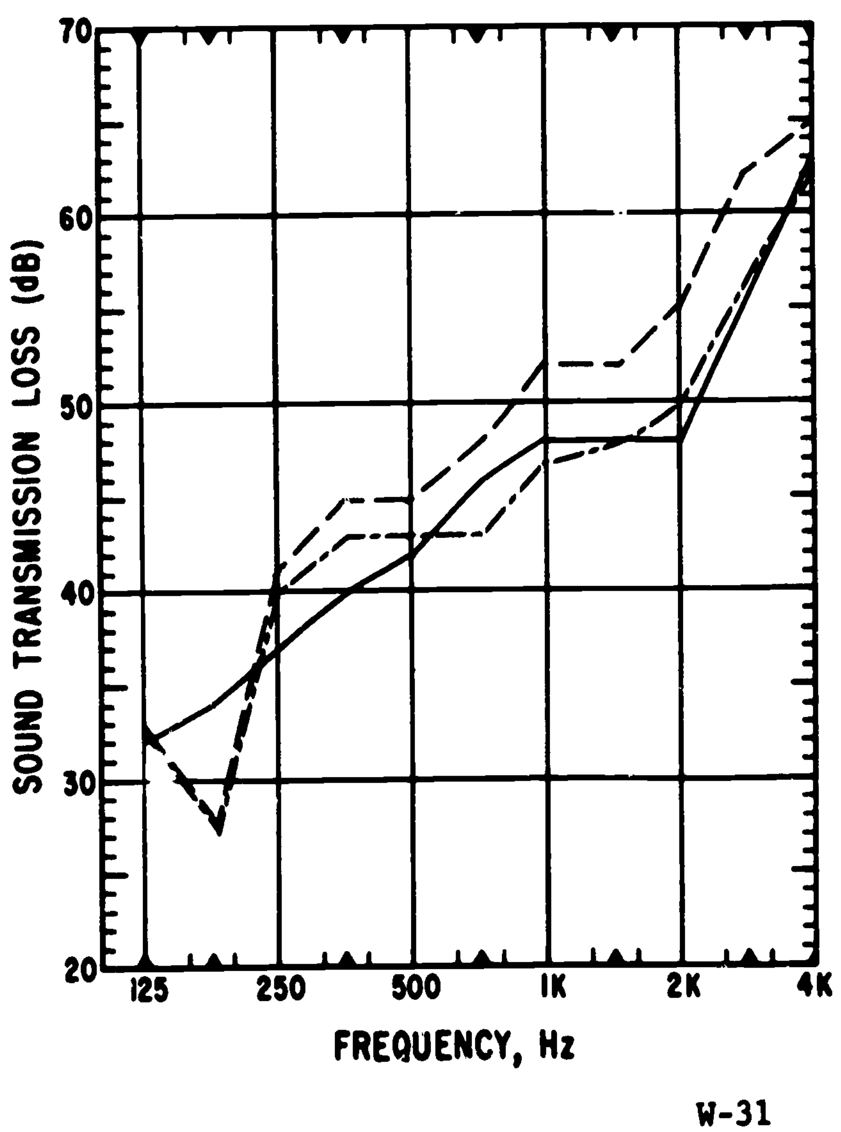
Area weight: 17-19 lb/ft^2

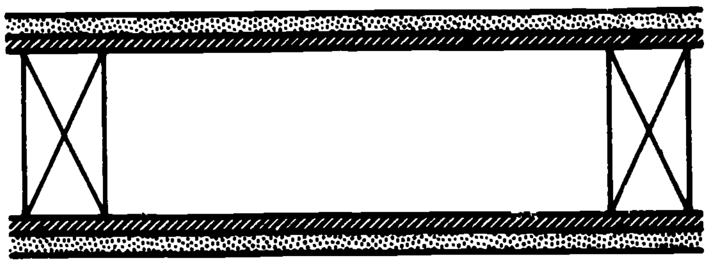
(a) ———— STC = 46; Fire Rating: 45 min. - combustible

(b) – – – – – STC = 47; Fire Rating: 45 min. - combustible

(c) –·–·–·– STC = 46; Fire Rating: 45 min. - combustible

REMARKS: The STC value of curve (a) is based upon nine test frequencies.





TYPE: WOODEN STUDS, GYPSUM WALLBOARD

TEST REF: (a) 2-(225); (b) 3-(241)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers; on each side two layers of 3/8-in. gypsum wallboard cemented together; joints in exposed surfaces taped and finished.

Total thickness: 5 1/2 in.

Area weight: 8.2 lb/ft^2

(b) Similar to (a), except that the gypsum wallboard was 5/8 in. thick, and the first layer was nailed 7 in. on centers and the second layer 14 in. on centers; joints in exposed surfaces taped and finished.

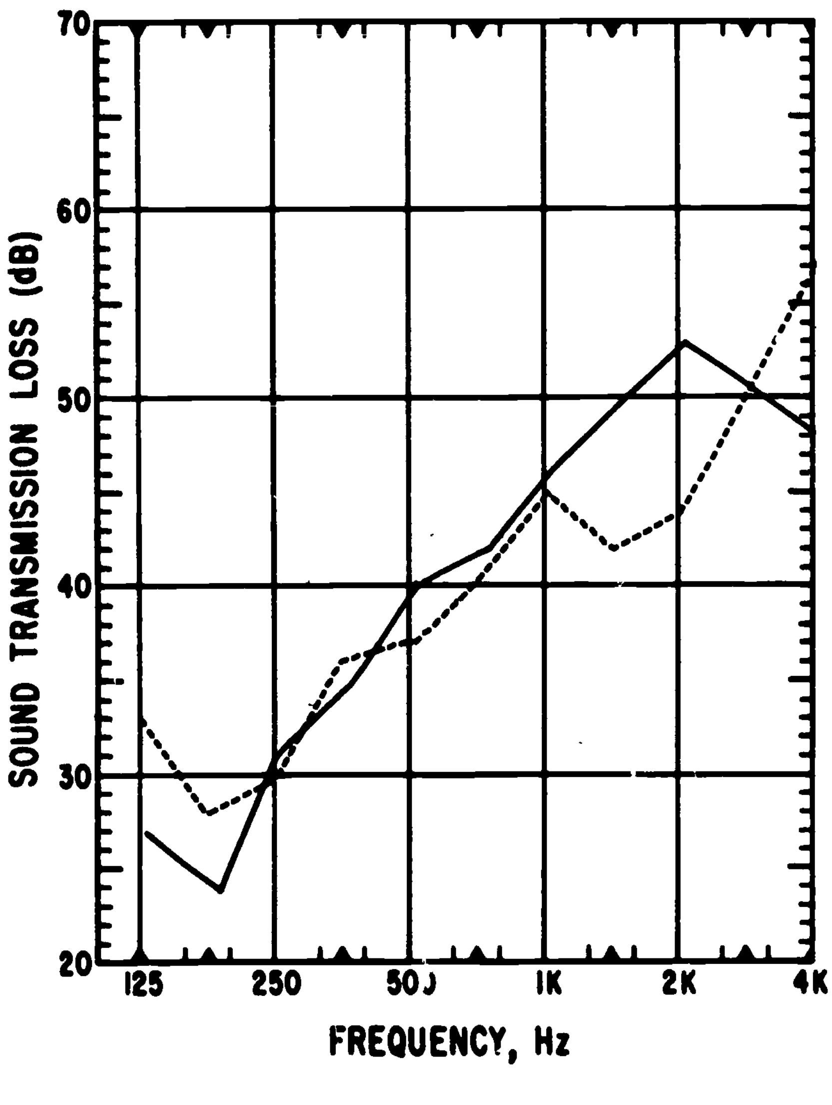
Total thickness: 6 1/2 in.

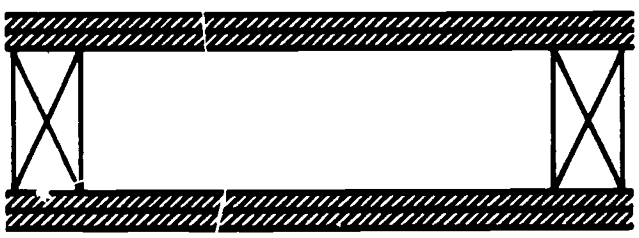
Area weight: 12.9 lb/ft^2

(a)———————STC = 40; Fire Rating: 1 hr. - combustible

(b)--------------STC = 41; Fire Rating: 1 1/2 hrs. (est.) - combustible

REMARKS: The STC value of curve (a) is based upon nine test frequencies.





TYPE: WOODEN STUD, FIBER BOARD, PLASTER

TEST REF: 2-(205)

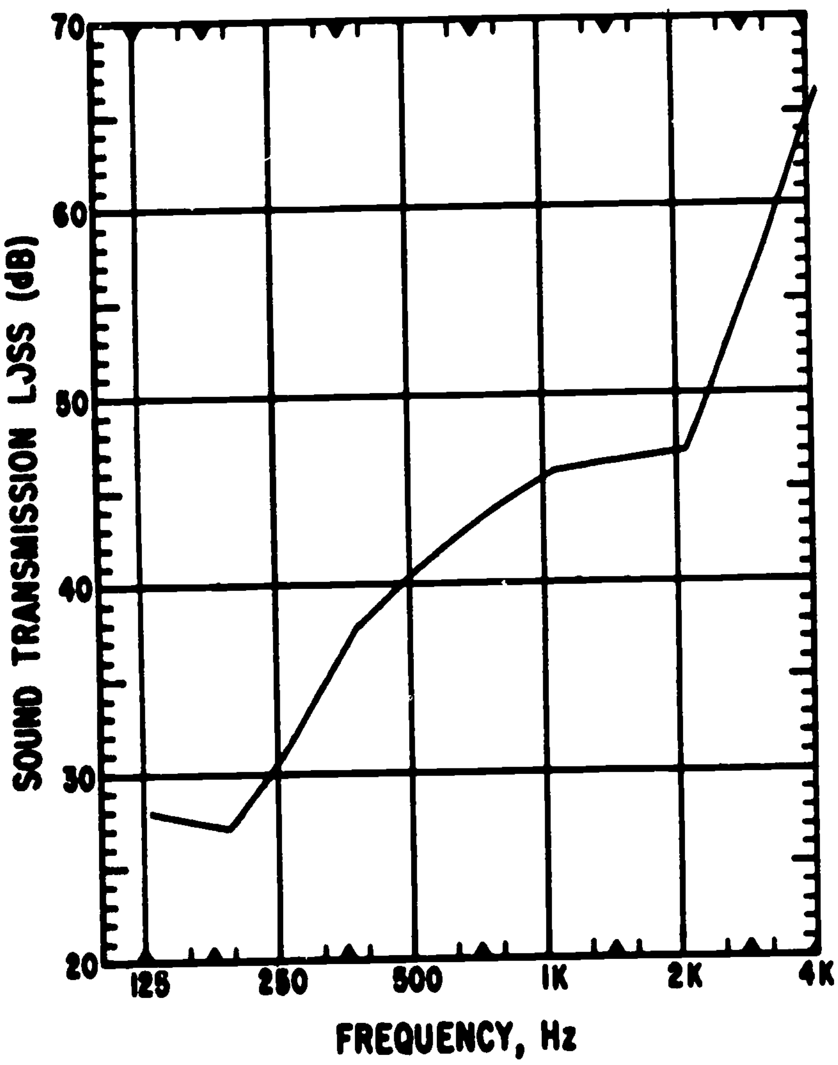
DESCRIPTION: 2- by 4-in. wooden studs 16 in. on centers, 1/2-in. wood fiber board nailed 3 in. on centers along edges of fiber board to studs, 1/2-in. sanded gypsum plaster on both sides.

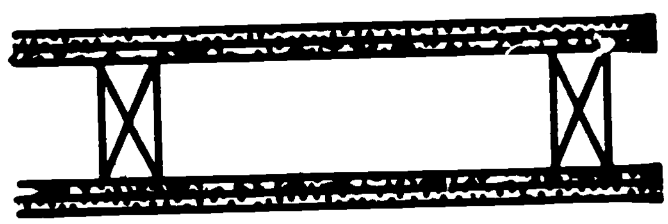
Total thickness: 6 in.

Area weight: 12.6 lb/ft^2

STC = 42; Fire Rating: 1/2 hr. - combustible

REMARKS: The STC is based upon nine test frequencies.





TYPE: STAGGERED WOODEN STUD, GYPSUM BOARD

TEST REF: (a) 3-(242); (b) 3-(243)

DESCRIPTION: (a) 2- by 3-in. wooden studs 16 in. on centers, staggered 8 in. on centers, attached to 2- by 4-in. wooden plates at ceiling and floor; 1/2-in. gypsum wallboard nailed 7 in. on centers on both sides to studs. All joints taped and finished.

Total thickness: 5 in.

Area weight: 6.2 lb/ft^2

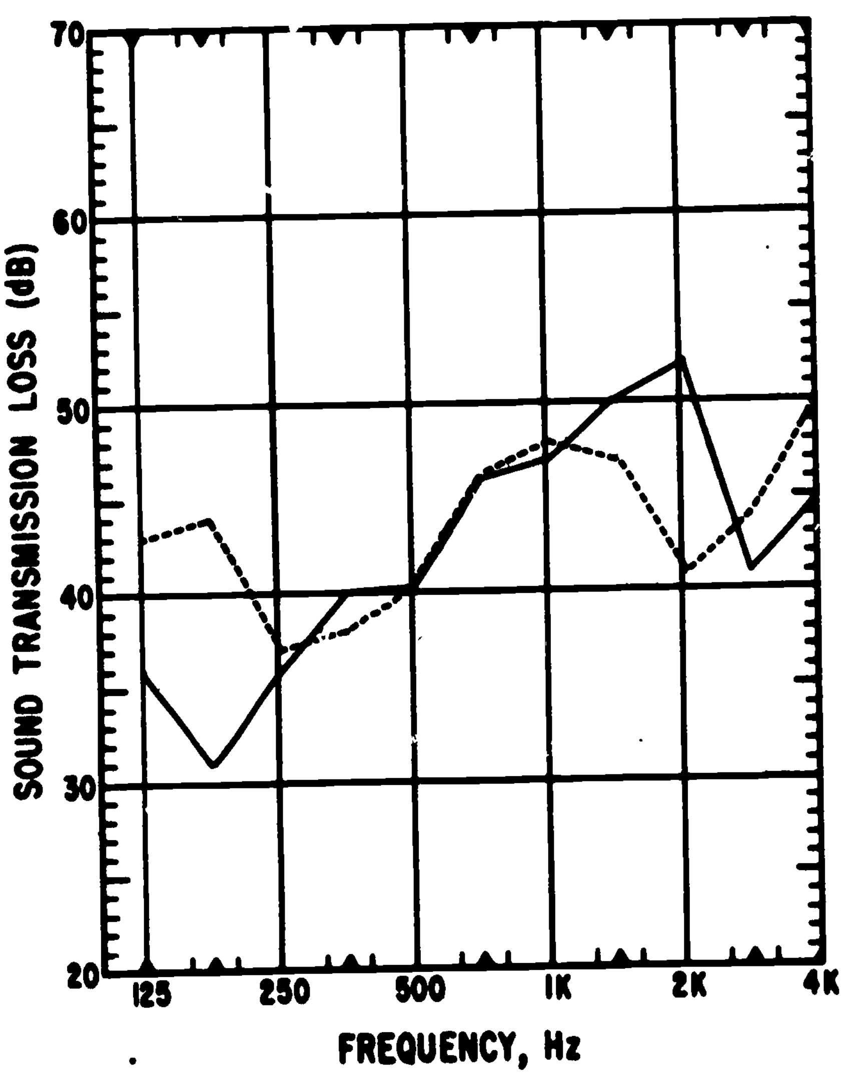
(b) Similar to (a) except the gypsum wallboard was 5/8 in. thick.

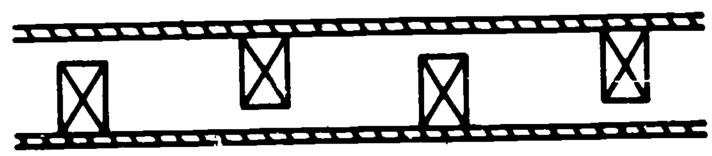
Total thickness: 5 1/4 in.

Area weight: 7.7 lb/ft^2

(a) ———— STC = 44; Fire Rating: 1/2 hr. (est.) - combustible

(b) ------------ STC = 44; Fire Rating: 45 min. (est.) - combustible





TYPE: STAGGERED WOODEN STUD, (a) GYPSUM BOARD (b) LATH AND PLASTER

TEST REF: (a) 3-(244); (b) 3-(245)

DESCRIPTION: (a) 2- by 3-in. wooden studs 16 in. on centers, staggered 8 in. on centers (attached to 2- by 4-in. wooden plates at floor and ceiling); two layers of 5/8-in. tapered-edge gypsum wallboard, first layer nailed 7 in. on centers, second layer nailed 16 in. on centers. All exposed joints taped and finished.

Total thickness: 6 1/2 in.

Area weight: 13.4 lb/ft^2

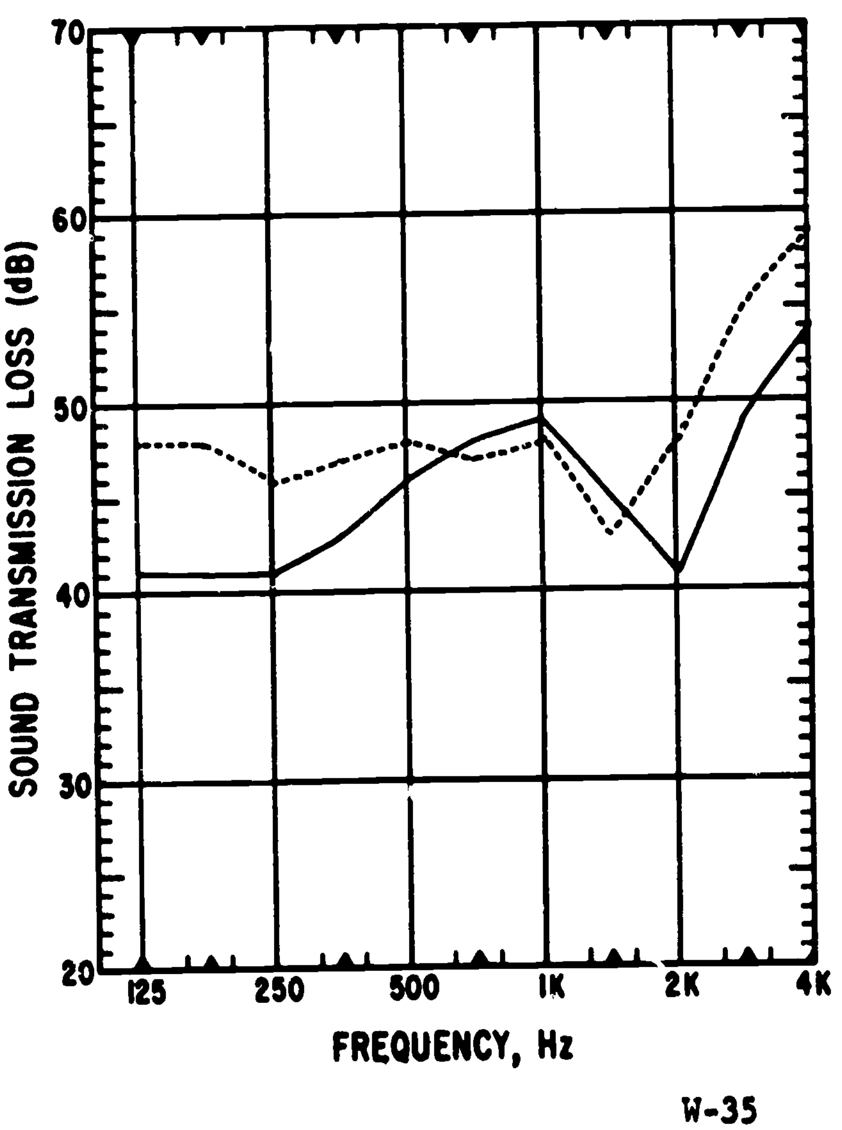
(b) Similar to (a) except the wall was constructed with 3/8-in. perforated gypsum lath and 1/2-in. sanded gypsum plaster with white-coat finish.

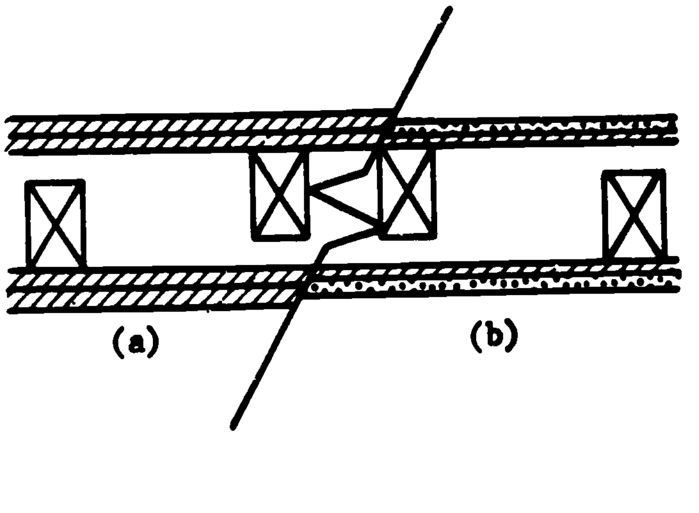
Total thickness: 5 3/4 in.

Area weight: 15.6 lb/ft^2

(a) ———— STC = 44; Fire Rating: 1 1/2 hrs. (est.) - combustible

(b) ------------ STC = 43; Fire Rating: 1 hr. (est.) - combustible





TYPE: STAGGERED WOODEN STUD, GYPSUM LATH AND PLASTER

TEST REF: (a) 3-(237); (b) 3-(238)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers staggered 8 in. on centers and offset 1/2 in. On each side 3/8-in. gypsum lath nailed to studs, 1/2-in. gypsum vermiculite plaster, machine-applied, and a hand-applied white-coat finish.

Total thickness: 6 1/4 in.

Area weight: 11.1 lb/ft^2

(b) Same as (a) except the space between the studs contained vermiculite fill with a density of 6.3 lb/ft^3.

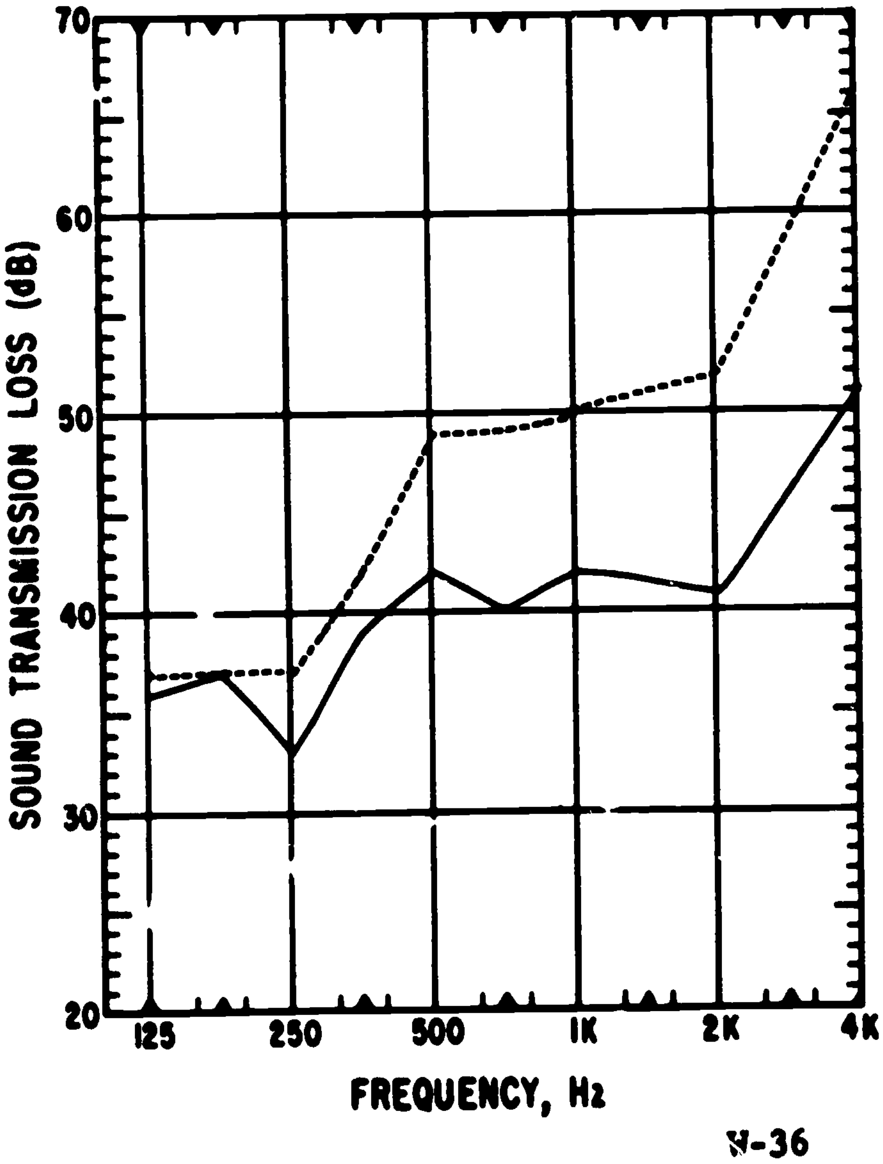
Total thickness: 6 1/4 in.

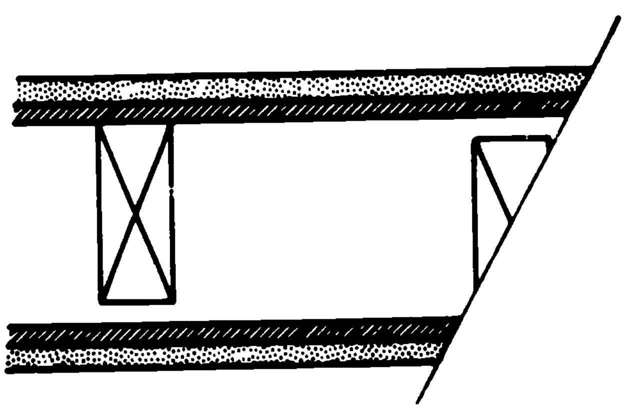
Area weight: 12.8 lb/ft^2

(a)———— STC = 43; Fire Rating: 45 min. (est.) - combustible

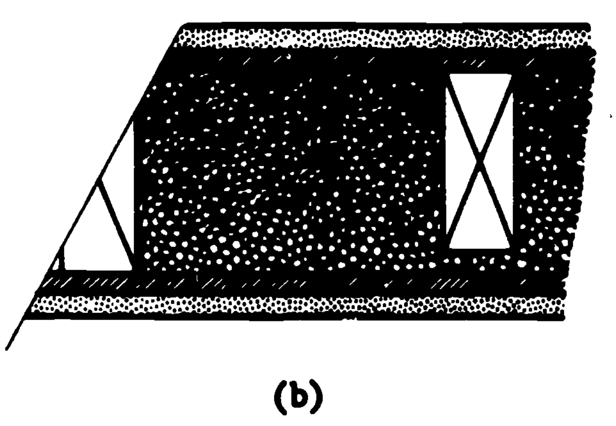
(b)------------ STC = 48; Fire Rating: 1 hr. (est.) - combustible

REMARKS: The STC values are based upon nine test frequencies.





(a)



(b)

TYPE: STAGGERED WOODEN STUD, GYPSUM BOARD WITH INSULATION

TEST REF: 2-(236)

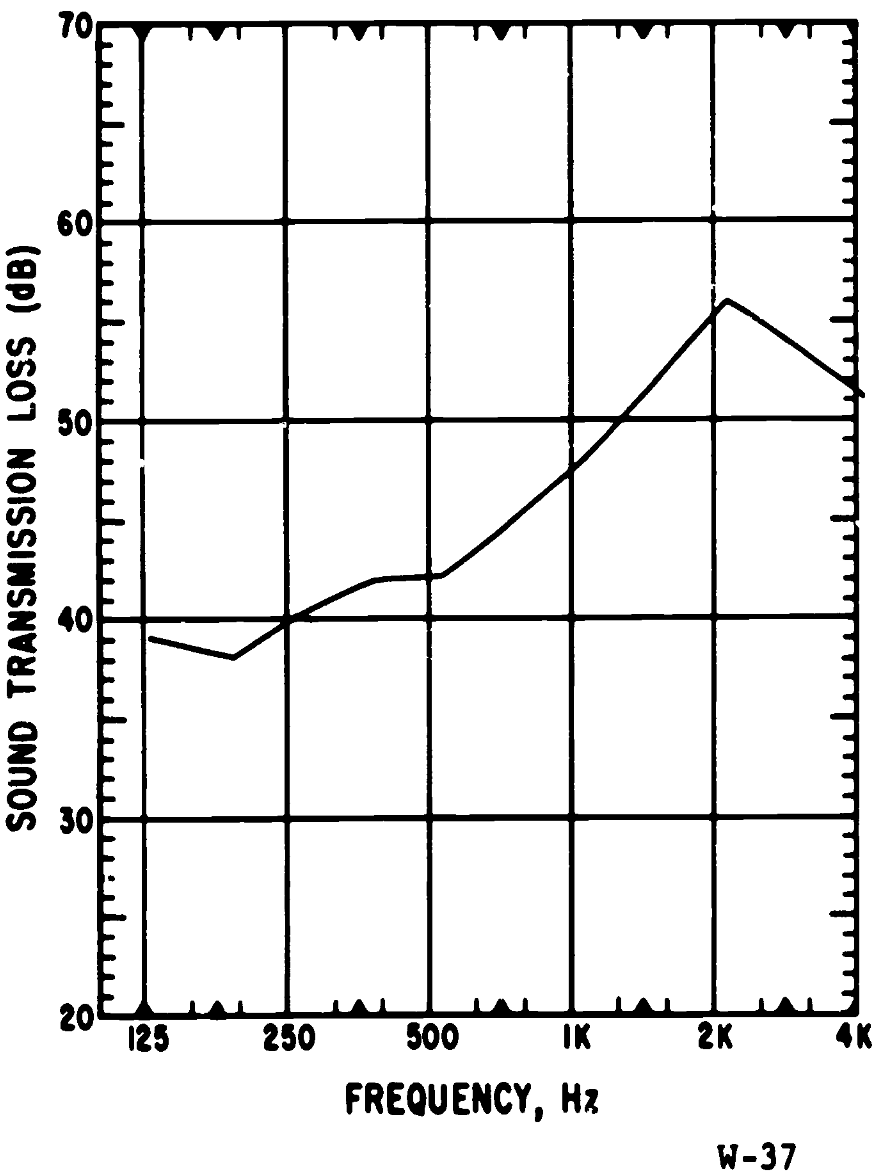
DESCRIPTION: 2- by 4-in. wooden studs 16 in. on centers, staggered 8 in. on centers, attached to 2- by 4 3/4-in. wooden floor and ceiling plates; 1/2-in. gypsum wallboard nailed on both sides to studs, 0.9-in. wood-fiber wool blanket stapled on the inside of one side of the wall. All joints taped and finished.

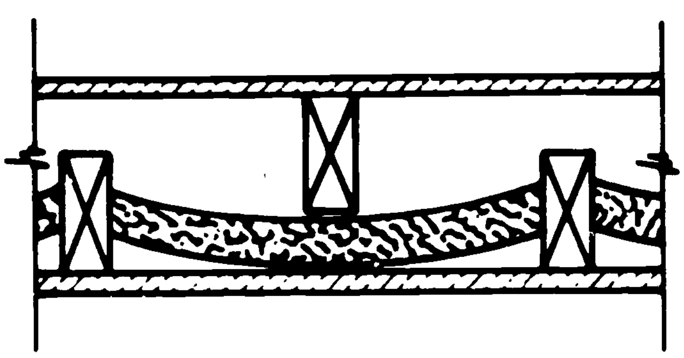
Total thickness: 5 3/4 in.

Area weight: 13.8 lb/ft^2

REMARKS: The STC value is based upon nine test frequencies.

STC = 46; Fire Rating: 1/2 hr. (est.) - combustible





TYPE: SLOTTED WOODEN STUD, PLASTERED GYPSUM LATH WITH INSULATION

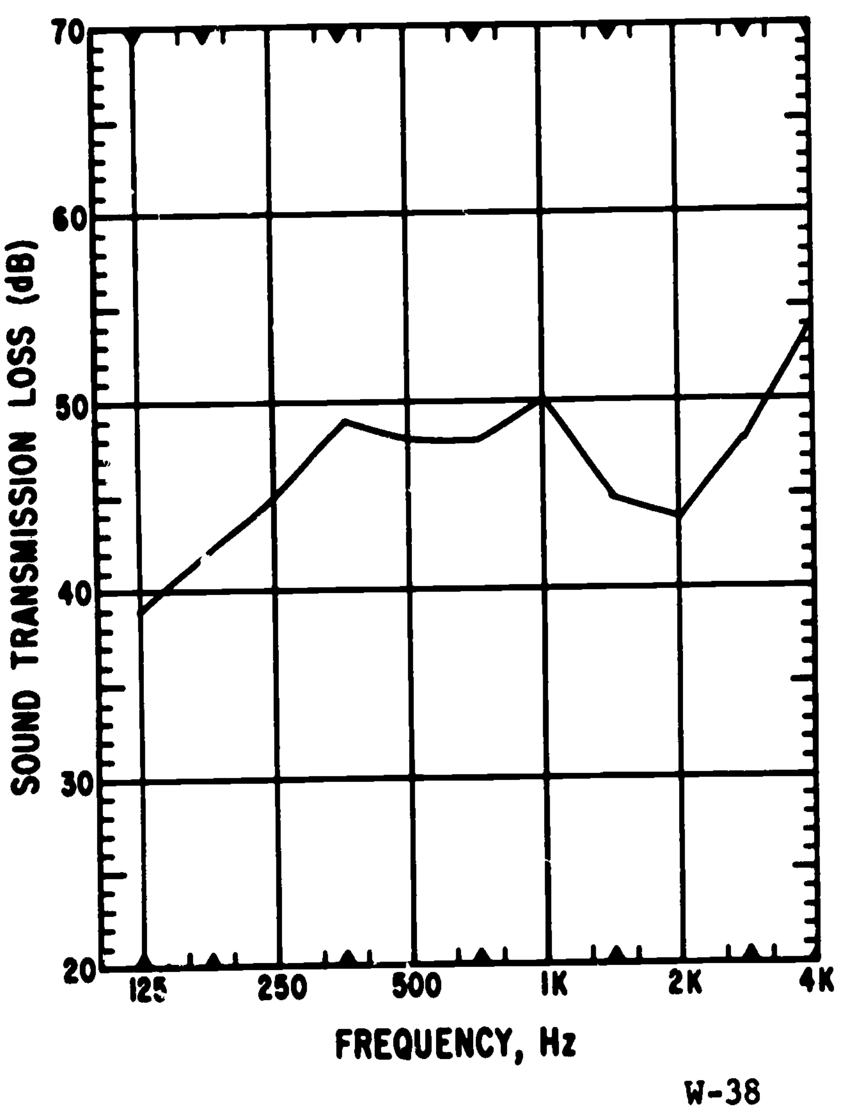
TEST REF: 7-(TL 62-348)

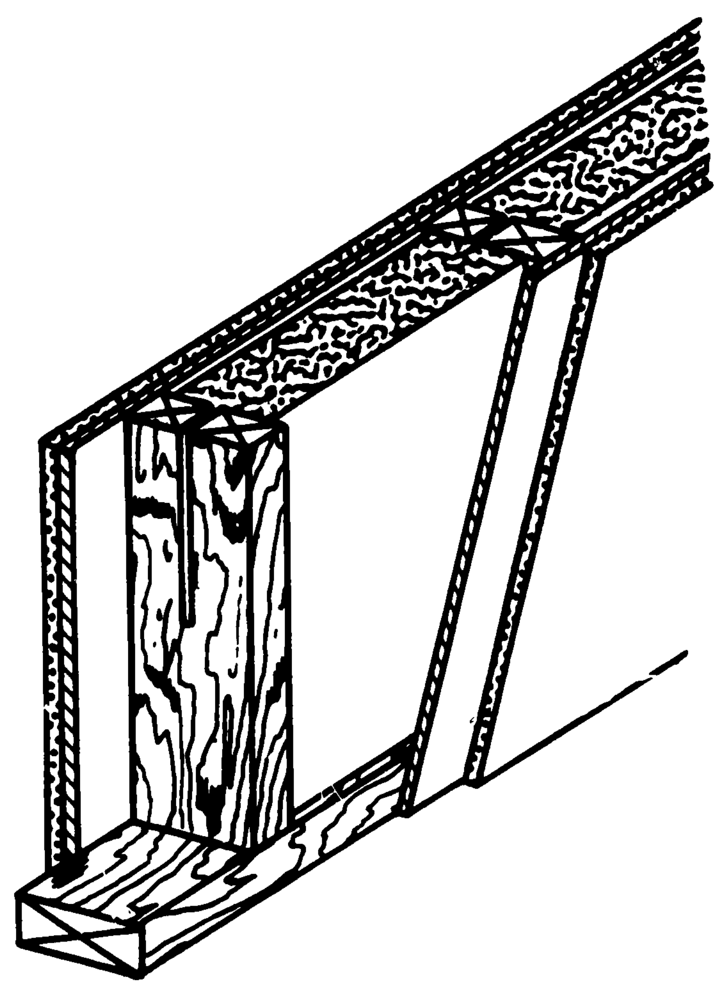
DESCRIPTION: 2- by 4-in. slotted wooden studs 16 in. on centers attached to 2- by 4-in. wooden floor and ceiling plates, 3/8-in. gypsum lath nailed 7 in. on centers to studs, 1/2-in. gypsum plaster with white-coat finish applied to both sides. 3-in. mineral fiber batts stapled between studs.

Total thickness: 5 3/8 in.

Area weight: 14.2 lb/ft^2

STC = 45; Fire Rating: 1 hr. (est.) - combustible





TYPE: WOODEN STUD, RESILIENT CHANNELS, GYPSUM BOARD

TEST REF: (a) 7-(TL 60-52); (b) 7(b)-(TL 61-10)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers attached to 2- by 4-in. wooden floor and ceiling plates, resilient channels nailed horizontally to both sides of studs 24 in. on centers, 5/8-in. gypsum wallboard screwed 12 in. on centers to channels. All joints taped and finished.

Total thickness: 6 1/4 in.

Area weight: 6.7 lb/ft^2

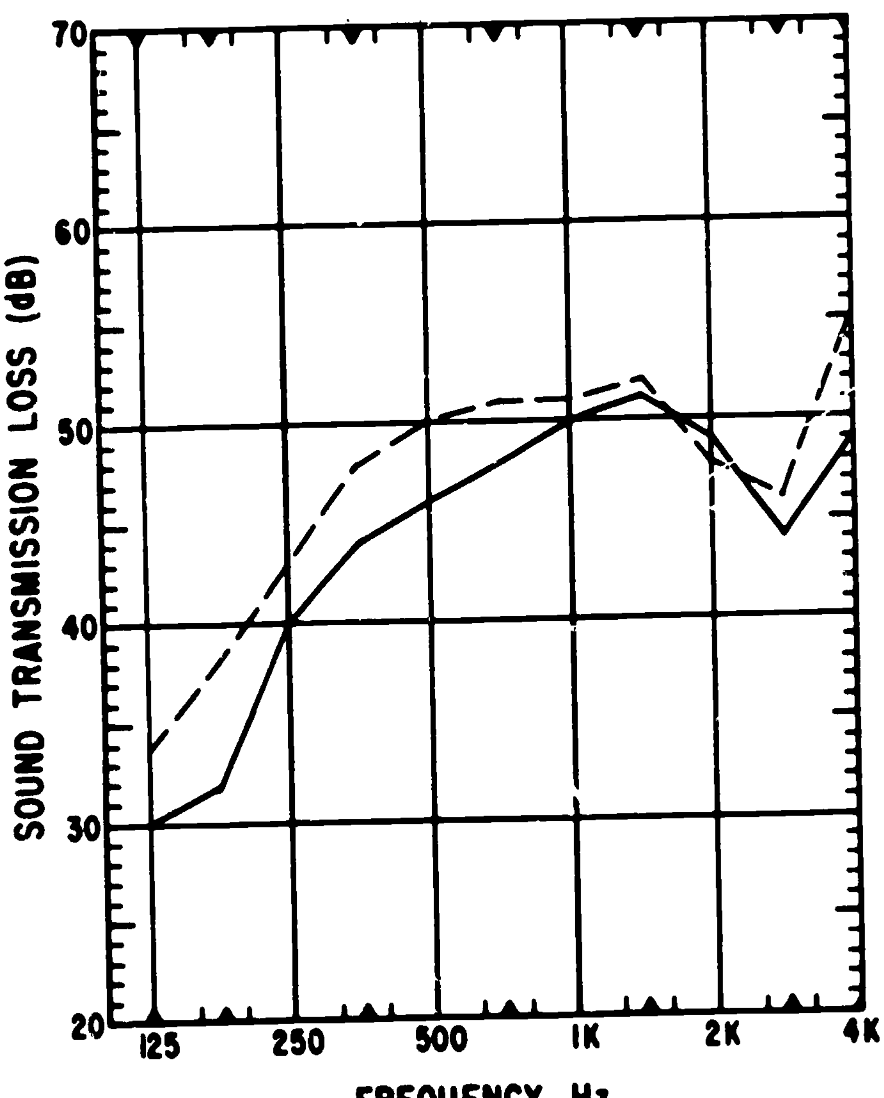
(b) Similar to (a) except an additional layer of 1/2-in. gypsum wallboard was laminated to 5/8-in. gypsum wallboard on one side.

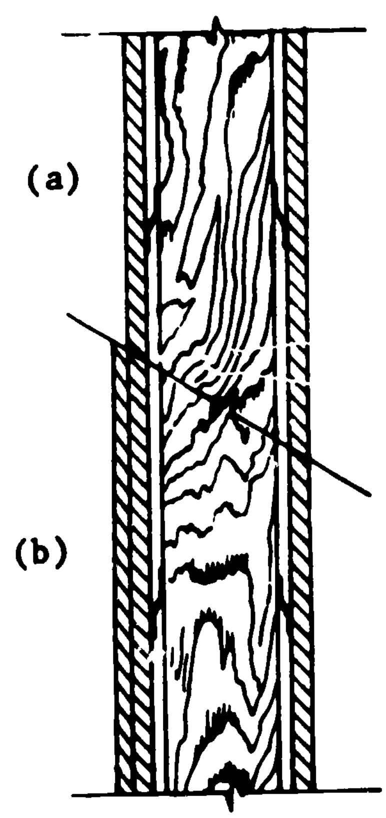
Total thickness: 6 3/4 in.

Area weight: approximately 9 lb/ft^2 (Not specified in reference)

(a) ———— STC = 47; Fire Rating: 1 hr. (est.) - combustible

(b) - - - - - STC = 48; Fire Rating: 1 hr. (est.) - combustible





TYPE: WOODEN STUD, PLASTERED GYPSUM LATH WITH RESILIENT CLIPS

TEST REF: (a) 3-(439); (b) 7-(TL 60-20)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers; resilient clips, nailed to studs on both sides, held 3/8-in. gypsum lath, 1/2-in. sanded gypsum plaster with white-coat finish.

Total thickness: approximately 6 1/2 in.

Area weight: 14.4 lb/ft^2

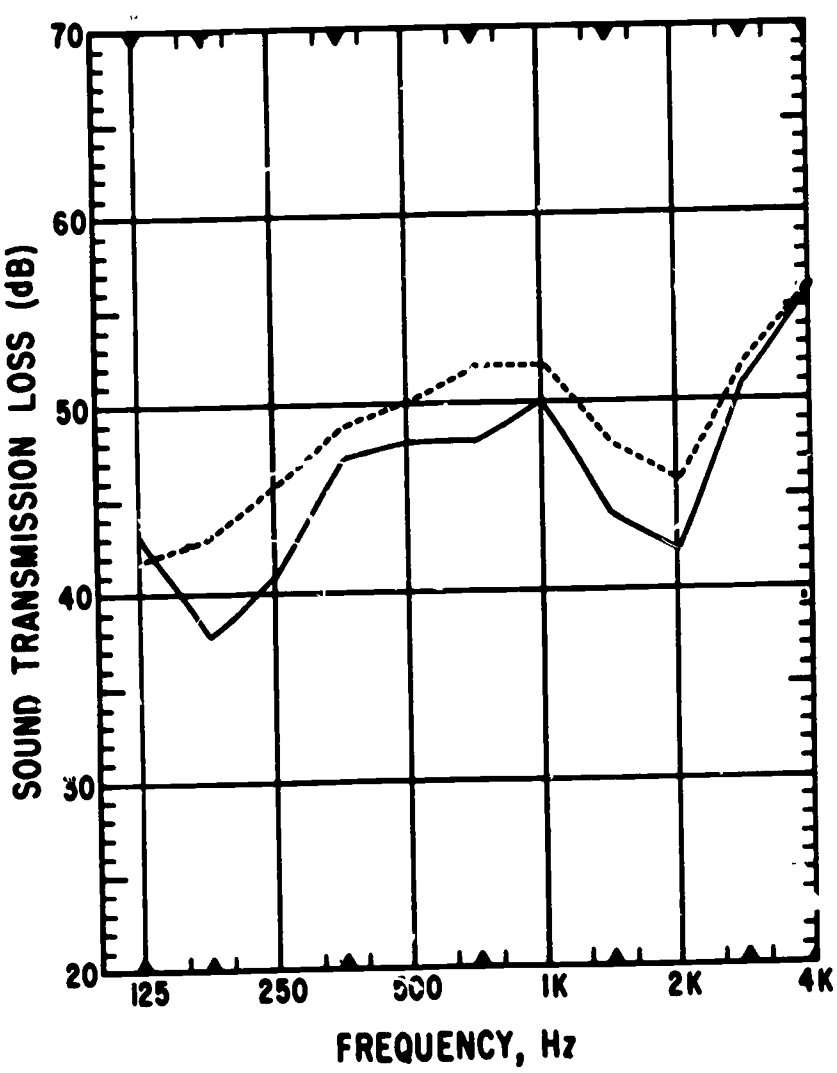
(b) Similar to (a) except different resilient clips were used.

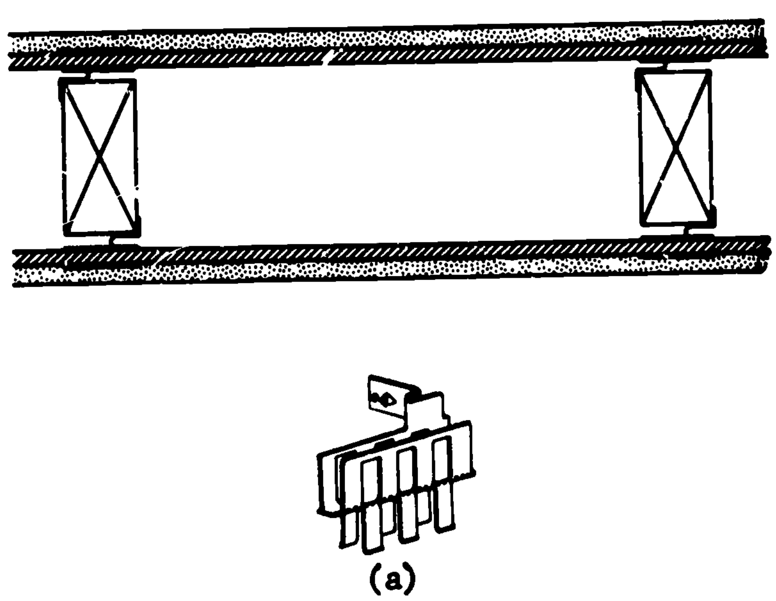
Total thickness: approximately 6 1/2 in.

Area weight: 14.1 lb/ft^2

(a) ———— STC = 44; Fire Rating: 1 hr. - combustible

(b) ------------ STC = 48





(a)

TYPE: WOODEN STUD, PLASTERED GYPSUM LATH WITH RESILIENT CLIPS

TEST REF: (a) 2-(420); (b) 2-(421); (c) 2-(422); (d) 2-(423)

DESCRIPTION: (a) 2- by 4-in. wooden studs 16 in. on centers; resilient clips, nailed to studs on both sides, held 3/8-in. plain gypsum lath, 1/2-in. sanded gypsum plaster with white-coat finish.

(b) Similar to (a) except a less resilient clip was used.

(c) Similar to (a) except the least resilient clip of the three was used.

Total thickness: approximately 6 1/2 in.

Area weight: 13.1 lb/ft^2

(d) Same as (a) except perforated gypsum lath and perlite aggregate plaster were used.

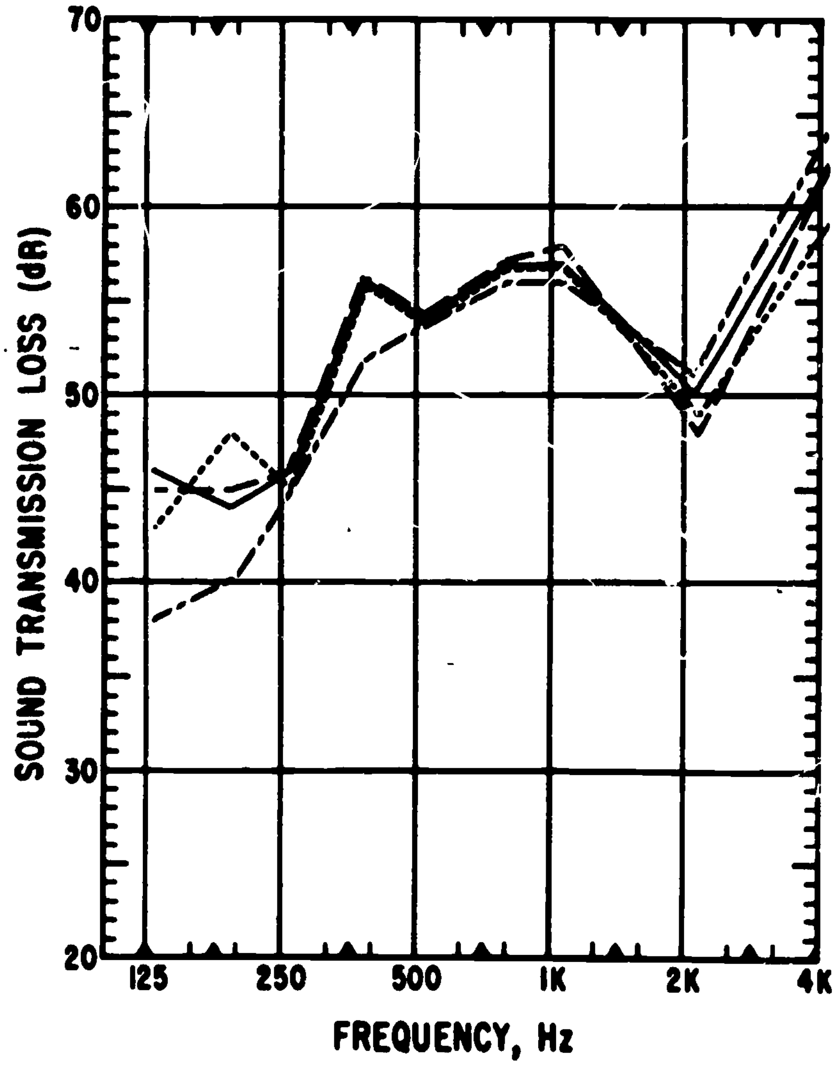
Total thickness: approximately 6 1/2 in.

Area weight: 11.9 lb/ft^2

(a) ———— STC = 52 (c) – – – – – STC = 50

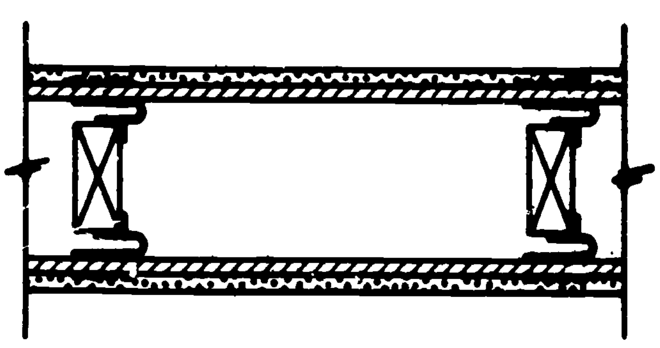
(b) .... STC = 51 (d) –·–·–·– STC = 53

REMARKS: The STC values for the above panels are based upon nine test frequencies.



(a)-(c) Fire Rating: 45 min. - combustible

(d) Fire Rating: 1 hr. - combustible



TYPE: STEEL TRUSS STUD, METAL LATH AND PLASTER

TEST REF: (a) 2-(166A); (b) 2-(166B); (c) 2-(229)

DESCRIPTION: (a) 3 1/4-in. steel truss studs 16 in. on centers; on both sides diamond mesh metal lath wire-tied to studs, 7/8-in. sanded gypsum plaster.

Total thickness: 5 1/4 in.

Area weight: 19.6 lb/ft^2

(b) Similar to (a) except the space between the studs was packed with mineral wool batts with a density of 5.2 lb/ft^3.

Total thickness: 5 1/4 in.

Area weight: 21.1 lb/ft^2

(c) Similar to (a) except the sanded gypsum plaster was 3/4 in. thick.

Total thickness: 5 in.

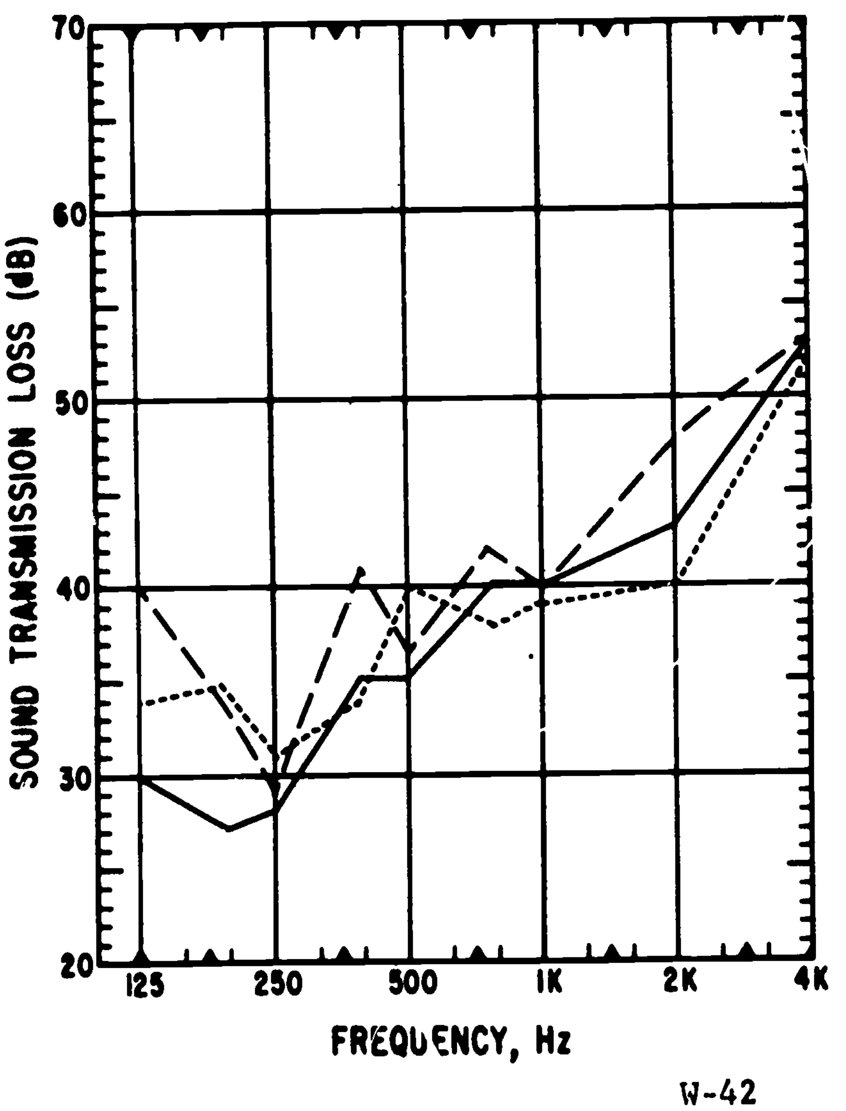
Area weight: 19.1 lb/ft^2

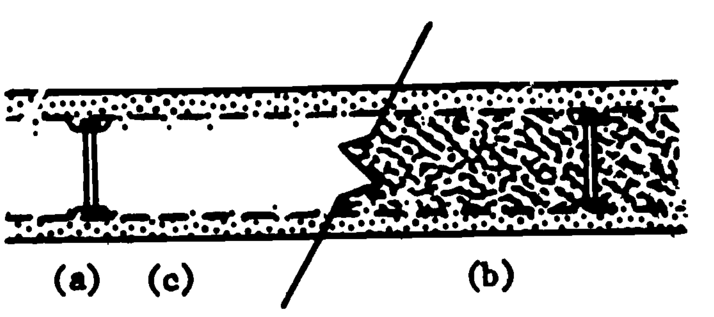
(a) ——— STC = 39; Fire Rating: 1 1/4 hrs.

(b) ·········· STC = 39; Fire Rating: 1 1/2 hrs. (est.)

(c) — — — STC = 41; Fire Rating: 1 hr.

REMARKS: The STC values are based upon nine test frequencies.





TYPE: STEEL TRUSS STUD, LATH AND PLASTER WITH LEAD

TEST REF: (a) 16-(Fig. 7); (b) 16-(Fig. 7); (c) 16-(Fig. 7)

DESCRIPTION: (a) 1 5/8-in. steel truss studs; 3/8-in. gypsum lath, 1/2-in. plaster on both sides.

Total thickness: 3 3/8 in.

Area weight: 12.3 lb/ft^2

(b) Similar to (a) except a layer of lead, 2.95 lb/ft^2, was laminated to one side of partition.

Total thickness: approximately 3 1/2 in.

Area weight: 15.2 lb/ft^2

(c) Similar to (a) except a layer of lead, 2.95 lb/ft^2, was laminated to each side of partition.

Total thickness: approximately 3 1/2 in.

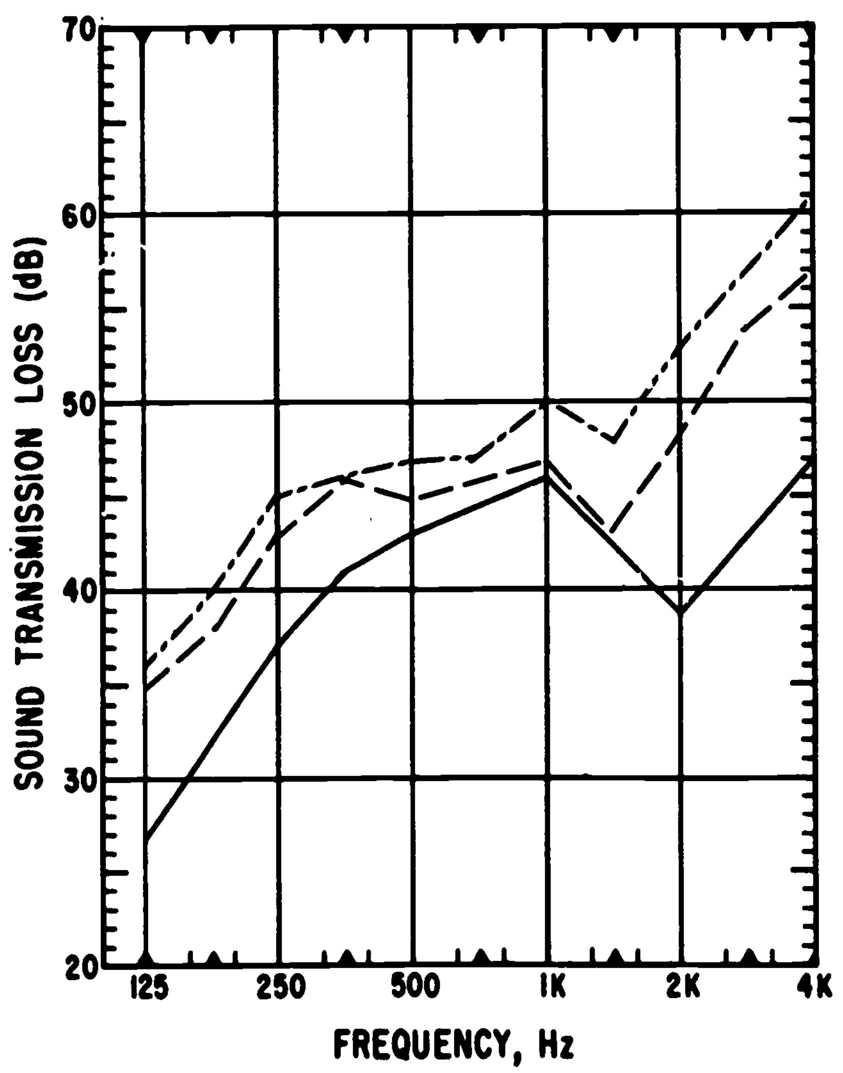
Area weight: 18.2 lb/ft^2

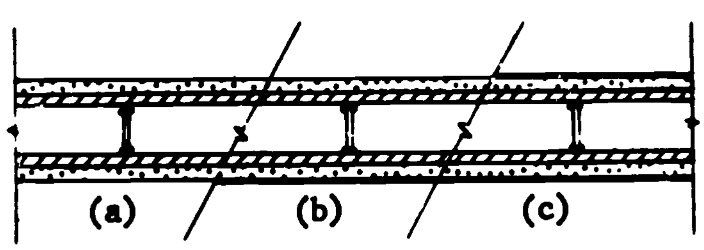
REMARKS: Stud spacirg not specified in reference.

(a)————STC = 41; Fire Rating: 45 min. (est.)

(b)– – – – –STC = 43; Fire Rating: 45 min. (est.)

(c)·–·–·–·–STC = 48; Fire Rating: 45 min. (est.)





TYPE: STEEL TRUSS STUD, GYPSUM LATH AND PLASTER

TEST REF: (a) 2-(424); (b) 2-(433, 434); (c) 2-(437)

DESCRIPTION: (a) 3 1/4-in. steel truss studs 24 in. on centers attached to metal floor and ceiling tracks; on both sides 3/8-in. perforated gypsum lath attached with wire clips wire-tied to studs, 1/2-in. sanded gypsum plaster.

Total thickness: 5 in.

Area weight: 15.7 lb/ft^2

(b) Similar to (a) except 2 1/2 in. steel truss studs 16 in. on centers were used.

Total thickness: 4 1/4 in.

Area weight: 14 lb/ft^2

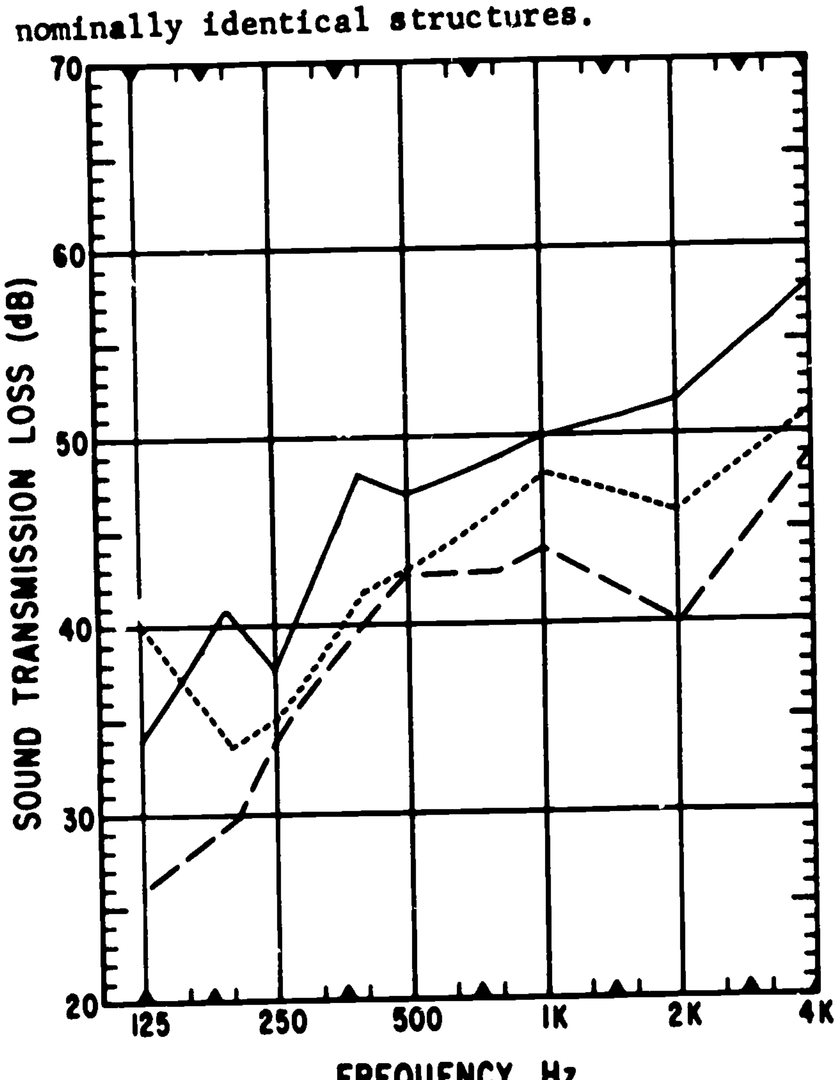
(c) Similar to (b) except that 5/8-in. perlite gypsum plaster was used.

Total thickness: 4 1/2 in.

Area weight: 11.7 lb/ft^2

(a) ———— STC = 51 (b) ············ STC = 47 (c) — — — — STC = 42

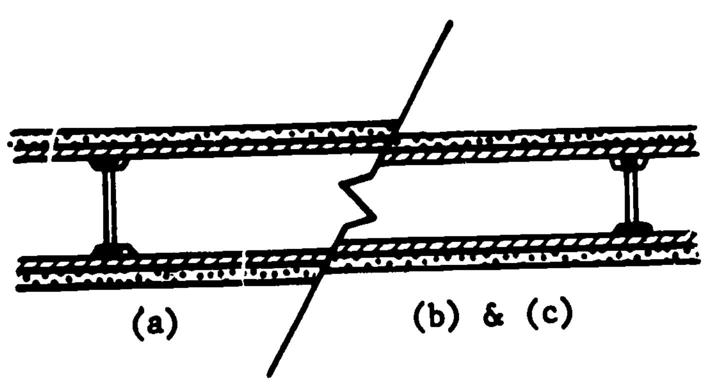
REMARKS: The STC values are based upon nine test frequencies. The plotted curve, (b), represents the average of laboratory tests of two nominally identical structures.



(a) Fire Rating: 1 hr.

(b) Fire Rating: 1 hr.

(c) Fire Rating: 1 1/4 hrs. (est.)



TYPE: STEEL TRUSS STUD, GYPSUM LATH AND LIGHTWEIGHT PLASTER

TEST REF: (a) 3-(438); (b) 4-(Fig. 13.41)

DESCRIPTION: (a) 2 1/2- by 1/2-in. steel studs spaced 16 in. on centers. Galvanized wire clips, attached to studs on both sides, held 3/8-in. gypsum lath, 7/16-in. gypsum vermiculite plaster and 1/16-in. white-coat finish. (Laboratory measurements)

(b) Similar to (a) except gypsum perlite plaster was used and the construction was tested in the field.

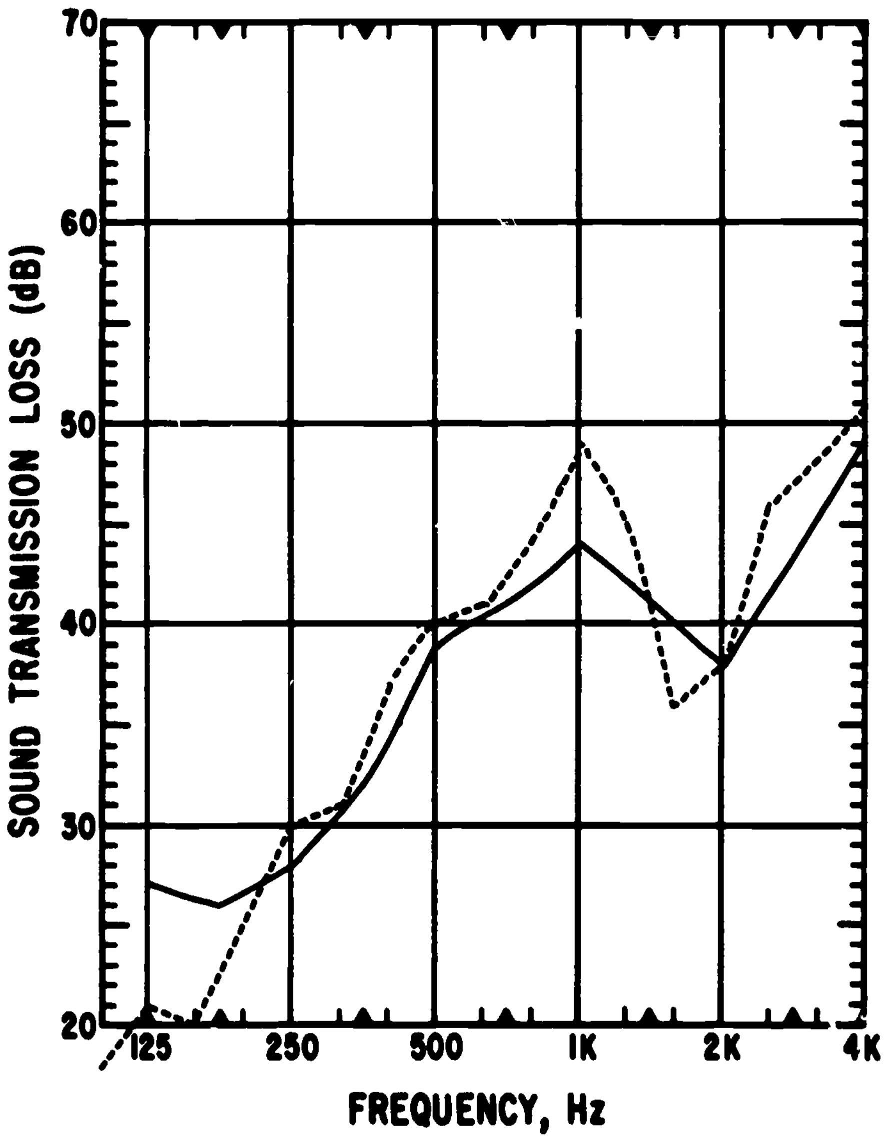
Total thickness: 4 1/4 in.

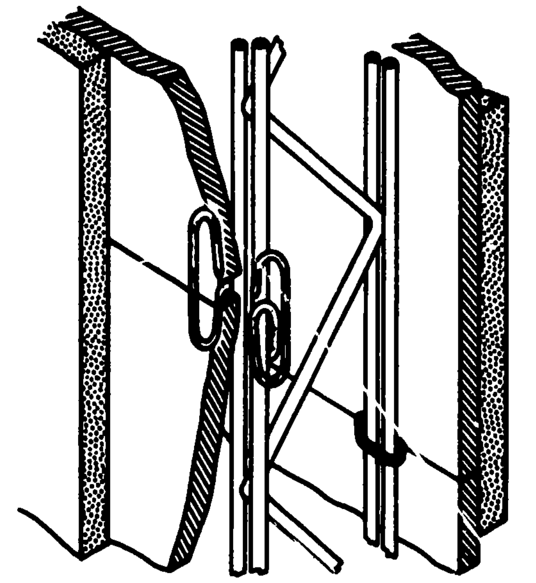
Area weight: 9 lb/ft^2

(a) ———— STC = 38; Fire Rating: 45 min. (est.)

(b) ············ STC = 37; Fire Rating: 45 min. (est.)

REMARKS: The STC value of curve (a) is based upon nine test frequencies.





TYPE: STEEL TRUSS STUD, DOUBLE LAYER GYPSUM BOARD

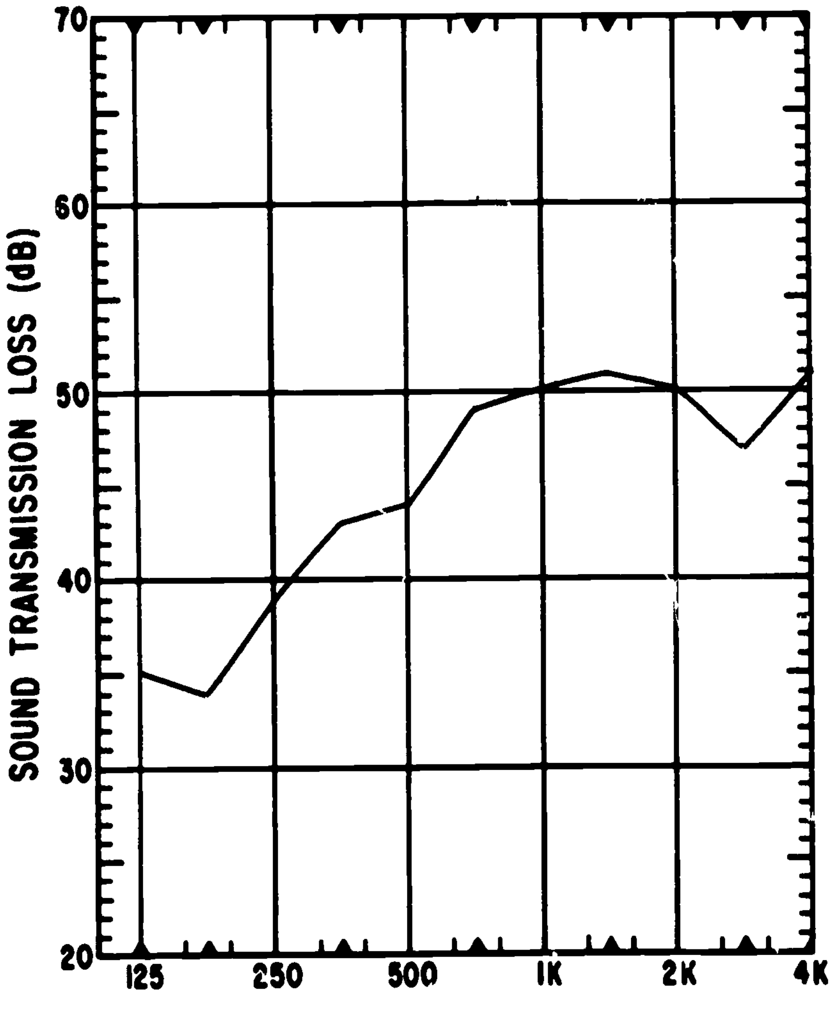
TEST REF: 3-(247)

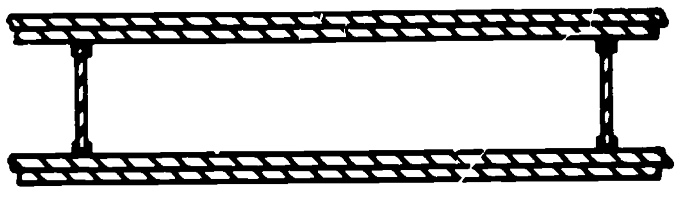
DESCRIPTION: 3 1/4-in. steel truss studs, 16 in. on centers, attached to top and bottom by stud shoes, starter clips, and stud tracks; 3/8-in. gypsum wallboard (backer board) clipped to studs with galvanized wire clips; edges of wallboard held together by galvanized steel clips; 3/8-in. gypsum wallboard laminated to the inner layer with joint cement.

Total thickness: 4 3/4 in.

Area weight: 7.5 lb/ft^2

STC = 48; Fire Rating: 1 hr. (est.)





TYPE: STEEL TRUSS STUD, RESILIENT CLIPS ONE SIDE, GYPSUM LATH AND PLASTER

TEST REF: 7(a)-(TL 60-128)

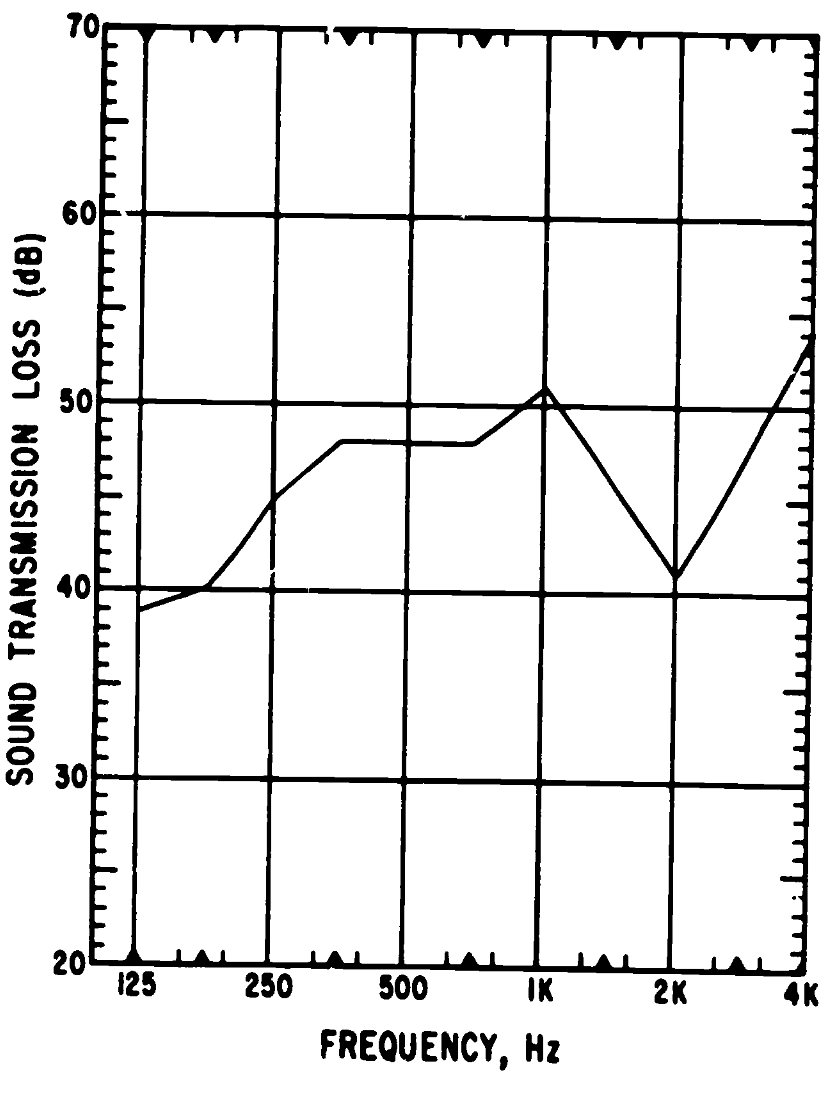
DESCRIPTION: 3 1/4-in. steel truss studs 16 in. on centers. 3/8-in. gypsum lath attached on one side with resilient clips, and to the other side with galvanized wire clips; 1/2-in. sanded gypsum plaster applied to both sides.

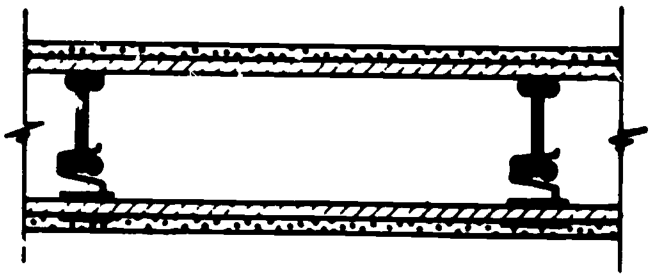
Total thickness: 5 1/2 in.

Area weight: 13 lb/ft^2

STC = 43; Fire Rating: 45 min. (est.)

REMARKS: The STC value is based upon nine test frequencies.





TYPE: STEEL TRUSS STUD, PLASTERED GYPSUM LATH, RESILIENT CLIPS ONE SIDE

TEST REF: 9-(8-1090072b)

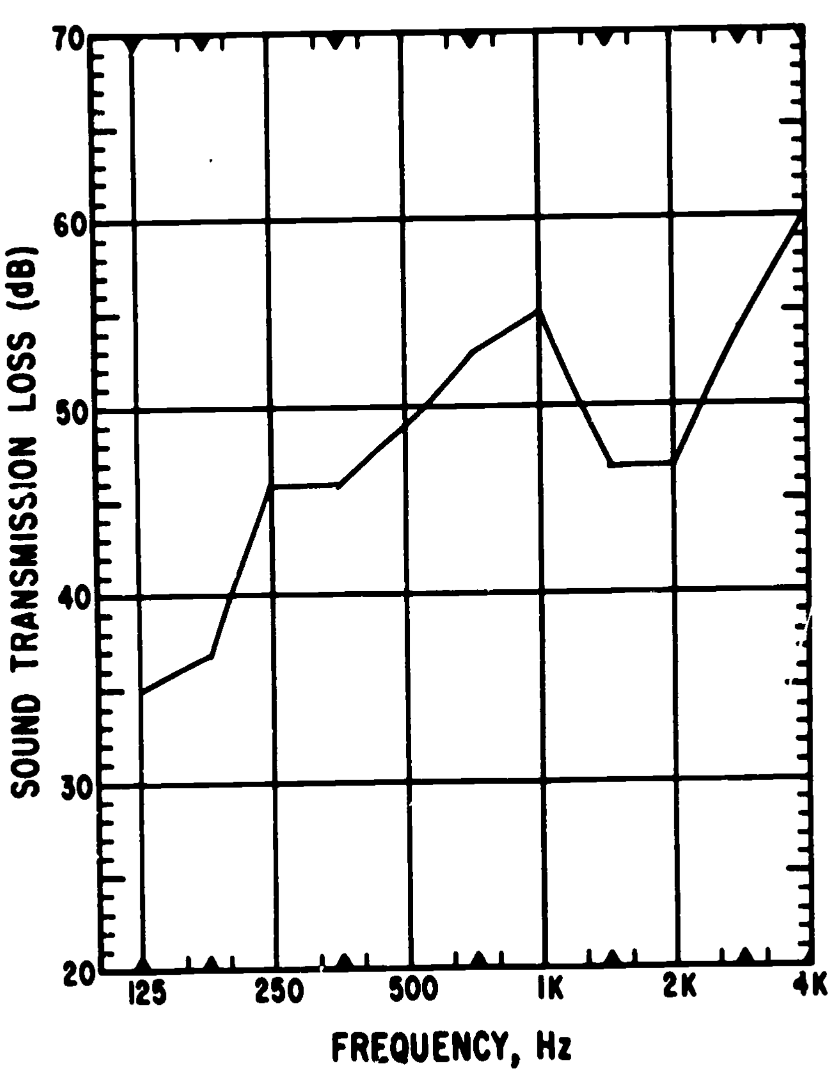
DESCRIPTION: 3 1/4-in. steel truss studs 16 in. on centers set into floor and ceiling tracks. Tracks isolated at floor and ceiling with 1/2-in.-thick continuous resilient gaskets. Floor track attached 24 in. on centers to concrete slab. On one side, 3/8-in. gypsum lath attached with resilient clips 16 in. on centers, 1/2-in. sanded gypsum plaster with white-coat finish applied to lath; on the other side, the gypsum lath was attached with galvanized wire clips. 2-in. mineral fiber blankets stapled between studs on non-resilient side. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound.

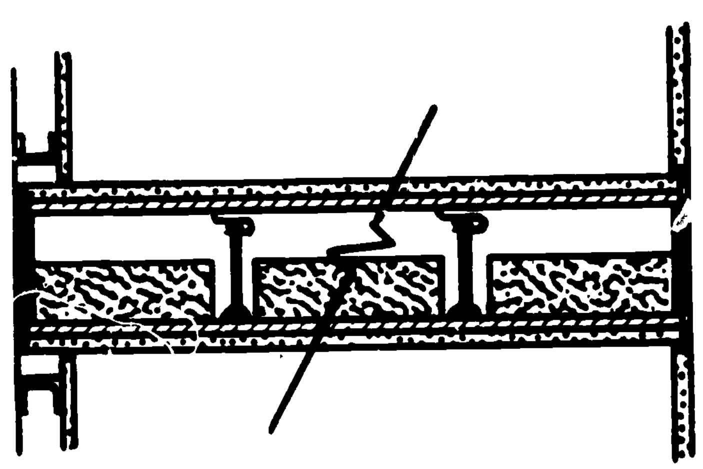
Total thickness: 5 1/2 in.

Area weight: 12.3 lb/ft^2

STC = 47; Fire Rating: 1 hr. (est.)

REMARKS: The above test was conducted in the field. One adjoining wall was constructed of 1 5/8-in. metal channel studs, 1/2-in. gypsum lath and finish coat of plaster; the other wall was 5/8-in. plaster on masonry.





TYPE: STEEL TRUSS STUD, PLASTERED LATH WITH RESILIENT CLIPS

TEST REF: 7(a)-(TL 61-9)

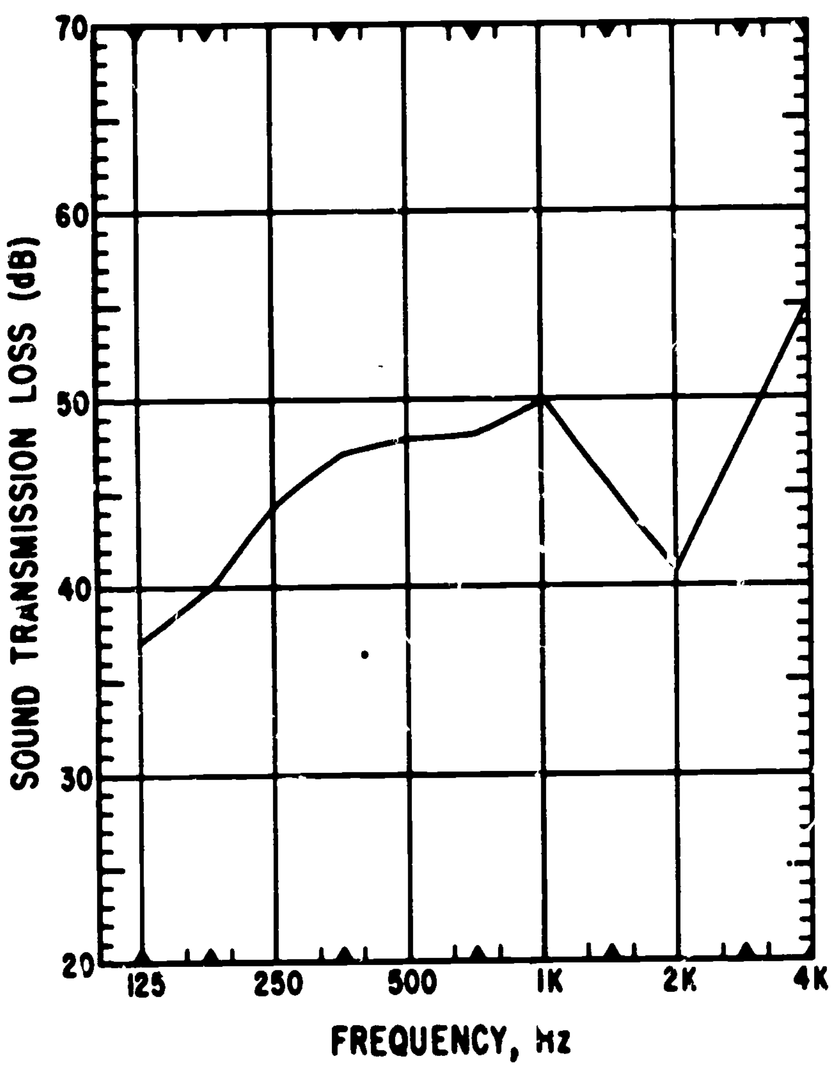
DESCRIPTION: 1 5/8-in. steel truss studs 16 in. on centers; on both sides 3/8-in. gypsum lath attached with resilient clips to studs, 1/2-in. sanded gypsum plaster applied to lath.

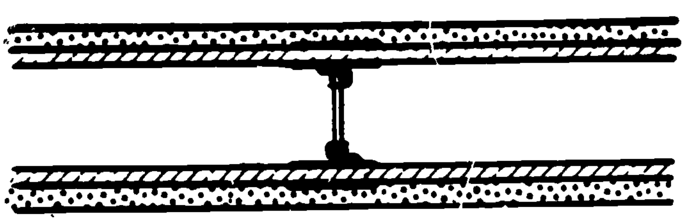
Total thickness: 4 1/8 in.

Area weight: 13 lb/ft^2

STC = 43; Fire Rating: 45 min. (est.)

REMARKS: The STC value is based upon nine test frequencies.





TYPE: STEEL TRUSS STUD, PLASTERED GYPSUM LATH WITH RESILIENT CLIPS

TEST REF: 5-(Figs. 2,3,4)

DESCRIPTION: (a) 2 1/2-in. steel truss studs 16 in. on centers, 3/8-in. gypsum lath attached with resilient clips to studs, 1/2-in plaster applied to both sides.

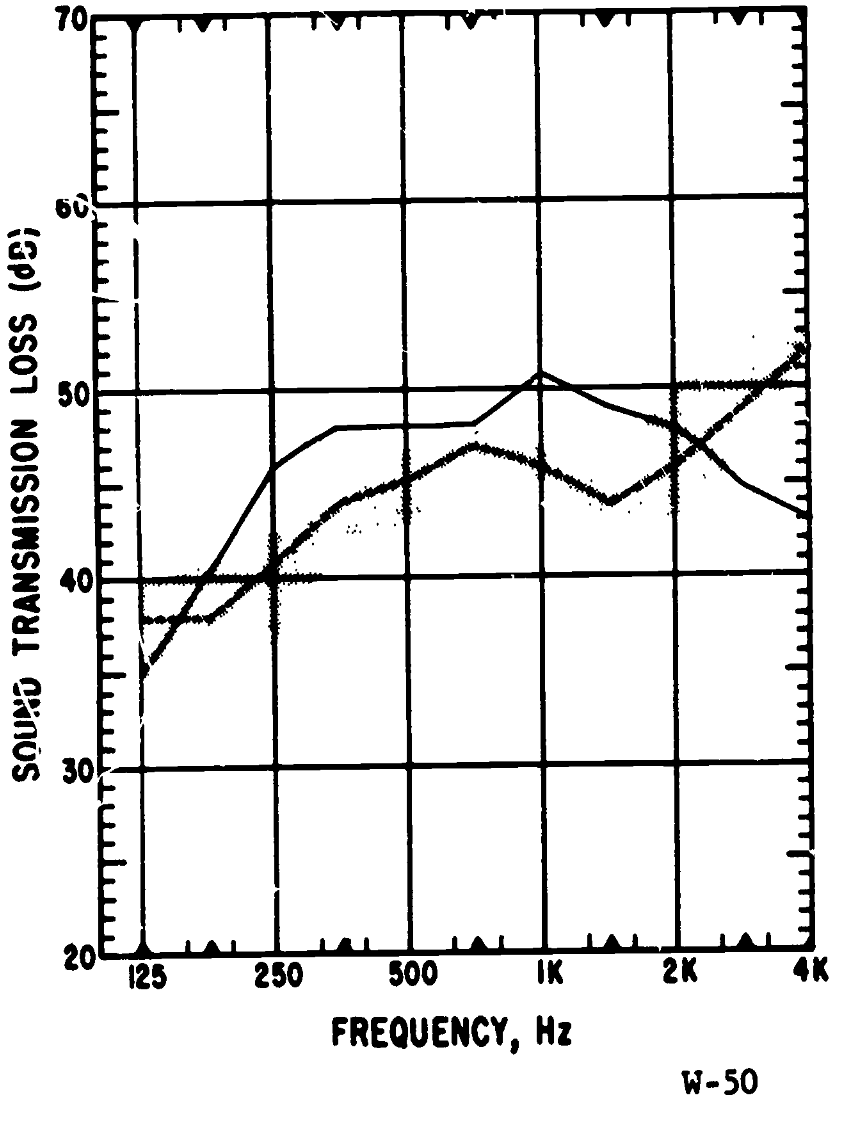
(b) Similar to (a) except measurements [illegible] conducted in the field. The shaded area indicates the spread of the [illegible] ments of three nominally identical structures, and the broken line indicates the average of these measurements.

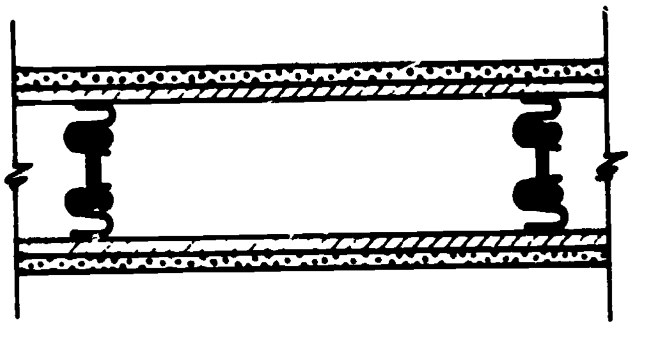
Total thickness: 5 1/4 in.

Area weight: approximately 13 lb/ft^2 (Not specified in reference)

(a) ———— STC = 45; Fire Rating: 45 min. (est.)

(b) ———— STC = 44





TYPE: STEEL TRUSS STUD, PLASTERED GYPSUM LATH WITH RESILIENT CLIPS

TEST REF: (a) 9-(1090071a); (b) 9-(1090071b)

DESCRIPTION: (a) 2 1/2-in. steel truss studs 16 in. on centers set into floor and ceiling tracks. Tracks isolated at floor and ceiling with 1/4-in.-thick continuous resilient gaskets. Floor track attached 24 in. on centers to concrete slab. 3/8-in. perforated gypsum lath attached 16 in. on centers to both sides of studs with resilient clips; 1/2-in. sanded gypsum plaster with white-coat finish applied to lath. The 3/16-in. clearance around perimeter closed with a non-setting resilient caulking compound. One face of the wall primed with a pigmented sealer and the other face with shellac.

(b) Similar to (a) except latex applied over pigmented sealer and vinyl over shellac.

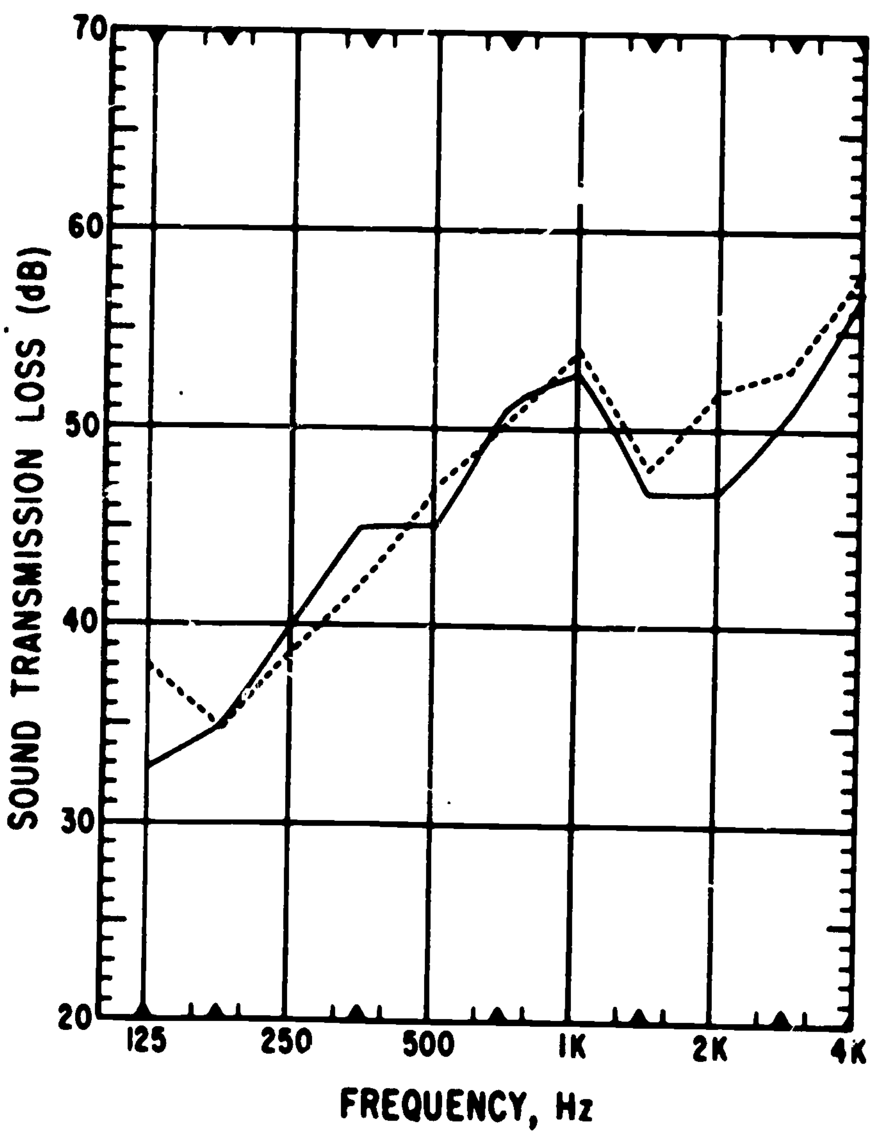
Total thickness: 5 in.

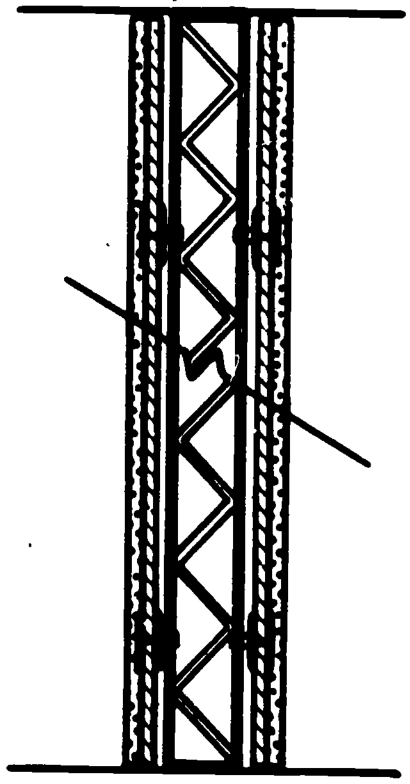
Area weight: 13.0 lb/ft^2

(a) ———— STC = 47; Fire Rating: 1 hr.

(b) ------------ STC = 48

REMARKS: The above tests were conducted in the field.





TYPE: STEEL TRUSS STUDS, RESILIENT CLIPS, METAL LATH AND PLASTER

TEST REF: 2-(429)

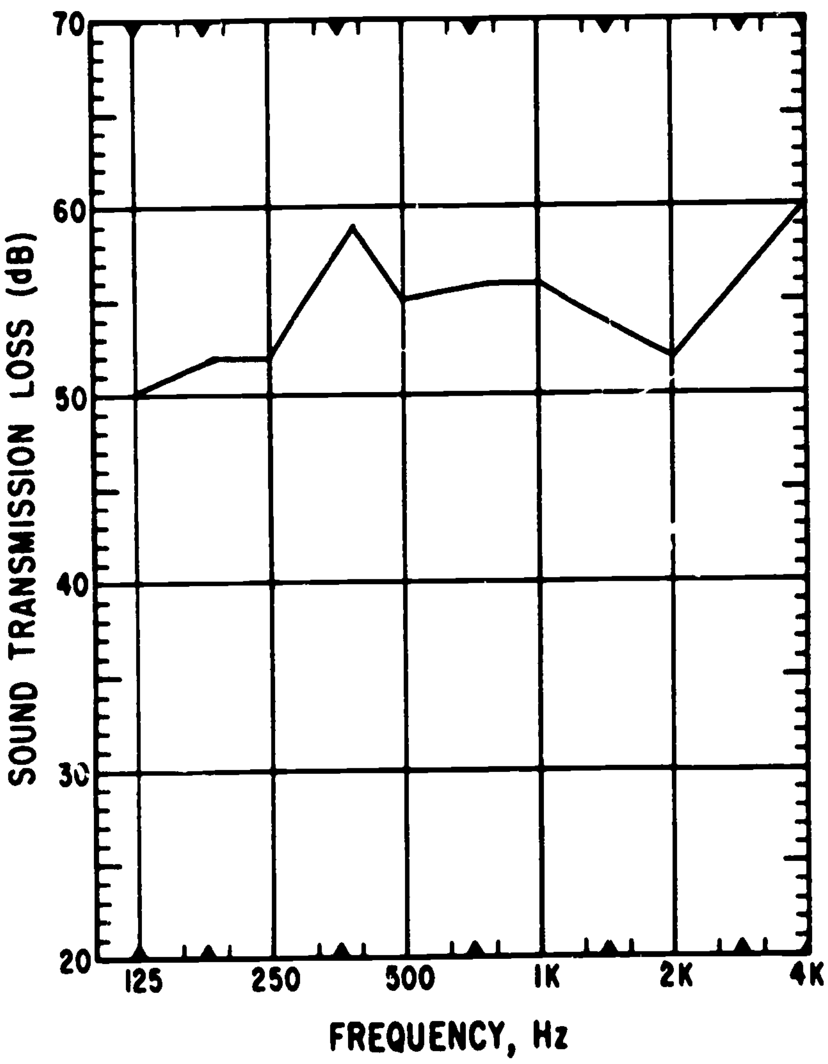
DESCRIPTION: 3 1/4-in. steel truss studs 16 in. on centers; on each side resilient clips fastened 16 in. on centers to studs, 1/4-in. metal rod wire-tied to clips, diamond mesh metal lath wire-tied to metal rods, 3/4-in. sanded gypsum plaster.

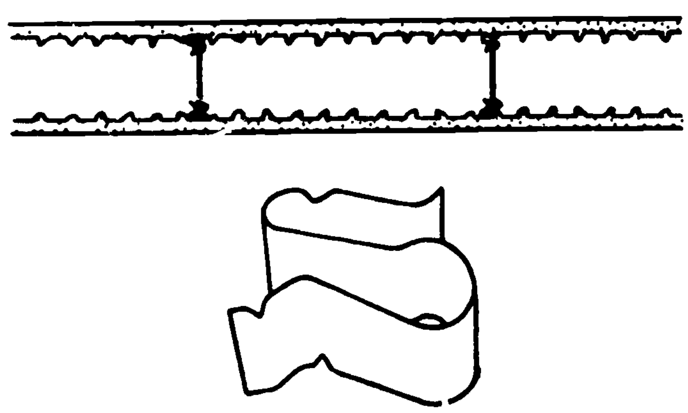
Total thickness: 5 in.

Area weight: 19.0 lb/ft^2

STC = 54; Fire Rating: 1 hr.

REMARKS: The STC value is based upon nine test frequencies.





TYPE: STEEL TRUSS STUD, RESILIENT CLIPS, GYPSUM LATH AND PLASTER

TEST REF: 9-(8-1090072c)

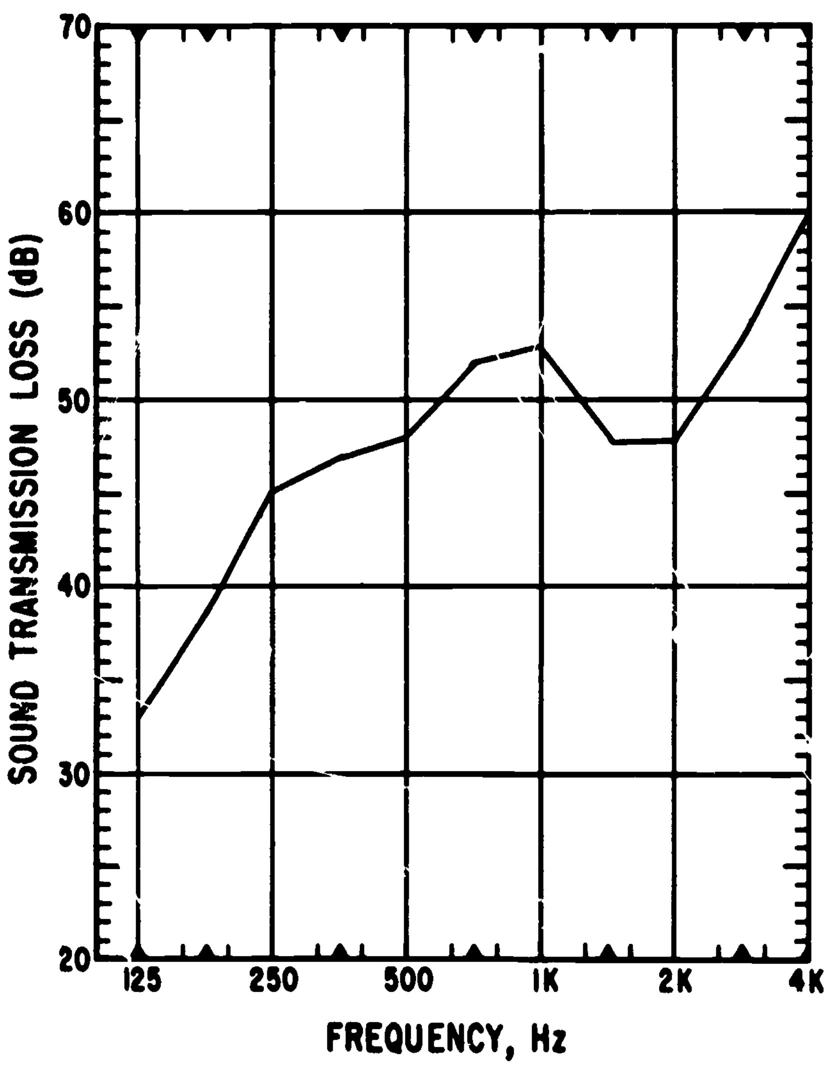
DESCRIPTION: 3 1/4-in. steel truss studs 8 in. on centers set into metal ceiling track with shoes wire-tied and metal "snap in" floor track attached 24 in. on centers to concrete floor. Both tracks set on 1/2-in. resilient gaskets. On both sides 3/8-in. gypsum lath, caulked at ceiling and floor, attached 16 in. on centers to alternate studs with resilient clips; 1/2-in. sanded gypsum plaster with finish coat. 2-in. mineral fiber blanket stapled between studs to lath on one side. The entire periphery was caulked with a non-setting resilient compound.

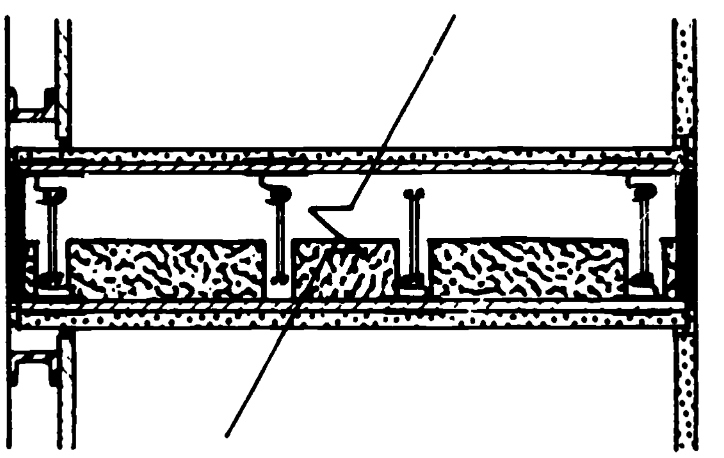
Total thickness: 5 3/4 in.

Area weight: 12.6 lb/ft^2

STC = 48; Fire Rating: 1 hr. (est.)

REMARKS: This test was conducted in the field. One adjoining wall was constructed with 1 5/8-in. metal channel studs, 1/2-in. gypsum lath and finish coat; the other wall was 5/8-in. plaster on masonry.





TYPE: METAL CHANNEL STUD, GYPSUM BOARD

TEST REF: (a) 7-(TL 64-132, 133, 134, 135); (b) 7-(TL 64-29)

DESCRIPTION: (a) 1 5/8-in. metal channel studs 24 in. on centers attached to metal floor and ceiling runners, 1/2-in. gypsum wallboard screwed 12 in. on centers to both sides of studs. All joints taped and finished.

Total thickness: 2 5/8 in.

Area weight: 4.6 lb/ft^2

(b) Similar to (a) except the gypsum wallboard was 5/8 in. thick.

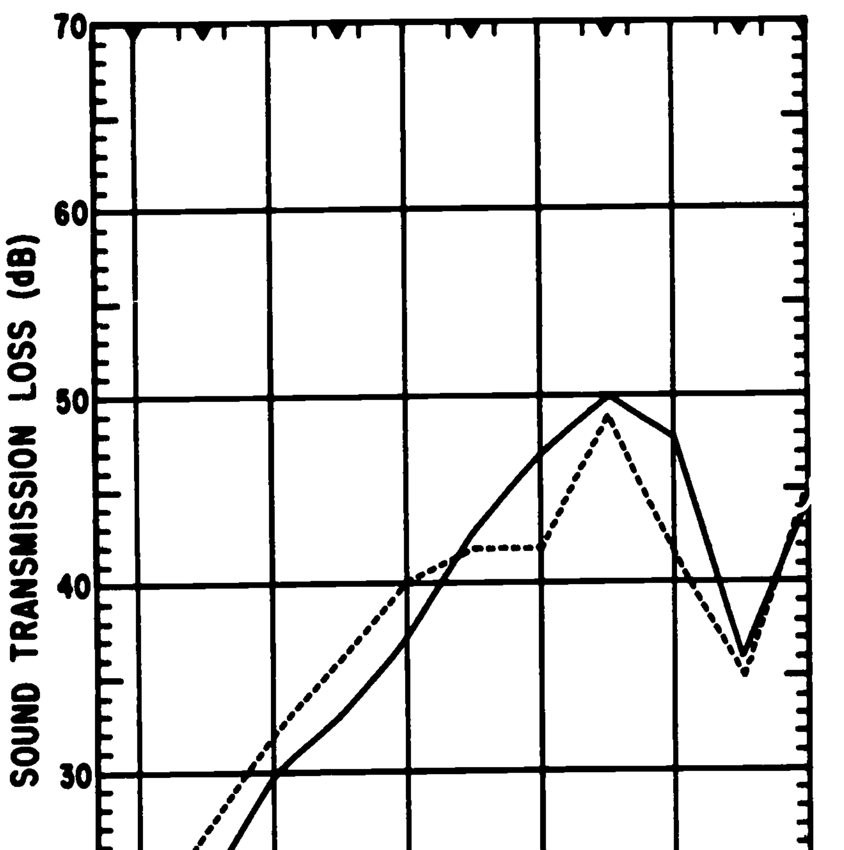
Total thickness: 2 7/8 in.

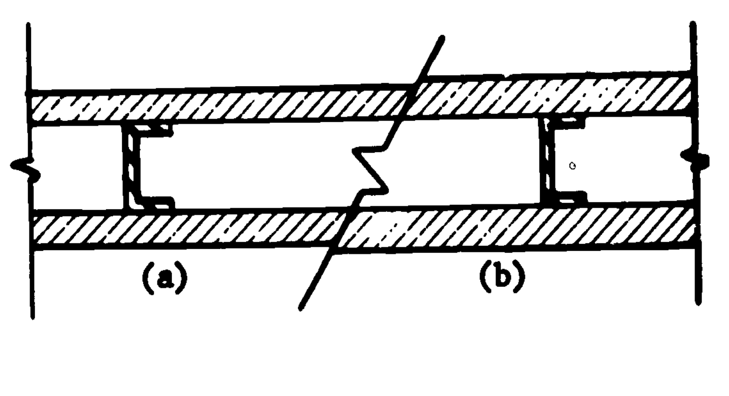
Area weight: 5.2 lb/ft^2

(a) ———— STC = 39; Fire Rating: 1/2 hr. (est.)

(b) -------------- STC = 38; Fire Rating: 1 hr.

REMARKS: The plotted curve, (a), shows the average value of four laboratory measurements of the same structure under four different conditions of relative humidity (28% - 92%) in the source room. The relative humidity in the receiving room held constant at 55%.





TYPE: METAL CHANNEL STUD, GYPSUM BOARD

TEST REF: (a) 7(b)-(TL 59-99); (b) 7-(TL 60-113)

DESCRIPTION: (a) 3 5/8-in. metal channel studs 24 in. on centers set into 3 5/8-in. metal floor and ceiling runners; 5/8-in. gypsum wallboard screwed to studs on both sides. All joints taped and finished.

Total thickness: 4 7/8 in.

Area weight: approximately 6 lb/ft^2 (Not specified in reference)

(b) Similar to (a) except an additional layer of 5/8-in. gypsum wallboard was laminated to both sides of panel.

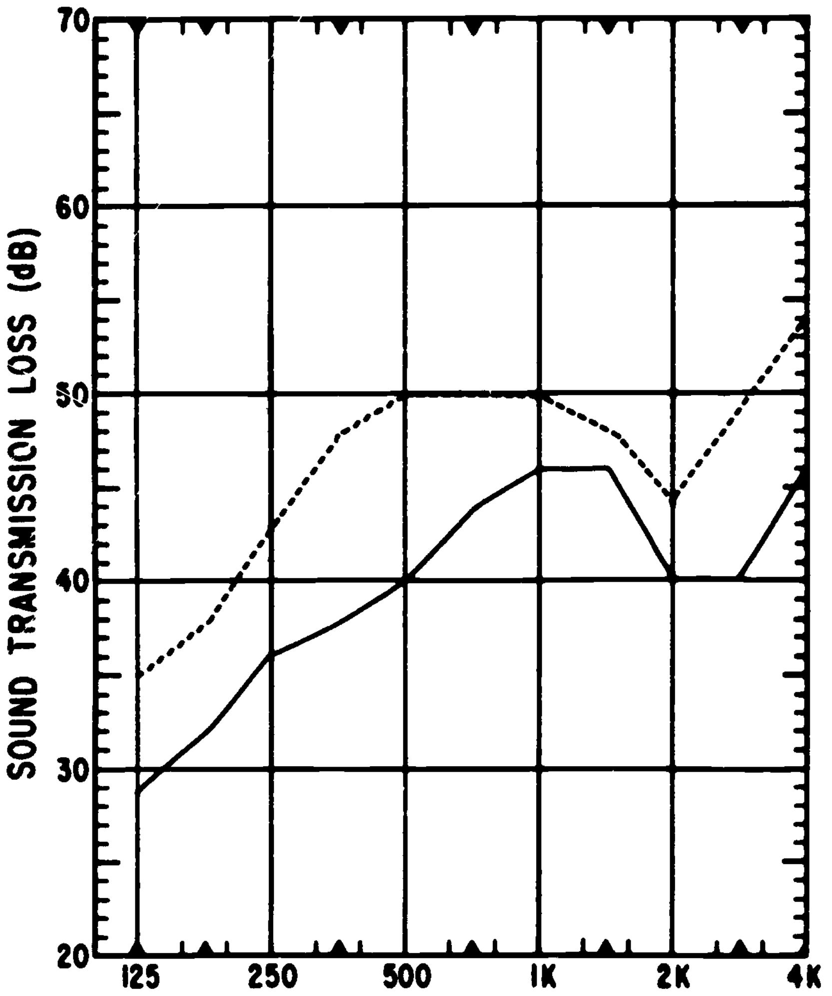
Total thickness: 6 1/8 in.

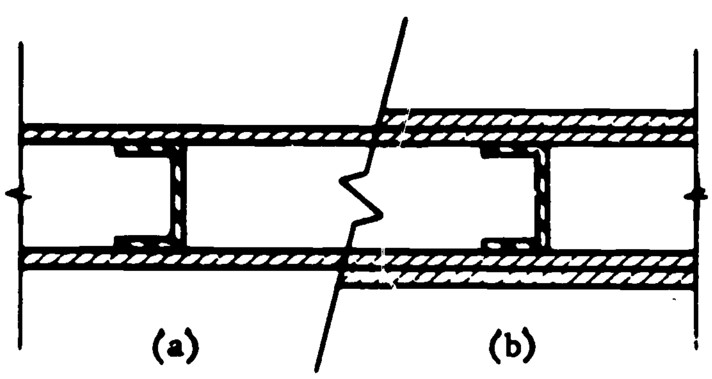
Area weight: 11.4 lb/ft^2

(a) ———— STC = 41; Fire Rating: 1 hr.

(b) ············ STC = 47; Fire Rating: 2 hrs.

REMARKS: The spacing of the screws not specified in reference.





TYPE: METAL CHANNEL STUD, TWO LAYERS GYPSUM BOARD

TEST REF: 9-(7-1152002a)

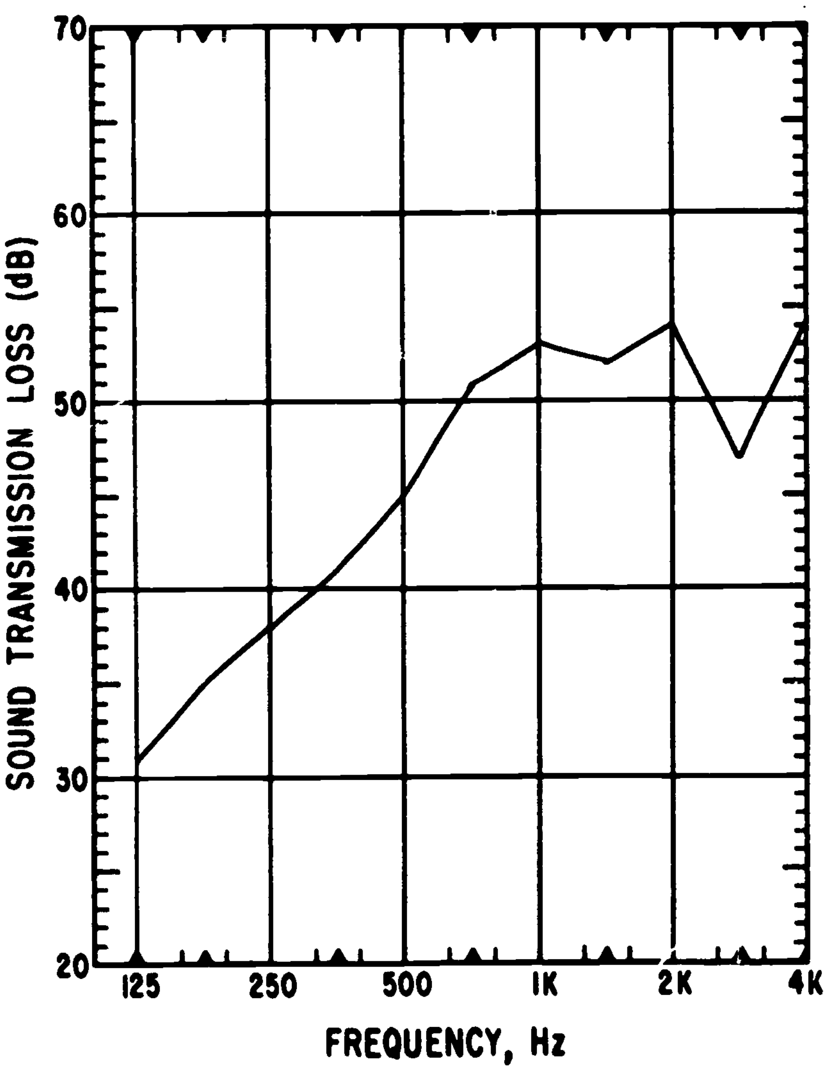
DESCRIPTION: 3 5/8-in. metal channel studs 27 3/4 in. on centers set into metal floor and ceiling tracks; stud at each adjoining wall and metal runners set on beads of non-setting resilient caulking compound. Two layers of 1/2-in. gypsum wallboard attached to both sides of studs; each layer screwed 12 in. on centers with screws staggered 6 in. in reference to each other. Joints of gypsum board staggered 24 in. with all exposed joints taped and finished. The 1/4-in. perimeter clearance around both layers closed with a non-setting resilient caulking compound.

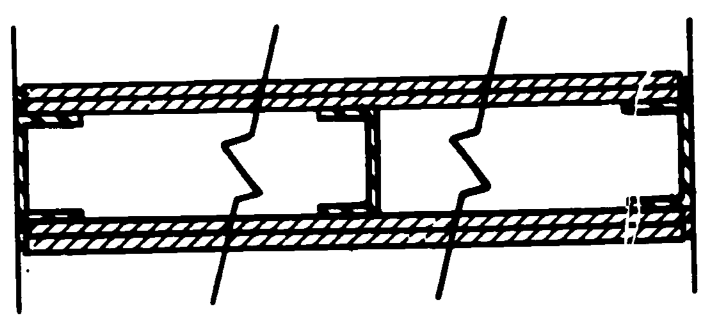
Total thickness: 5 5/8 in.

Area weight: 8.7 lb/ft^2

STC = 47; Fire Rating: 1 1/4 hrs. (est.)

REMARKS: The above test was conducted in the field.





TYPE: METAL CHANNEL STUD, FIBER BOARD, GYPSUM BOARD

TEST REF: 9-($1057c_1$)

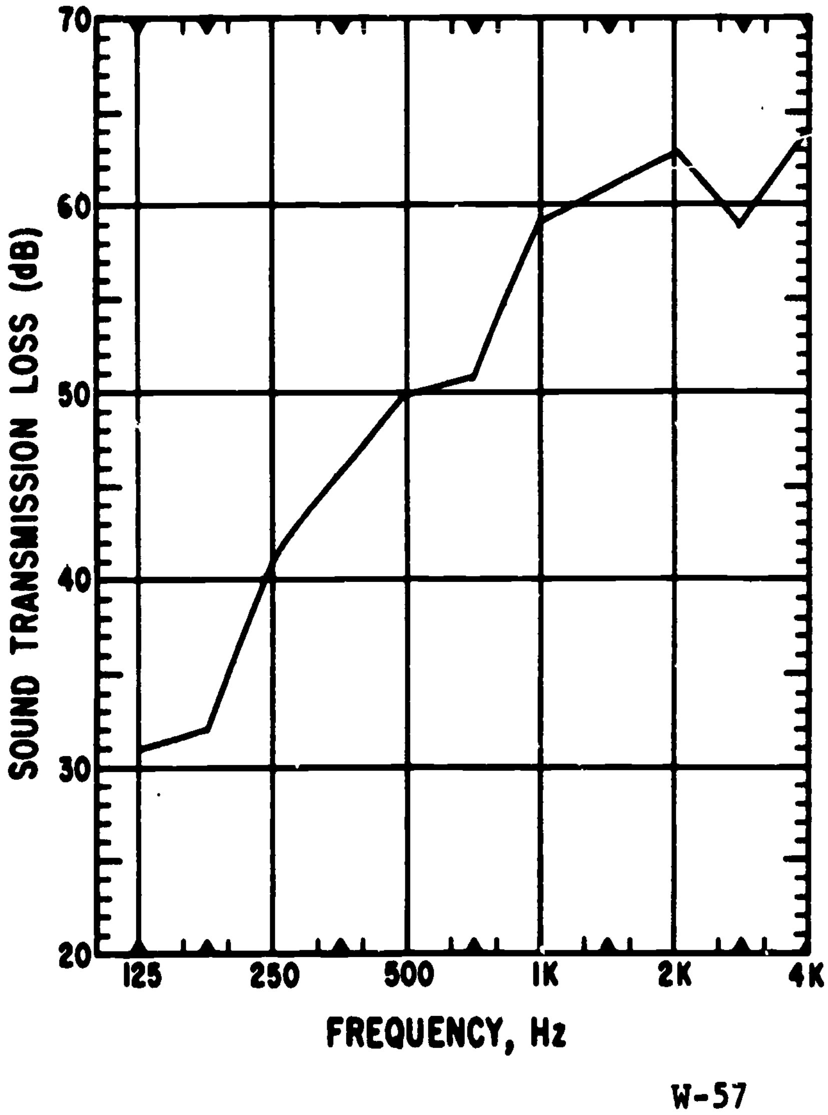
DESCRIPTION: 3 5/8-in. metal channel studs 12 in. on centers. Top, bottom and side channels isolated from concrete floor and ceiling with a resilient caulking compound. 1/2-in. mineral fiber board screwed 24 in. on centers to alternate studs on both sides such that both faces were not screwed to the same stud. 1/2-in. gypsum wallboard laminated and screwed 8 in. on centers along panel periphery and 12 in. on centers in field; lamination strips offset from screws. All exposed joints taped and finished.

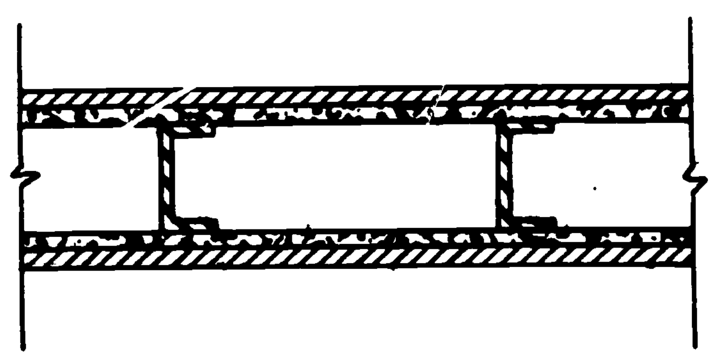
Total thickness: 5 5/8 in.

Area weight: 6.2 lb/ft^2

STC = 50; Fire Rating: 1 1/2 hrs. (est.)

REMARKS: The above test was conducted in the field with as many flanking paths as possible eliminated.





TYPE: METAL CHANNEL STUD, FIBER BOARD, GYPSUM BOARD

TEST REF: (a) 9-(109006b); (b) 9-($109006b_1$)

DESCRIPTION: (a) 3 5/8-in. metal channel studs 24 in. on centers set into floor and ceiling metal runner tracks; stud at each adjoining wall and metal runner tracks set on two beads of non-setting resilient caulking compound. 1/2-in. mineral fiber board screwed 24 in. on centers to both sides of studs, 5/8-in. gypsum wallboard laminated to fiber board using joint compound, spread so as to miss ar \s falling on studs; 1 5/8-in. screws, 12 in. on centers, set through both layers to studs during lamination. All exposed joints taped and finished. The 1/4-in. perim clearance around both layers closed with a non-setting resilient ca[illegible]ng compound. The partition was tested 98 hours after erection.

(b) Same as (a) but tested 243 hours after erection.

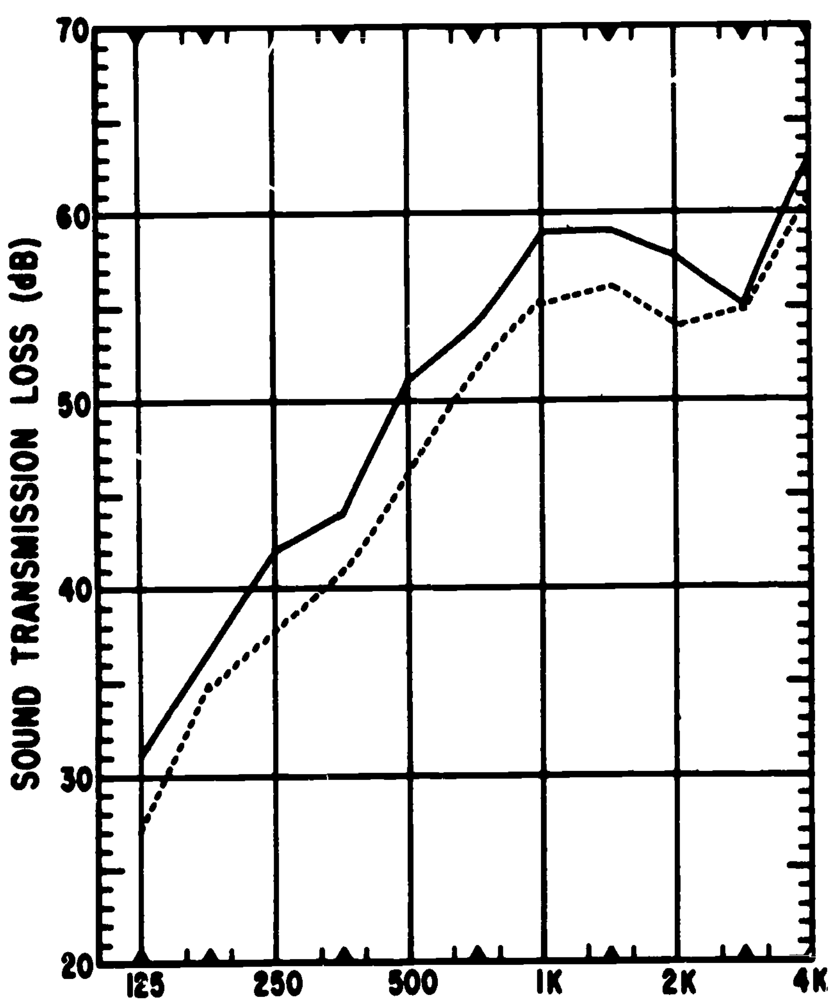
Total thickness: 5 7/8 in.

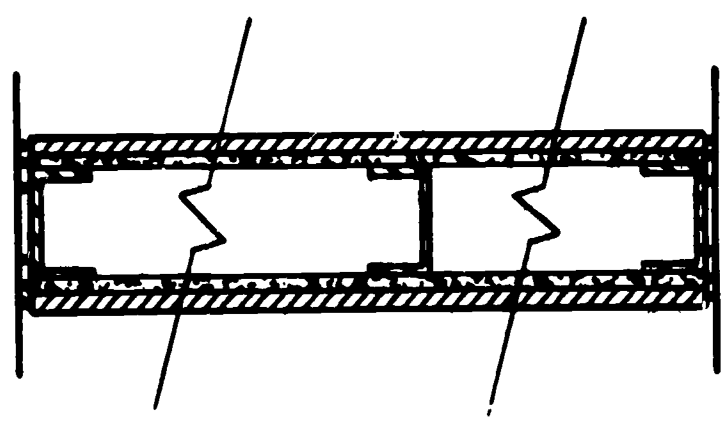
Area weight: 7.0 lb/ft^2

(a) ———— STC = 50; Fire Rating: 2 hrs. (est.)

(b) ·········· STC = 47

REMARKS: The above tests were conducted in the field.





TYPE: METAL CHANNEL STUD, FIBER BOARD, GYPSUM BOARD

TEST REF: 9-($1057b_1$)

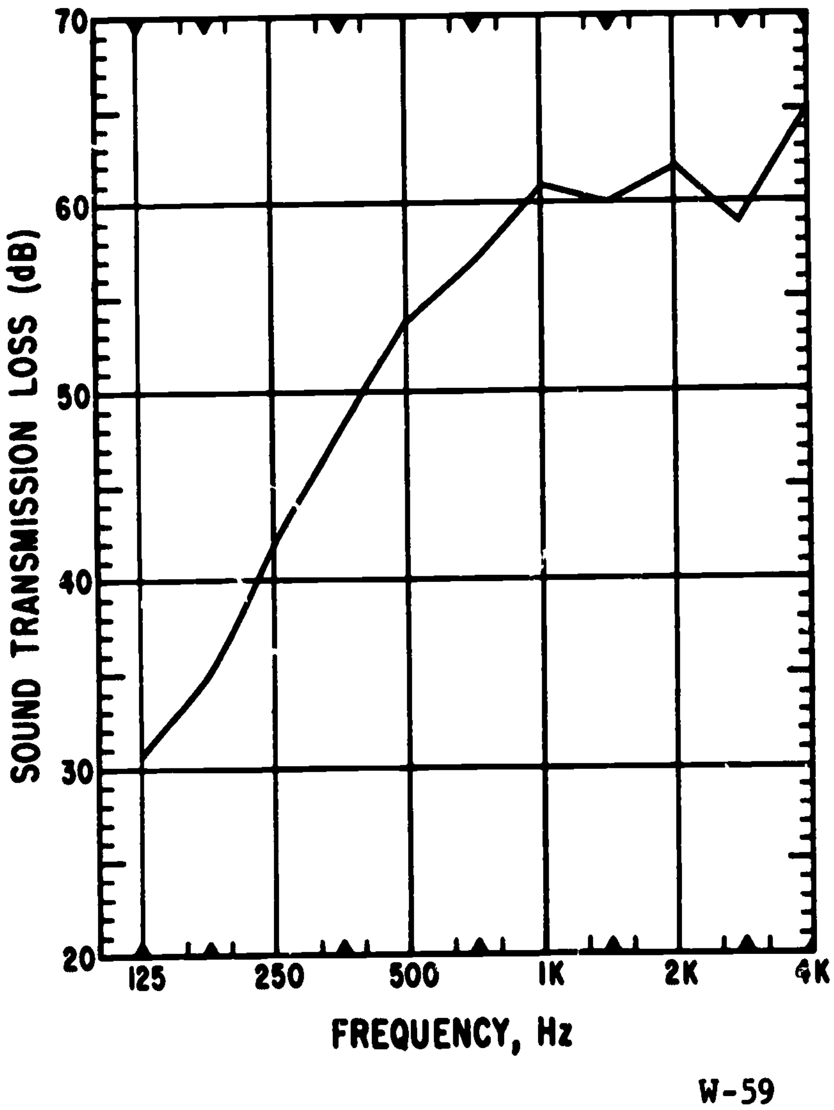
DESCRIPTION: 3 5/8-in. metal channel studs 24 in. on centers. Top, bottom and s' 'e channels isolated from concrete floor and ceiling with a resilient caulking compound. 1/2-in. mineral fiber board screwed 24 in. on centers to each side. On one side, 1/2-in. gypsum wallboard laminated and screwed 8 in. on centers along panel periphery and 12 in. on centers in field; lamination strips offset from screws. On other side, two layers of 1/2-in. gypsum wallboard, both attached in same manner as above. All exposed joints taped and finished.

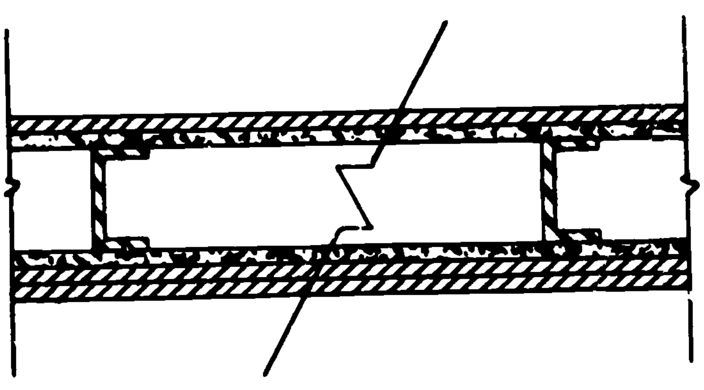
Total thickness: 6 1/8 in.

Area weight: 8.2 lb/ft^2

STC = 52; Fire Rating: 1 1/2 hrs. (est.)

REMARKS: The above test was conducted in the field with as many flanking paths as possible eliminated.





TYPE: METAL CHANNEL STUD, GYPSUM BOARD WITH INSULATION

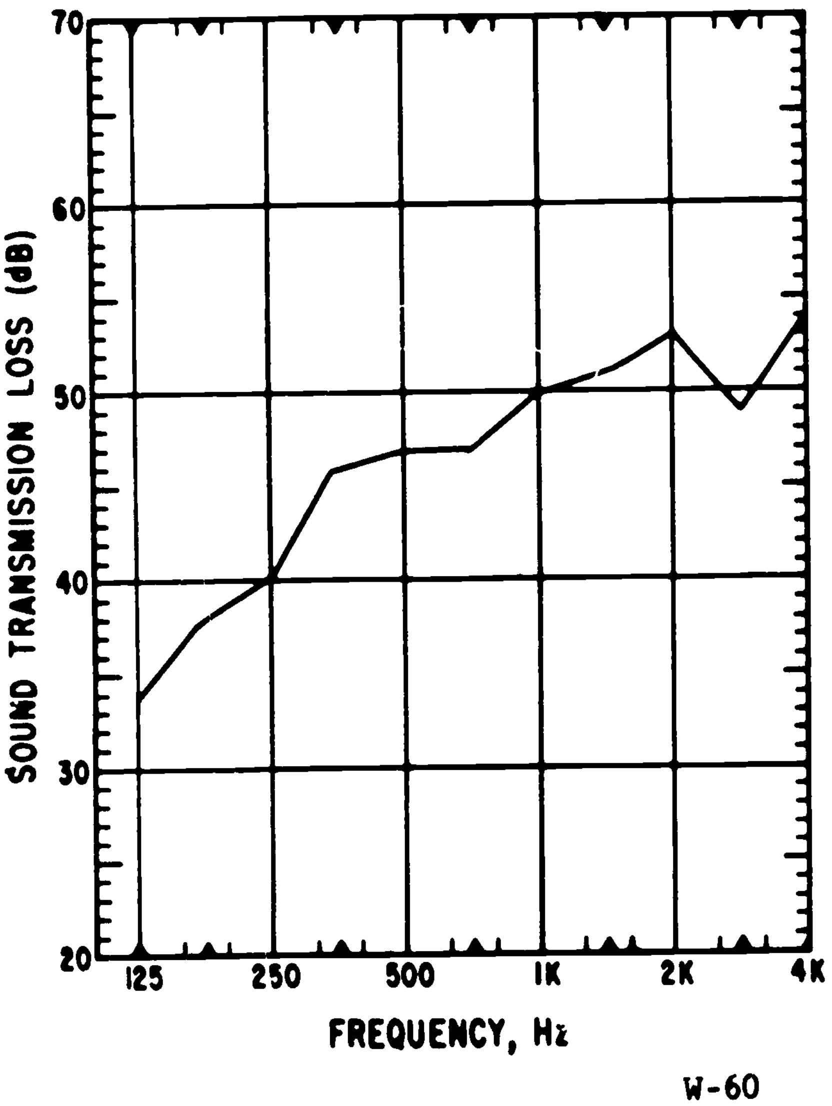
TEST REF: 7-(TL 63-127)

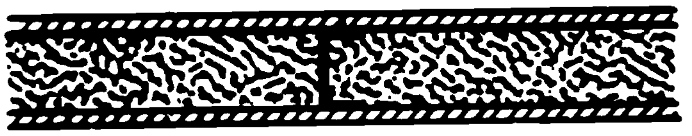
DESCRIPTION: 2 1/2-in. metal channel studs 24 in. on centers set in 2 1/2-in. metal floor and ceiling runners; 1/2-in. vinyl-coated gypsum wallboard adhesively attached and screwed to studs on both sides. All joints sealed with caulking compound. Aluminum batten strips screwed 12 in. on centers to gypsum board at joints; top and bottom finished with aluminum ceiling and base trim. 2-in. mineral fiber blankets hung between studs.

Total thickness: 3 1/2 in.

Area weight: 5.4 lb/ft^2

STC = 50; Fire Rating: 1 hr.





TYPE: METAL CHANNEL STUD, DOUBLE LAYER GYPSUM BOARD WITH INSULATION

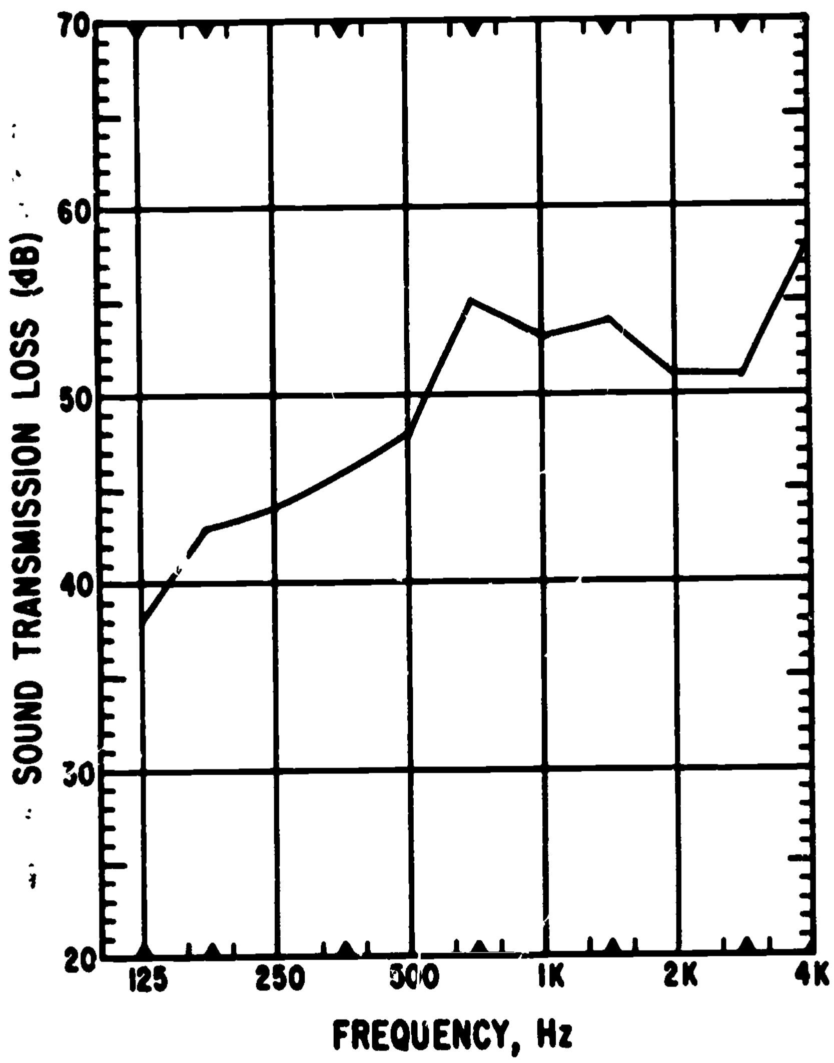
TEST REF: 9-(1068r)

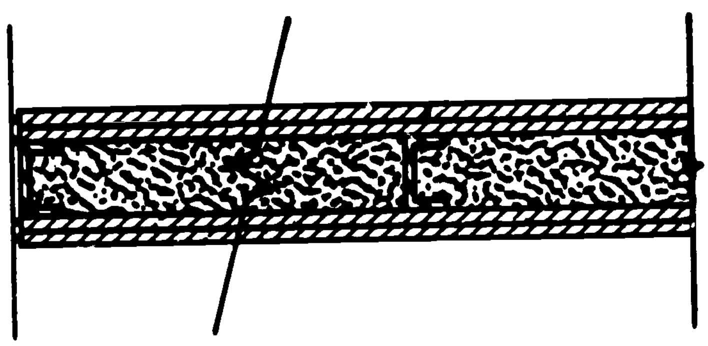
DESCRIPTION: 2 1/2-in. metal channel studs 24 in. on centers set into metal floor and ceiling runners which were set on beads of non-setting resilient caulking compound. Two layers of 1/2-in. gypsum wallboard attached to both sides of studs, both layers screwed 12 in. on centers with screws of each layer staggered 6 in. relative to each other. 3 1/2-in.-thick glass fibered blankets, 2 lb/ft^3, stapled between studs. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound.

Total thickness: 4 1/2 in.

Area weight: 8.3 lb/ft^2

STC = 52; Fire Rating: 1 1/4 hr. (est.)





TYPE: METAL CHANNEL STUD, GYPSUM BOARD WITH INSULATION

TEST REF: 9-(7-1131001a)

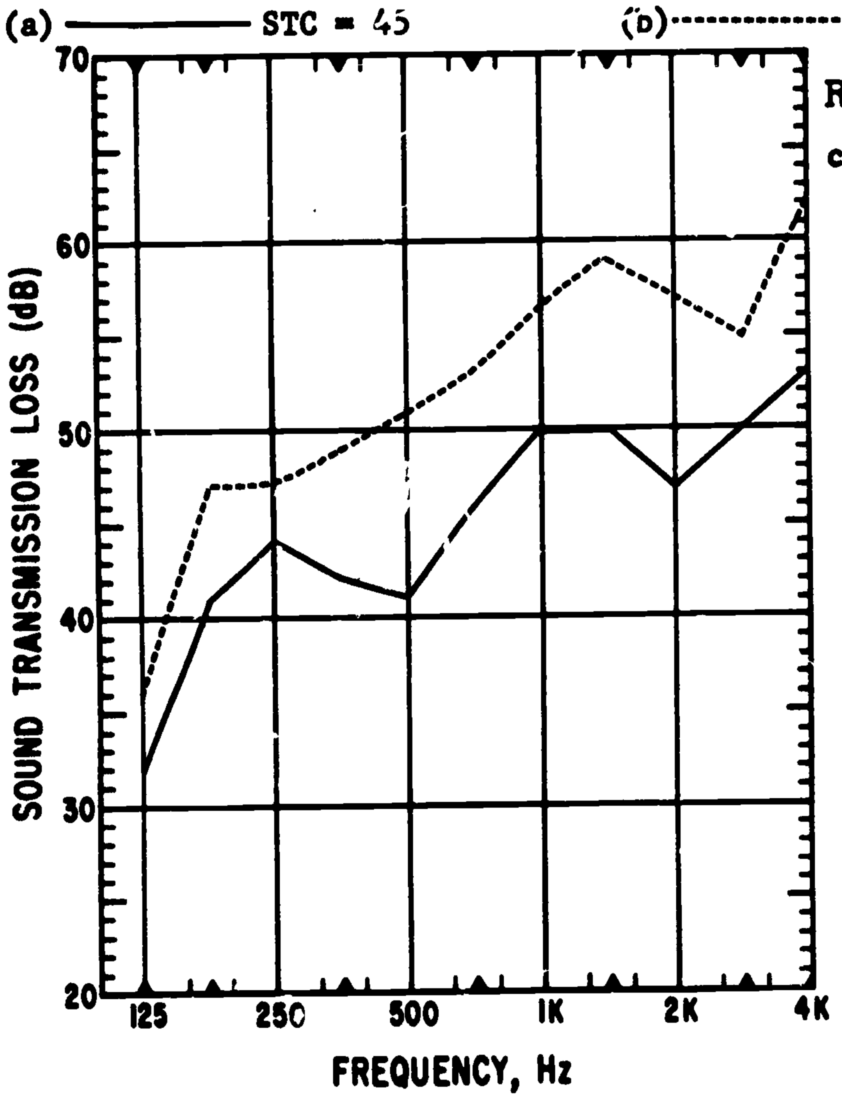
DESCRIPTION: (a) 3 5/8-in. metal channel studs 24 in. on centers set into floor and ceiling runners; stud at each adjoining wall and metal runners set on beads of non-setting resilient caulking compound. On both sides, two layers of 5/8-in. gypsum wallboard; first layer screwed 12 in. on centers midway between joints and 8 in. on centers along joints, second layer glued to base layer with mastic spread so as to omit areas falling on the studs, screws 24 in. on centers at joints only. 1 1/2-in. mineral wool blankets, 3 lb/ft^3, stapled between studs. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound. All exposed joints taped and finished.

(b) Same as (a) except all possible flanking paths were eliminated. Therefore, the difference in sound transmission loss values may be attributed to the presence of flanking paths through the exterior window wall.

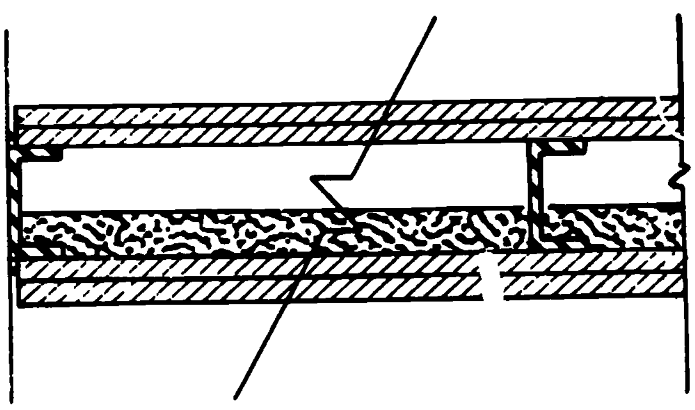
Total thickness: 6 1/8 in.

Area weight: 11.5 lb/ft^2

(a) ———— STC = 45 (b)············ STC = 55; Fire Rating: 2 hrs.



REMARKS: The above tests were conducted in the field.



TYPE: METAL CHANNEL STUD, DOUBLE LAYER GYPSUM BOARD WITH INSULATION

TEST REF: 9-(109006a)

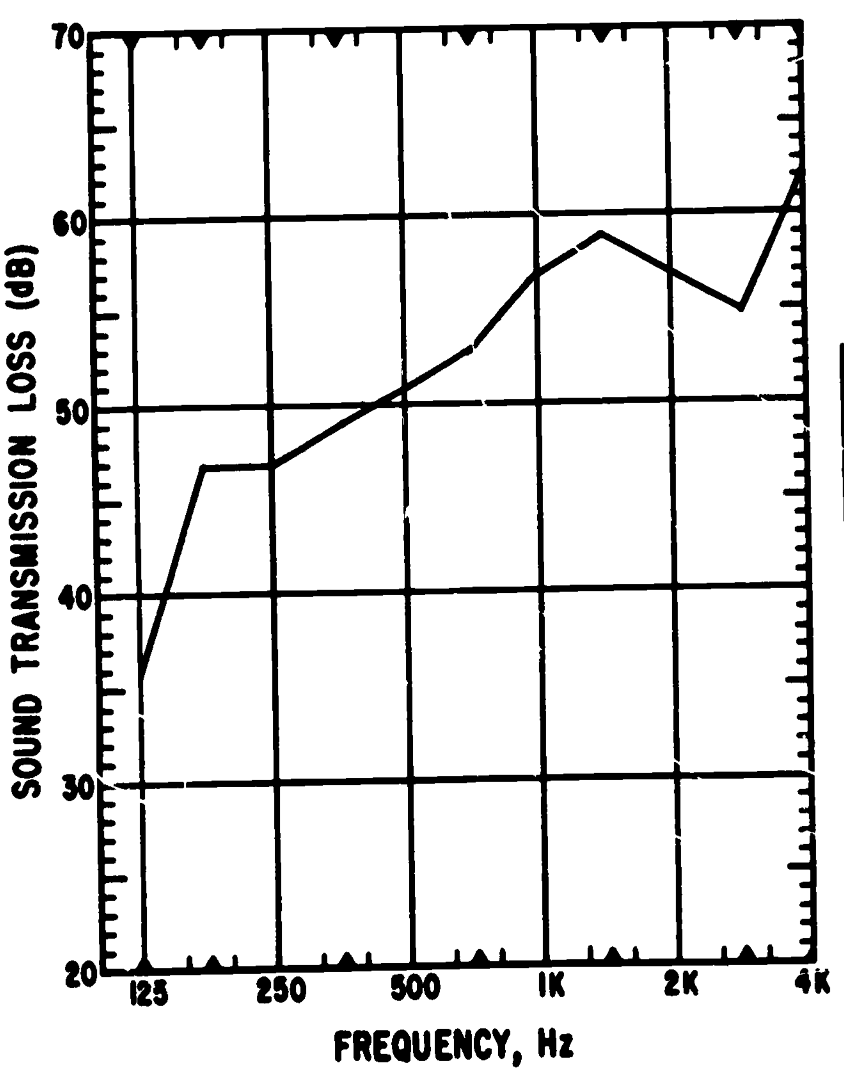
DESCRIPTION: 3 5/8-in. metal channel studs 24 in. on centers set into 3 5/8-in. metal runners which were attached through continuous beads of non-setting resilient caulking compound to floor and ceiling respectively. Two layers of 5/8-in. gypsum wallboard attached to both sides of studs; first layer screwed 8 in. on centers at joints and 12 in. on centers in field, second layer laminated and screwed 24 in. on centers to first layer with joints staggered 24 inches. 1 1/2-in.-thick mineral fiber felt, 3 lb/ft^3, stapled between studs. All exposed joints taped and finished. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound.

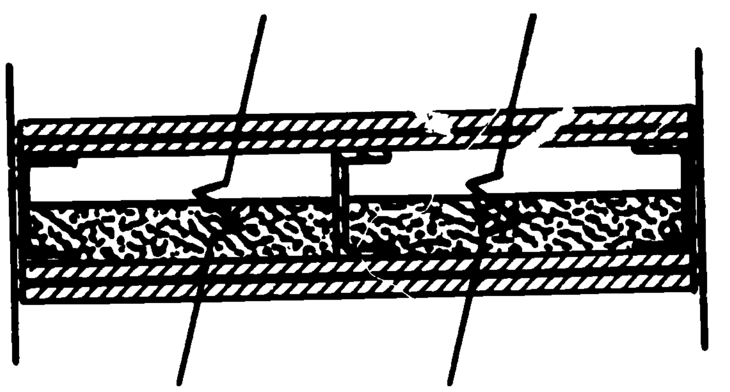
Total thickness: 6 1/8 in.

Area weight: 11.5 lb/ft^2

STC = 55; Fire Rating: 2 hrs. (est.)

REMARKS: The above test was conducted in the field.





TYPE: METAL CHANNEL STUD, TWO LAYERS GYPSUM BOARD

TEST REF: 9-(7-1152008a, 1121b)

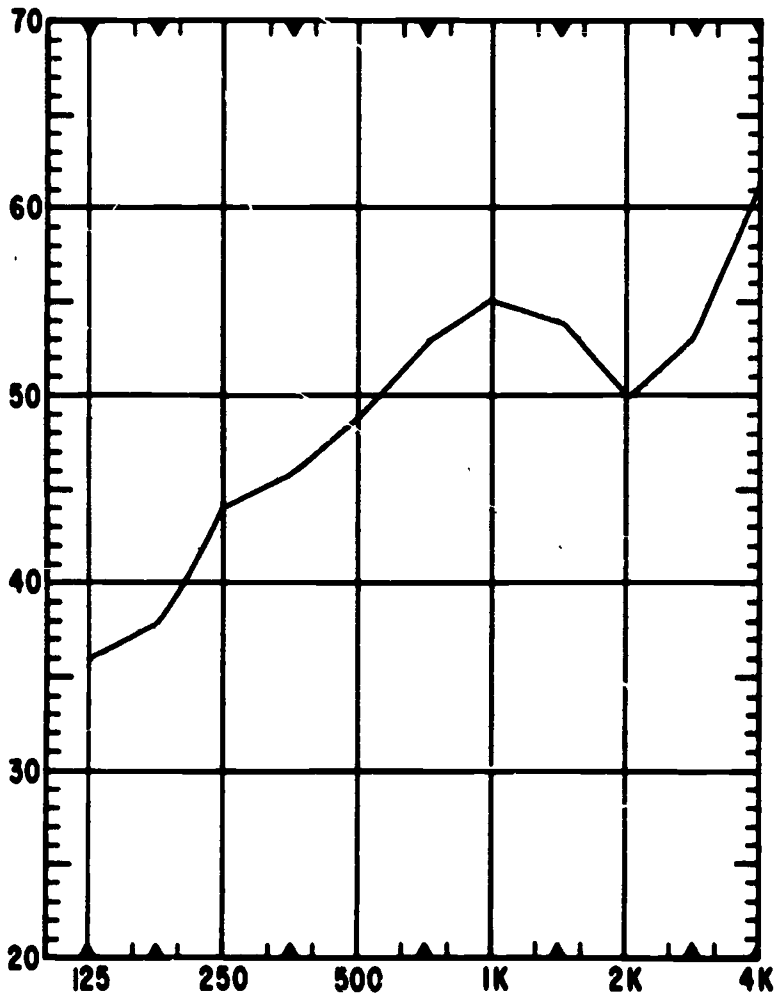
DESCRIPTION: 3 5/8-in. metal channel studs 24 in. on centers set into metal floor and ceiling tracks; stud at each adjoining wall and metal runners set on beads of non-setting resilient caulking compound. Two layers of 5/8-in. gypsum wallboard attached to both sides of studs; each layer screwed 12 in. on centers with screws staggered 6 in. relative to each other. 1 1/2-in.-thick fibered glass blankets stapled between studs. Joints of gypsum board staggered 24 in. with all exposed joints taped and finished. The 1/4-in. perimeter clearance around both layers closed with a non-setting resilient caulking compound.

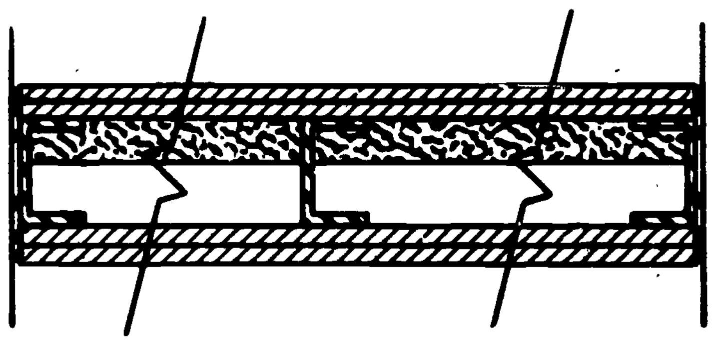
Total thickness: 6 1/8 in.

Area weight: 10.9-11.5 lb/ft^2

STC = 52; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curve represents the average of field measurements of two nominally identical structures.





TYPE: METAL CHANNEL STUD, DOUBLE LAYER GYPSUM LATH WITH INSULATION

TEST REF: 9-(8-1090072a)

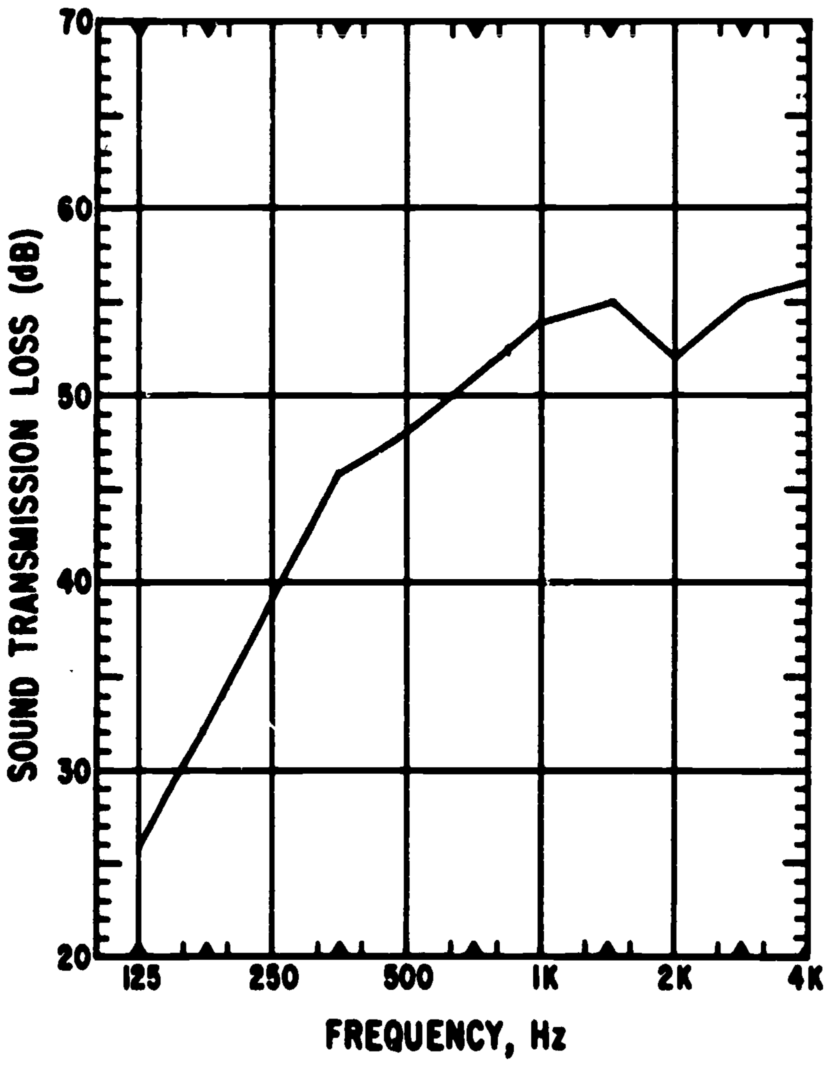
DESCRIPTION: 2 1/2-in. metal channel studs 24 in. on centers set into metal floor and ceiling runners which were attached 24 in. on centers. Runners isolated at floor and ceiling with 1/2-in.-thick continuous resilient gaskets. Two layers of 1/2-in. gypsum lath attached to both sides of studs; first layer screwed 8 in. on centers at joints and 12 in. on centers in field, second layer laminated and screwed 36 in. on centers at board edges and 48 in. on centers in field with joints staggered 12 in. with respect to first layer. 2-in.-thick mineral fiber blankets, 2.5 lb/ft^3, stapled between studs. 1/16-in. finish coat of plaster applied to both sides of wall. The 1/4-in. clearance around the perimeter closed with a non-setting resilient caulking compound.

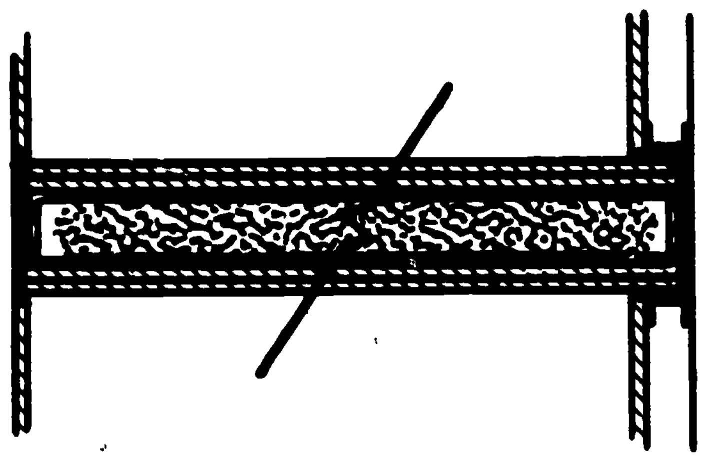
Total thickness: 4 5/8 in.

Area weight: 8.9 lb/ft^2

STC = 48; Fire Rating: 1 1/4 hrs. (est.)

REMARKS: The above test was conducted in the field. One adjoining wall was constructed with 1 5/8-in. metal channel studs, 1/2-in. gypsum lath and finish coat of plaster; the other wall was 5/8-in. plaster on masonry.





TYPE: METAL CHANNEL STUD, CORK, DOUBLE LAYER GYPSUM BOARD

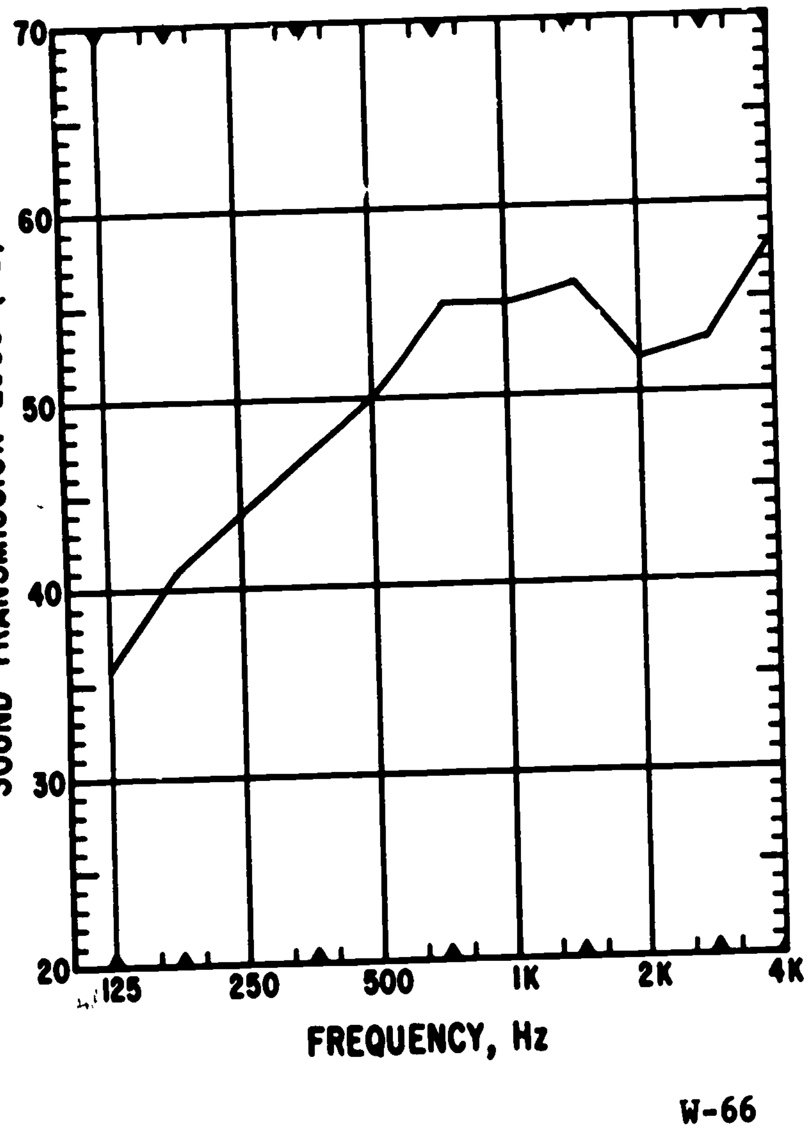
TEST REF: 7-(TL 65-60)

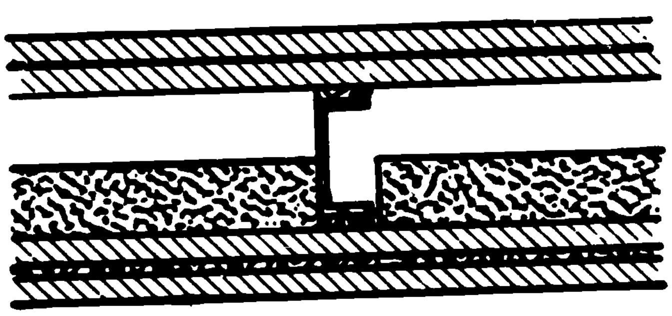
DESCRIPTION: 2 1/2-in. metal channel studs 24 in. on centers set in 2 1/2-in. metal floor and ceiling runners, 1/4- by 1-in. cork strips, 12 lb/ft^3, laminated vertically to studs; 5/8-in. gypsum wallboard screwed 12 in. on centers through cork to studs on both sides. On one side, 1/4-in. cork, 12 lb/ft^3, laminated to gypsum wallboard, and a second layer of 5/8-in. gypsum wallboard laminated to cork. On the other side, a second layer of 5/8-in. gypsum wallboard laminated to the first layer. 1 1/2-in. glass fibered blankets installed between studs. All exposed joints taped and finished.

Total thickness: 5 3/4 in.

Area weight: 10.6 lb/ft^2

STC = 53; Fire Rating: 1 1/2 hrs. (est.)





TYPE: METAL CHANNEL STUD, GYPSUM BOARD WITH INSULATION, RESILIENT

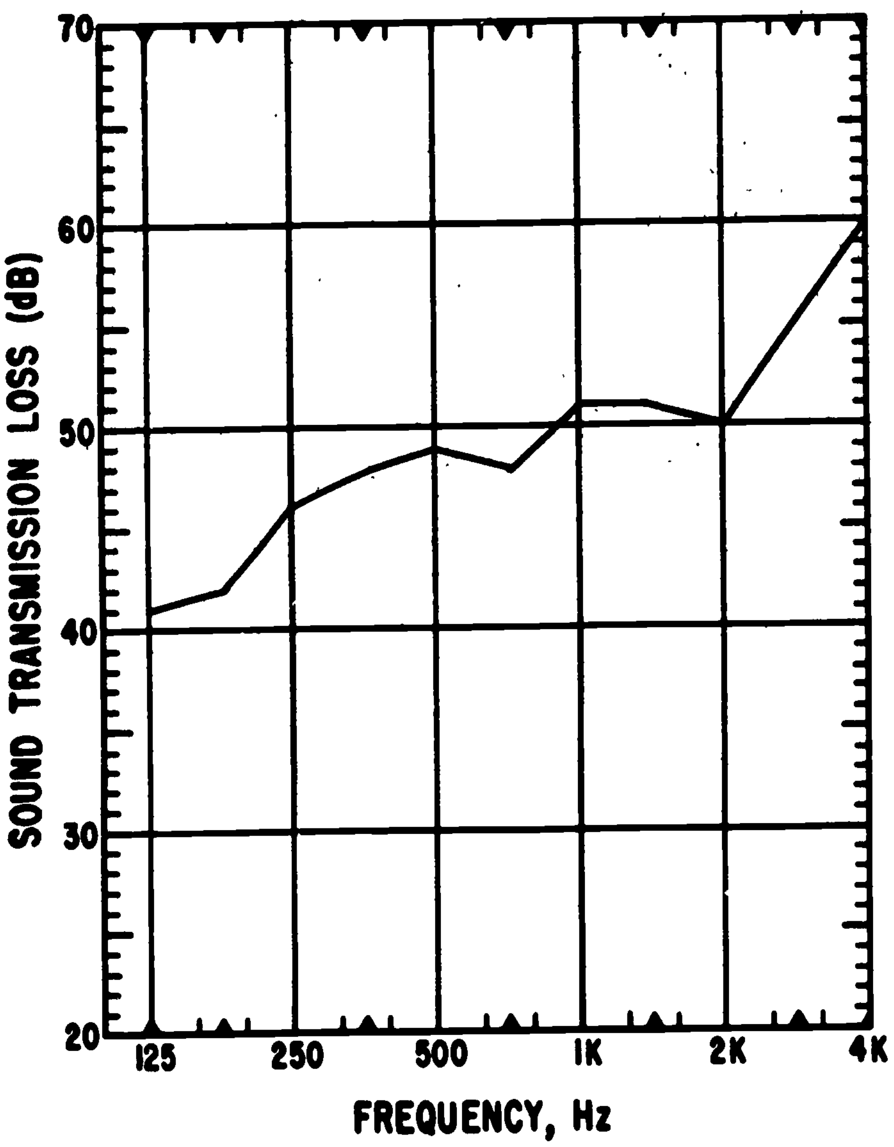
TEST REF: 7-(TL 62-212)

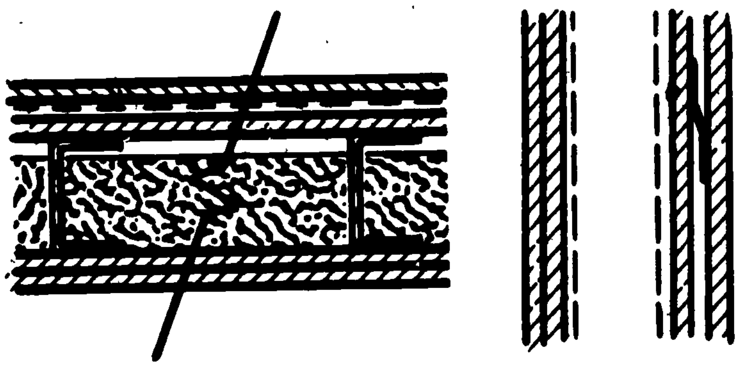
DESCRIPTION: 3 5/8-in. metal channel studs 24 in. on centers set in 3 5/8-in. metal floor and ceiling runners; 5/8-in. gypsum wallboard screwed to studs on both sides. On one side, resilient channels screwed horizontally 24 in. on centers to inner layer; 5/8-in. gypsum wallboard screwed to channels. On the other side, 5/8-in. gypsum wallboard laminated directly to inner layer. 3-in. mineral fiber blankets hung between studs. All exposed joints taped and finished.

Total thickness: 6 1/2 in.

Area weight: 11.3 lb/ft^2

STC = 51; Fire Rating: 2 hrs. (est.)





TYPE: STAGGERED METAL CHANNEL STUD, GYPSUM BOARD WITH INSULATION

TEST REF: (a) 7-(TL 64-1); (b) 7-(TL 64-3)

DESCRIPTION: (a) Two rows of 2 1/2-in. staggered metal channel studs 24 in. on centers attached to 2 1/2-in. metal floor and ceiling runners separated by 1/2-in. gypsum wallboard screwed 12 in. on centers to both sets of studs; 1/2-in. gypsum wallboard screwed 6 in. on centers at board joints and adhesively attached to intermediate studs on both sides of wall. 2-in. mineral fiber felt hung between studs on both sides. All exposed joints taped and finished.

Total thickness: approximately 7 in.

Area weight: 7.2 lb/ft^2

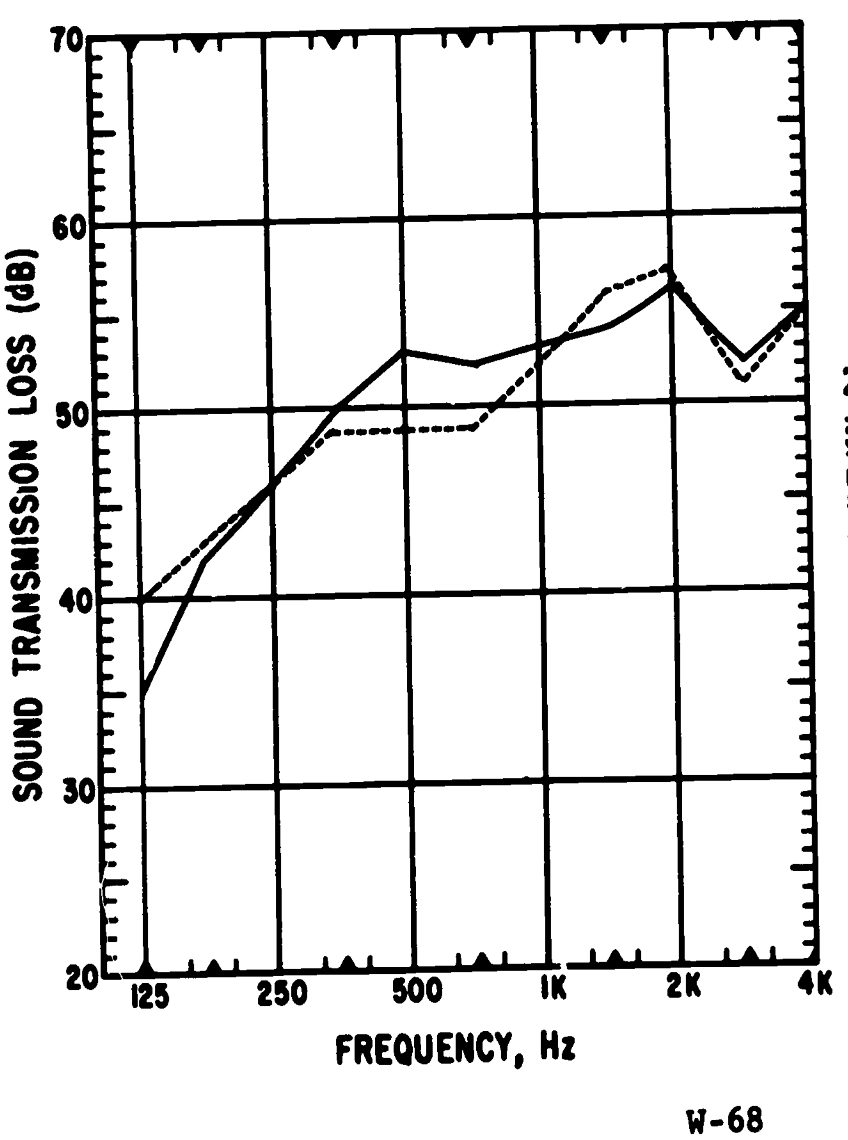
(b) Similar to (a) except the wall was painted.

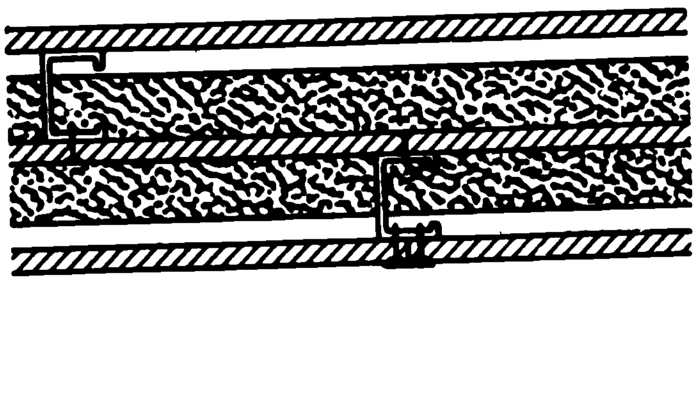
Total thickness: approximately 7 in.

Area weight: 7.4 lb/ft^2

(a) ———— STC = 54; Fire Rating: 1 1/4 hrs. (est.)

(b) ------------ STC = 52





TYPE: STAGGERED METAL BOX STUD, DOUBLE LAYER GYPSUM LATH

TEST REF: 9-(8-1090072g)

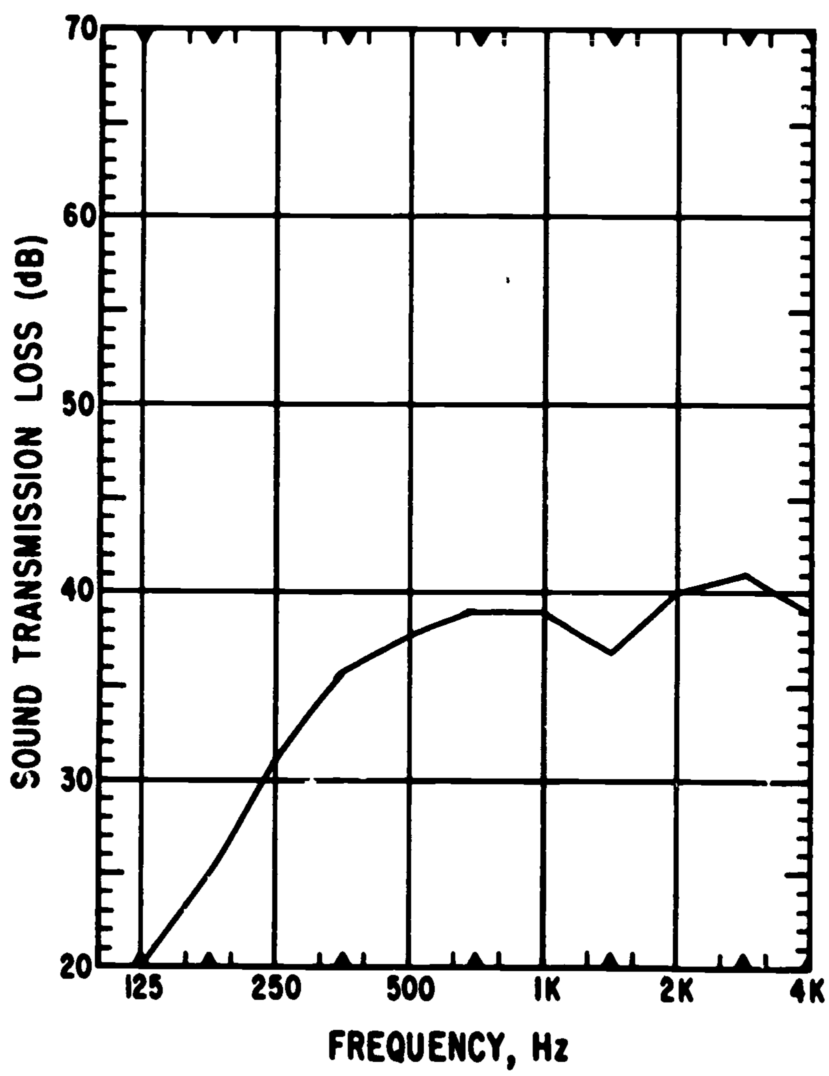
DESCRIPTION: Two rows of 1 5/8-in. metal box studs 24 in. on centers, staggered 10 in. on centers relative to opposite side, set into metal ceiling runners separated by 1/8 in. and on a wooden floor plate. 1/2-in. gypsum lath attached to both sides of wall with screws, 3 on each vertical edge and 2 at 1/3 points of intermediate studs, face layer of 1/2-in. gypsum lath screwed 12 in. on centers to first layer on both sides with joints staggered 24 in., 1/16-in. finish coat of plaster applied to both sides.

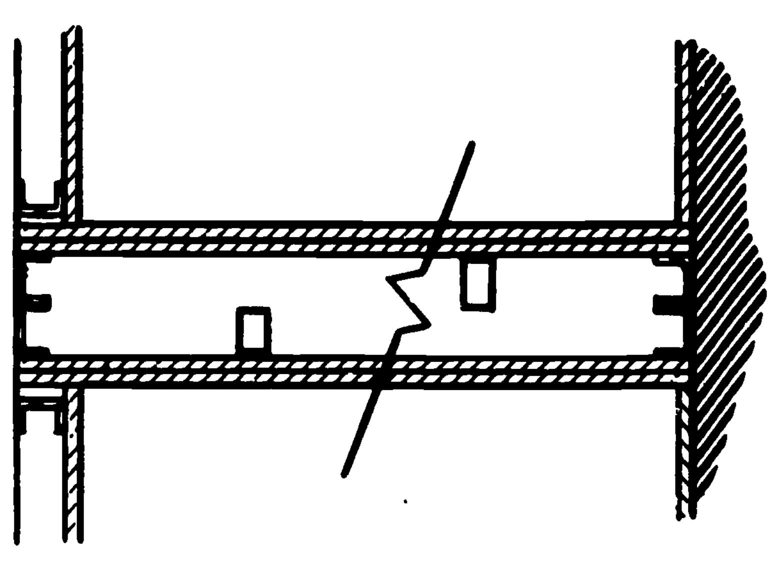
Total thickness: 5 1/2 in.

Area weight: 9.7 lb/ft^2

STC = 37; Fire Rating: 1 1/4 hrs. (est.)

REMARKS: The above test was conducted in the field. One adjoining wall was constructed with 1 5/8-in. metal channel studs, 1/2-in. gypsum lath and finish coat of plaster; the other wall was plastered masonry.





TYPE: METAL CHANNELS, GYPSUM LATH AND PLASTER

TEST REF: (a) 2-(427); (b) 2-(426)

DESCRIPTION: (a) One 3/4-in. cold-rolled steel channel set vertically in center of panel (corresponds to approximately 33 in. on centers); horizontal 3/4-in. channels 26 in. on centers wire-tied on each side of vertical channel, with channels on opposite sides displaced about 6 in. relative to each other and attached at ends to short lengths of ceiling runners. All channels placed with 3/4-in. dimension parallel to panel so as to bridge a 1 1/2-in. airspace. On each side, 1/2-in. gypsum lath wire-tied to channels and set into groove of wood floor runner; 3/4-in. sanded gypsum plaster applied to lath.

Total thickness: 4 in.

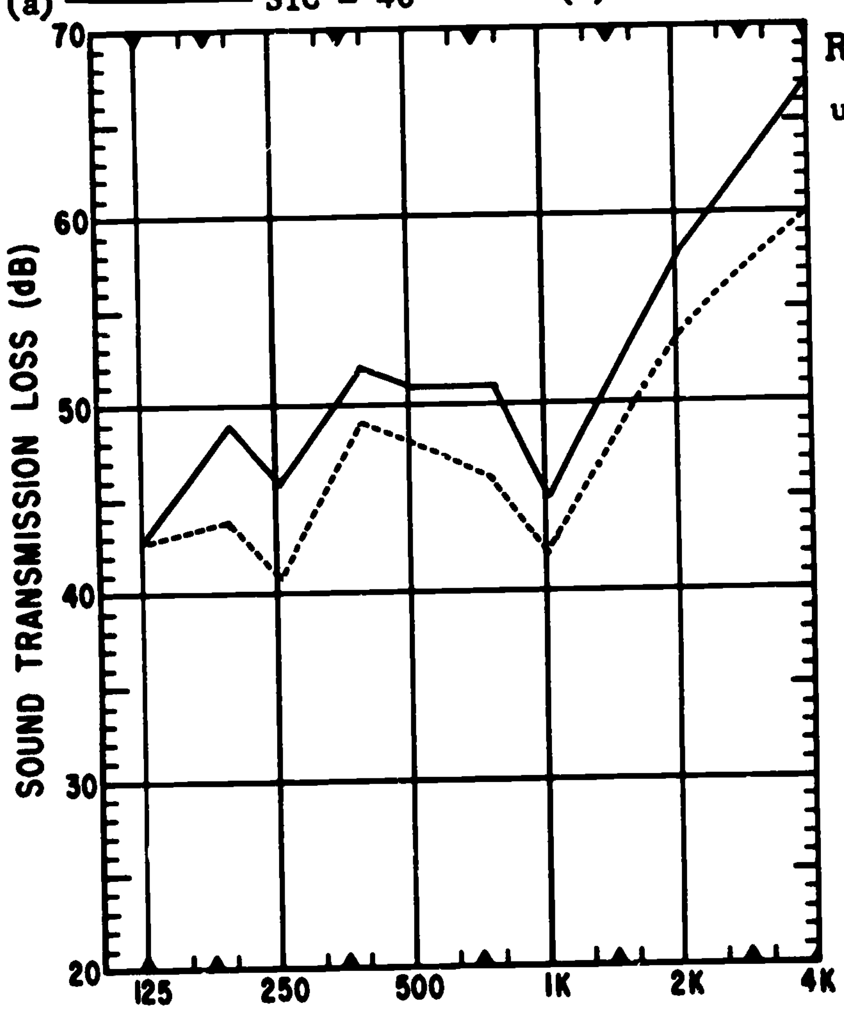
Area weight: 17.4 lb/ft^2

(b) Similar to (a) except the center channel was 1 1/2 in., with horizontal 1 1/2-in. channels 28 1/4 in. on centers wire-tied between vertical channel and edges of panel, thus bridging a 1 1/2-in. airspace.

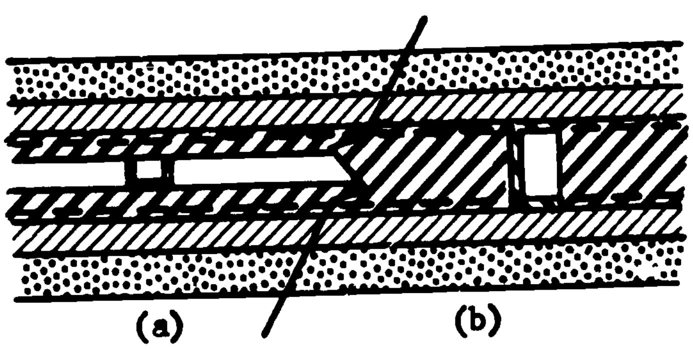
Total thickness: 4 in.

Area weight: 17.3 lb/ft^2

(a) ———— STC = 46 (b) ·········· STC = 43; Fire Rating: 1 hr. (est.)



REMARKS: The STC values are based upon nine test frequencies.



TYPE: STAGGERED METAL CHANNEL STUD, GYPSUM LATH AND PLASTER

TEST REF: 2-(435)

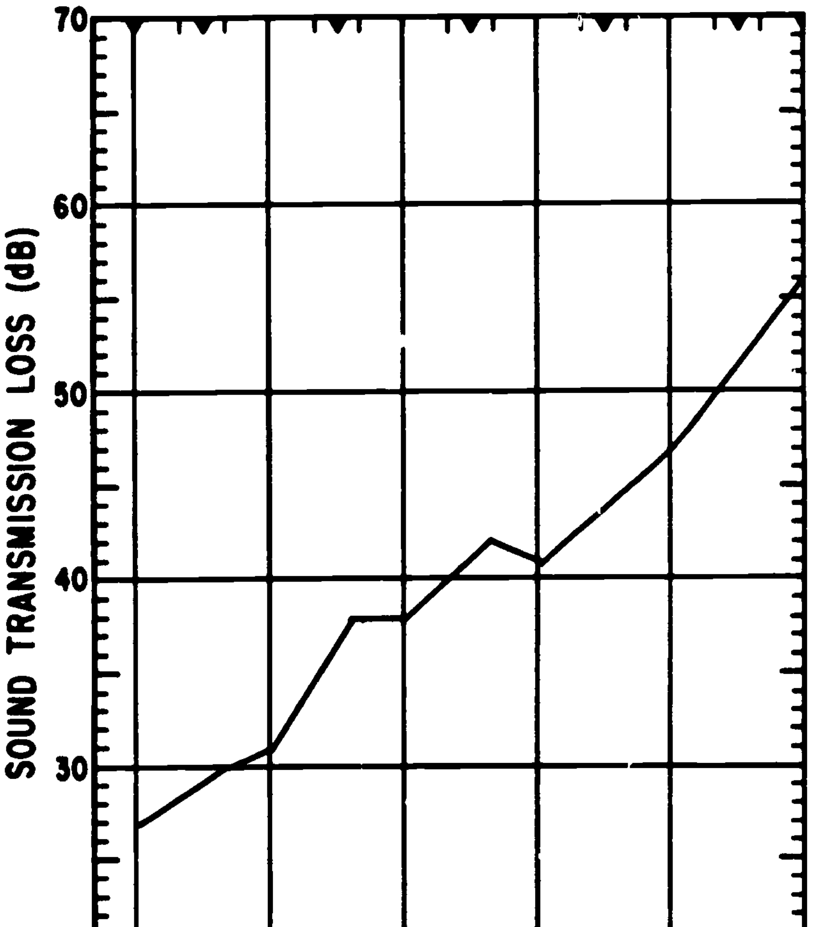
DESCRIPTION: Staggered 3/4-in. cold-rolled steel channels, spaced 16 in. on centers, staggered 1/2 in. and offset 1/4 in. relative to opposite face. Channels held at top by punched-out metal runner and at bottom, set into holes in a 1/4-in.-thick cork strip on top of another continuous layer of 1/4-in. cork. On each side, 3/8-in. gypsum lath held to studs with wire clips and from studs of opposite side by 3/8-in.-thick sponge-rubber dots; 1/2-in. perlite gypsum plaster applied to lath.

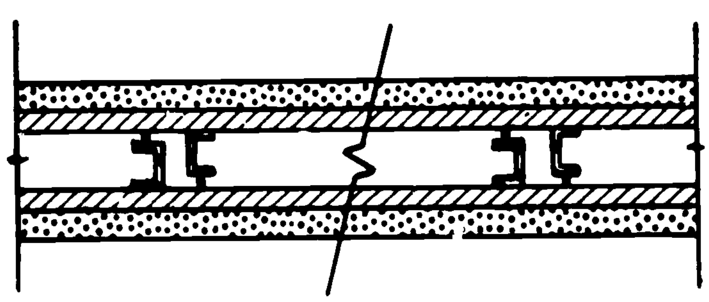
Total thickness: 2 3/4 in.

Area weight: 8.6 lb/ft^2

STC = 42; Fire Rating: Not available

REMARKS: The STC value is based upon nine test frequencies.





TYPE: METAL CHANNELS, GYPSUM LATH AND PLASTER

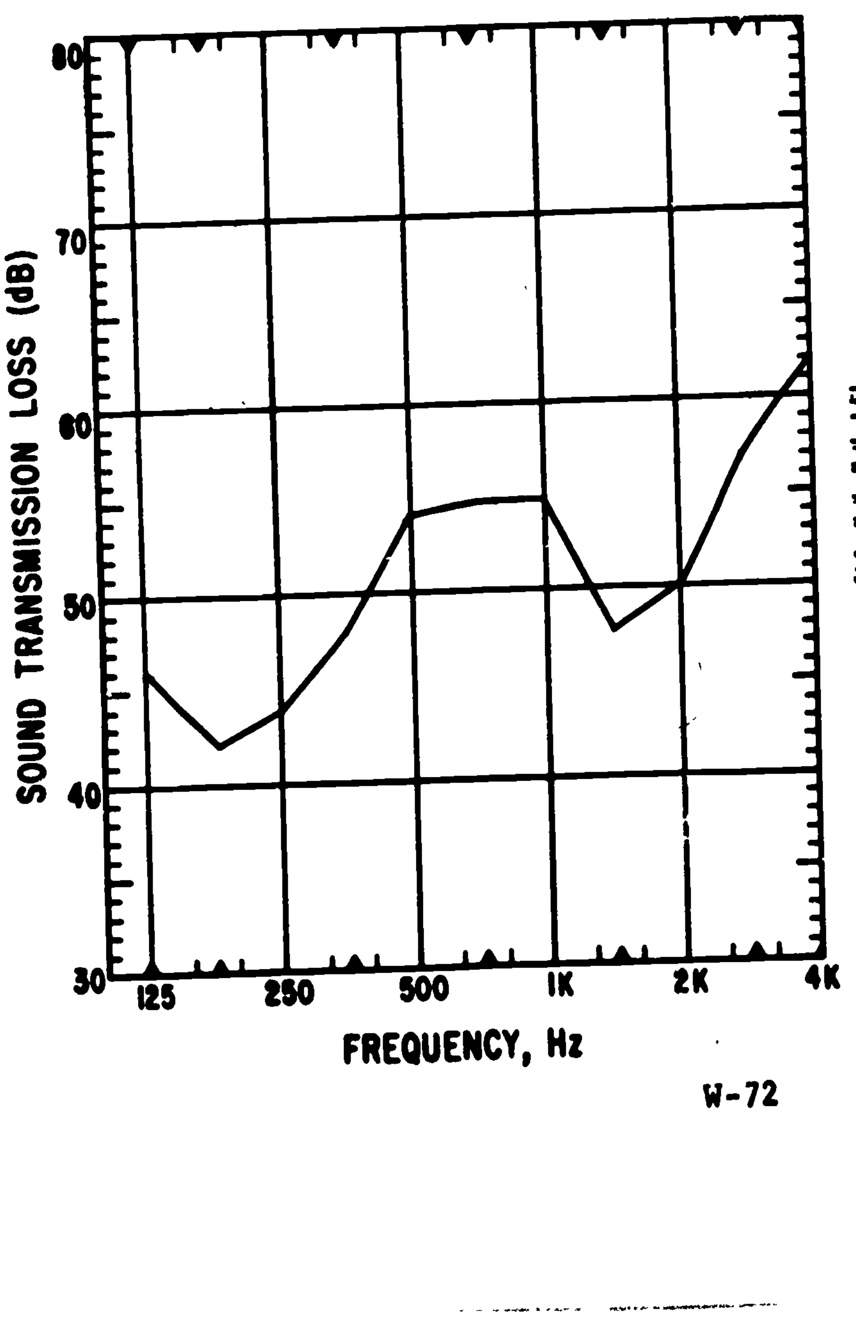
TEST REF: 3-(440)

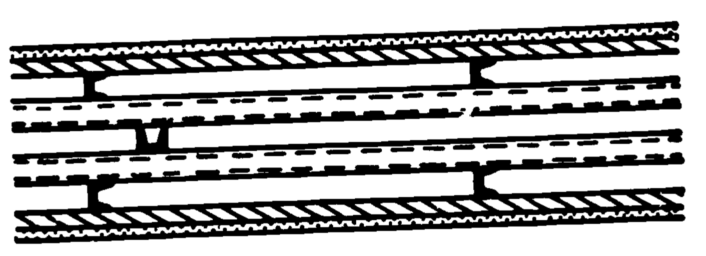
DESCRIPTION: Five layers of 3/4-in. cold-rolled steel channel, wire-tied together, formed core of panel. The center layer consisted of two pieces of channel 2 in. long placed vertically 40 in. apart and wire-tied between two horizontal lengths of channel. Vertical channels 16 in. on centers were wire-tied to the horizontal channels; 3/8-in. plain gypsum lath, 16 in. wide, was wire-tied to vertical channels, with lath joints held by sheet metal clips; 1/2-in. sanded gypsum plaster with white-coat finish applied to both sides.

Total thickness: 5 1/2 in.

Area weight: 13.5 lb/ft^2

STC = 48; Fire Rating: 45 min. (est.)





TYPE: DOUBLE WALL, SOLID PLASTER LEAVES

TEST REF: (a) 2-(160H); (b) 4-(Fig. 13.43)

DESCRIPTION: (a) Double wall on concrete with a separation of 4 1/2 in. Each leaf consisted of 3/4-in. metal channels 12 in. on centers stiffened by a 1-in. horizontal metal channel about halfway up the panel; expanded metal lath and 3/4-in. sanded gypsum plaster on both sides of wall.

Total thickness: 7 1/2 in.

Area weight: 17.2 lb/ft^2

(b) Similar to (a) except the measurements were conducted in the field and the plaster was 5/8 in. thick.

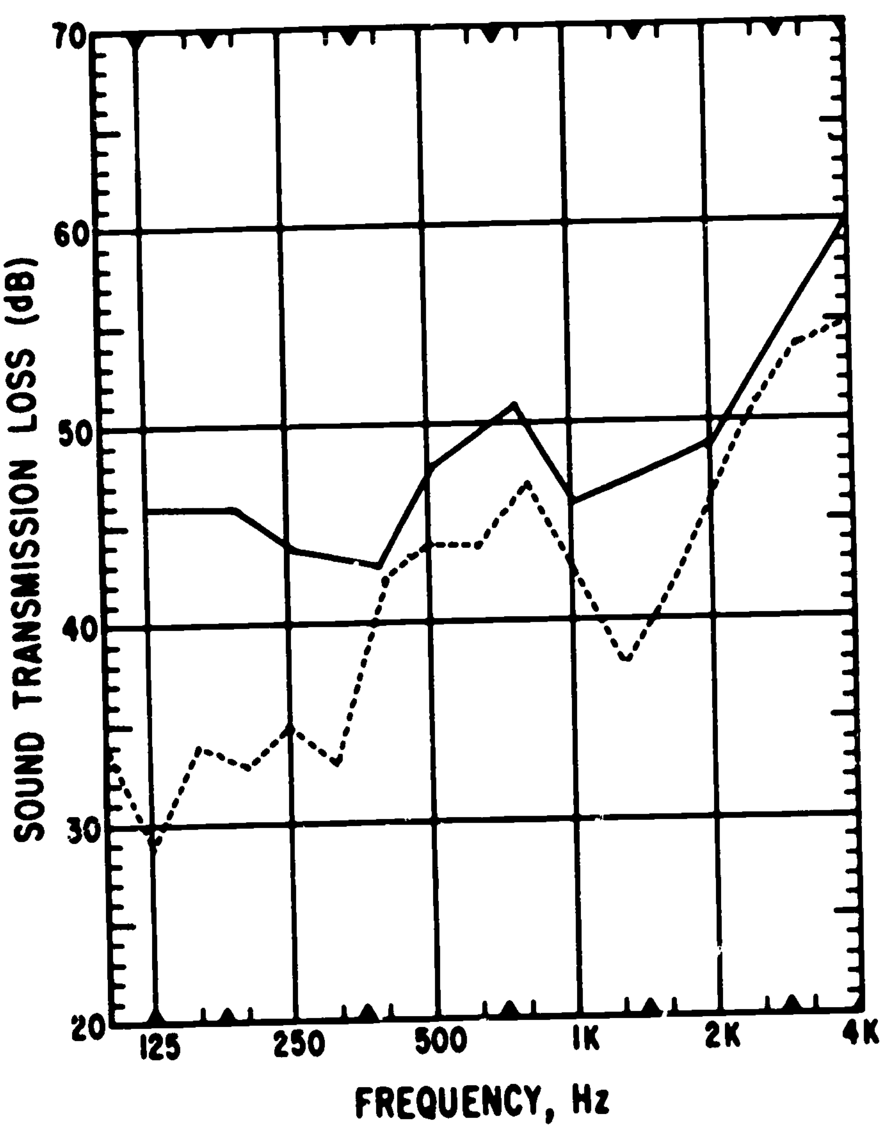
Total thickness: 7 1/2 in.

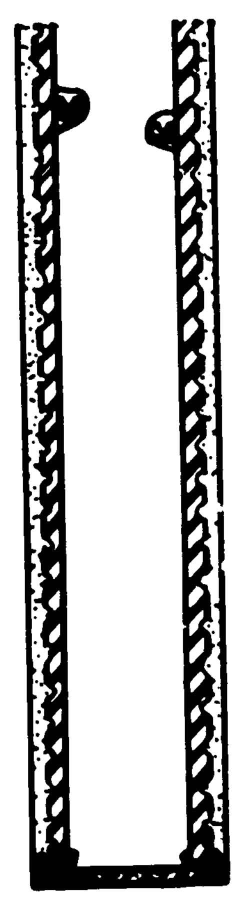
Area weight: approximately 15 lb/ft^2 (Not specified in reference)

(a) ———— STC = 47; Fire Rating: 1 hr. (est.)

(b) ------------ STC = 38

REMARKS: The STC value of (a) is based upon nine test frequencies.





TYPE: SOLID SANDED GYPSUM PLASTER

TEST REF: (a) 2-(527, 503); (b) 2-(526)

DESCRIPTION: (a) Diamond mesh metal lath with sanded gypsum plaster on both sides.

Total thickness: 2 in.

Area weight: 18.1-18.4 lb/ft^2

(b) Similar to (a) except gypsum perlite plaster was used.

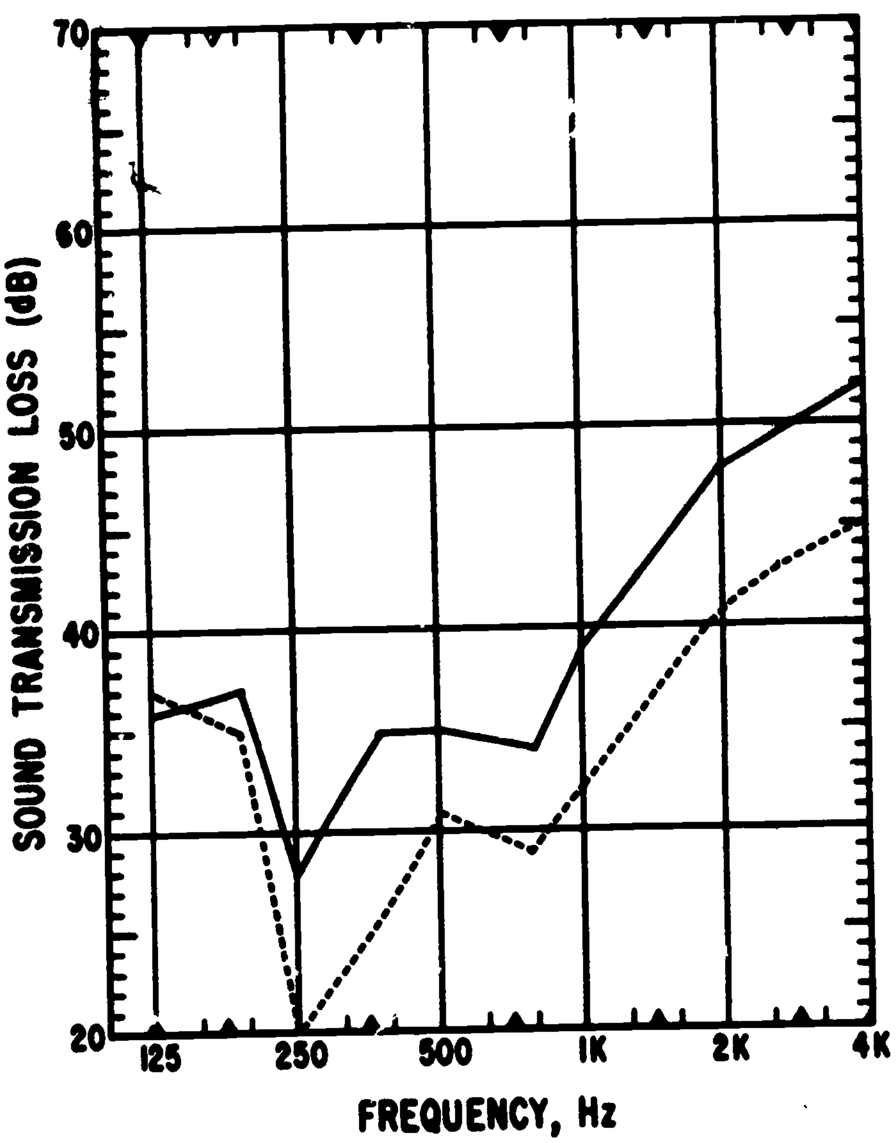
Total thickness: 2 in.

Area weight: 8.8 lb/ft^2

(a) ———— STC = 36; Fire Rating: 1 hr.

(b) ------------ STC = 31; Fire Rating: 1 1/4 hrs. (est.)

REMARKS: The plotted curve (a) represents the average value of measurements of two nominally identical structures. The STC values are based upon nine test frequencies.



TYPE: SOLID GYPSUM PLASTER WITH METAL CHANNELS

TEST REF: (a) 2-(523); (b) 2-(501)

DESCRIPTION: (a) 3/4-in. metal channels 16 in. on centers; diamond mesh expanded metal lath on one side, sanded gypsum plaster on both sides.

Total thickness: 2 in.

Area weight: 17.9 lb/ft^2

(b) Similar to (a) except gypsum vermiculite plaster was used.

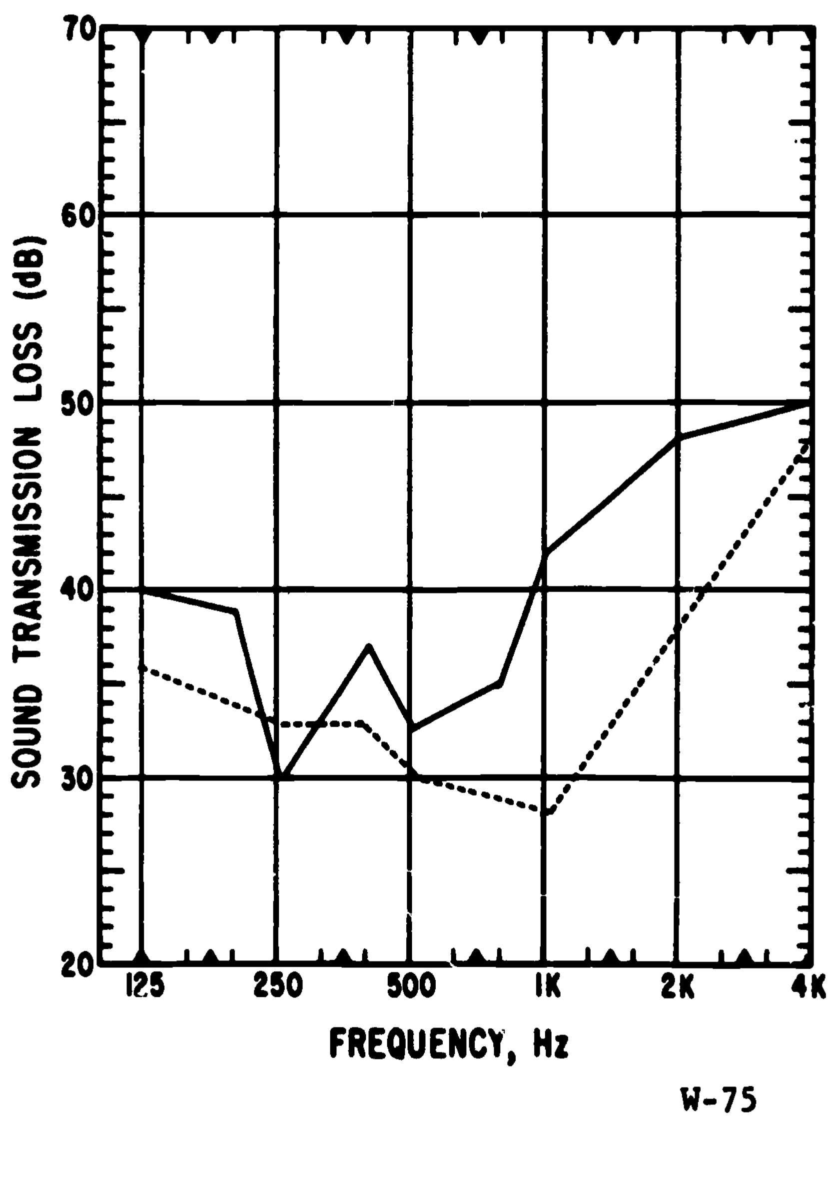
Total thickness: 2 in.

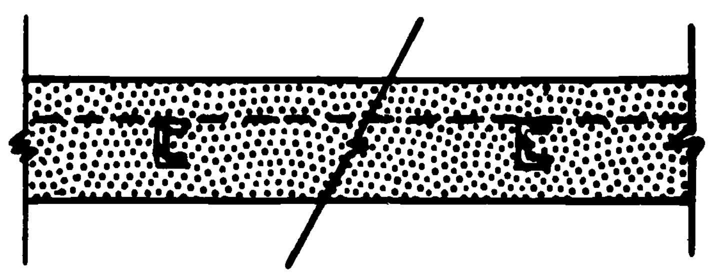
Area weight: 8.8 lb/ft^2

(a) ———— STC = 37; Fire Rating: 1 hr.

(b) ············ STC = 29; Fire Rating: 1 1/4 hrs. (est.)

REMARKS: The STC values are based upon nine test frequencies.





TYPE: SOLID SANDED GYPSUM PLASTER WITH METAL CHANNELS

TEST REF: (a) 2-(171A, 171B, 171C, 502); (b) 2-(518)

DESCRIPTION: (a) 3/4-in. metal channel studs 12 in. on centers, diamond mesh metal lath on one side, sanded gypsum plaster on both sides.

Total thickness: 2 in.

Area weight: 16.4-18.8 lb/ft^2

(b) Similar to (a) except studs were 11 in. on centers.

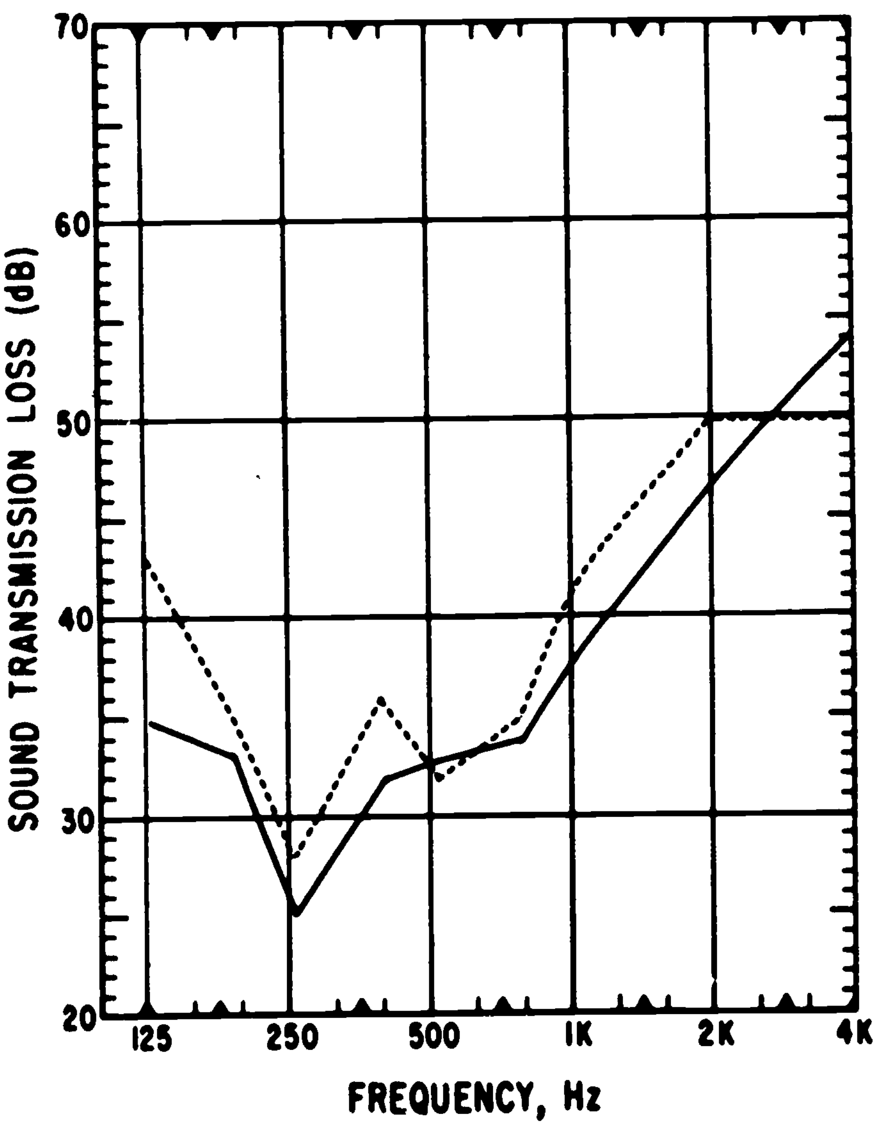
Total thickness: 2 in.

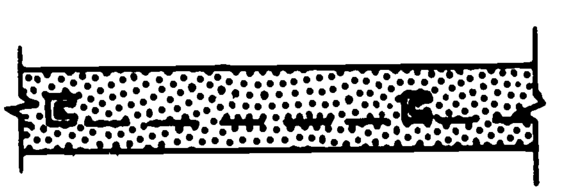
Area weight: 18.7 lb/ft^2

(a) ———— STC = 36; Fire Rating: 1 hr.

(b) -------- STC = 36; Fire Rating: 1 hr.

REMARKS: For structure (a) the plotted curve represents the average value of measurements of four nominally identical walls. The STC values are based upon nine test frequencies.





TYPE: SOLID SANDED GYPSUM PLASTER WITH METAL CHANNELS

TEST REF: (a) 2-(172); (b) 4-(Fig. 13.35)

DESCRIPTION: (a) 3/4-in. metal channel studs 12 in. on centers, expanded metal lath on one side, sanded gypsum plaster on both sides.

Total thickness: 2 1/2 in.

Area weight: 22.4 lb/ft^2

(b) Similar to (a) except the measurements were conducted in the field.

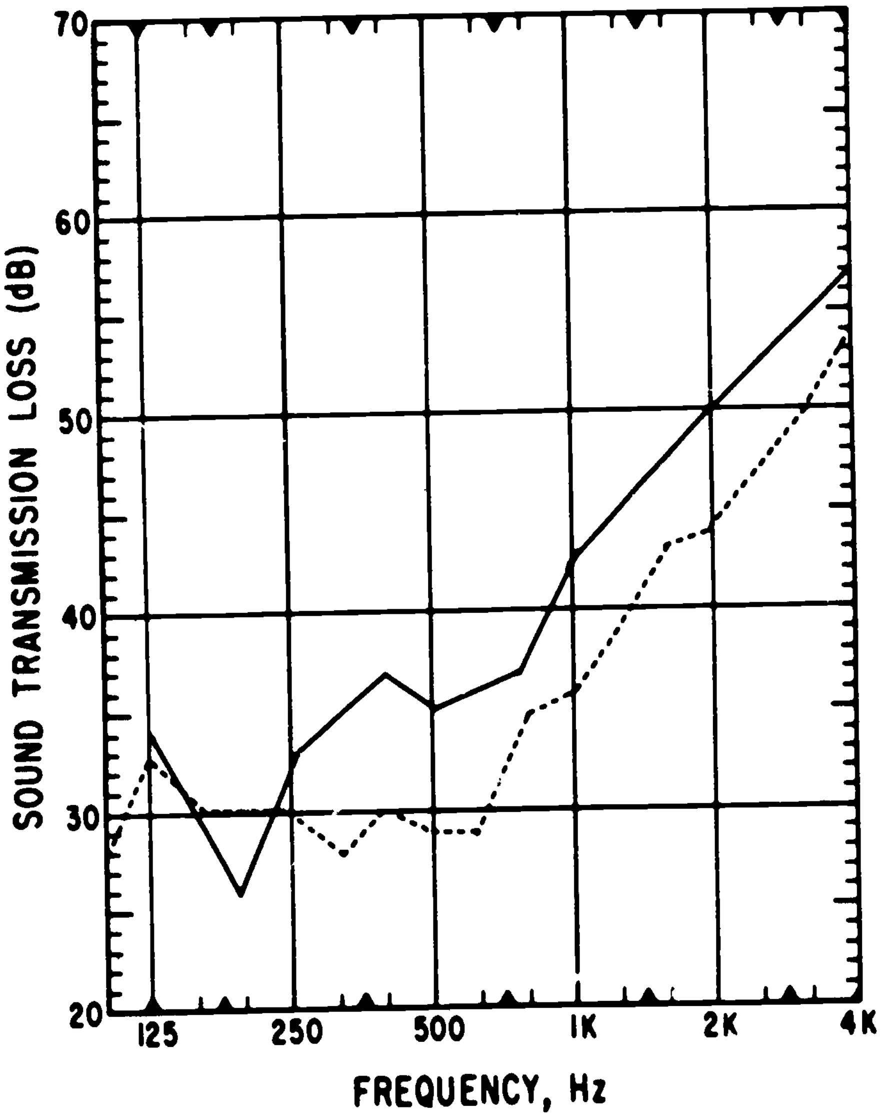
Total thickness: 2 1/2 in.

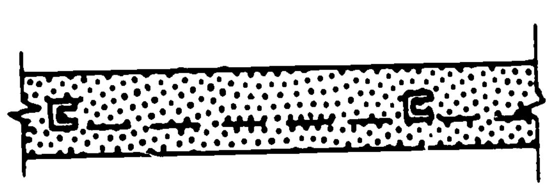
Area weight: approximately 22 lb/ft^2 (Not specified in reference)

(a) ———— STC = 39; Fire Rating: 1 hr.

(b) ------------- STC = 32

REMARKS: The STC value of (a) is based upon nine test frequencies.





TYPE: SOLID LIGHTWEIGHT AGGREGATE PLASTER WITH METAL CHANNELS

TEST REF: (a) 2-(519); (b) 4-(Fig. 13.34)

DESCRIPTION: (a) 3/4-in. metal channel studs 11 in. on centers, diamond mesh metal lath on one side, gypsum perlite plaster on both sides.

Total thickness: 2 in.

Area weight: 9.6 lb/ft^2

(b) Similar to (a) except the measurements were conducted in the field.

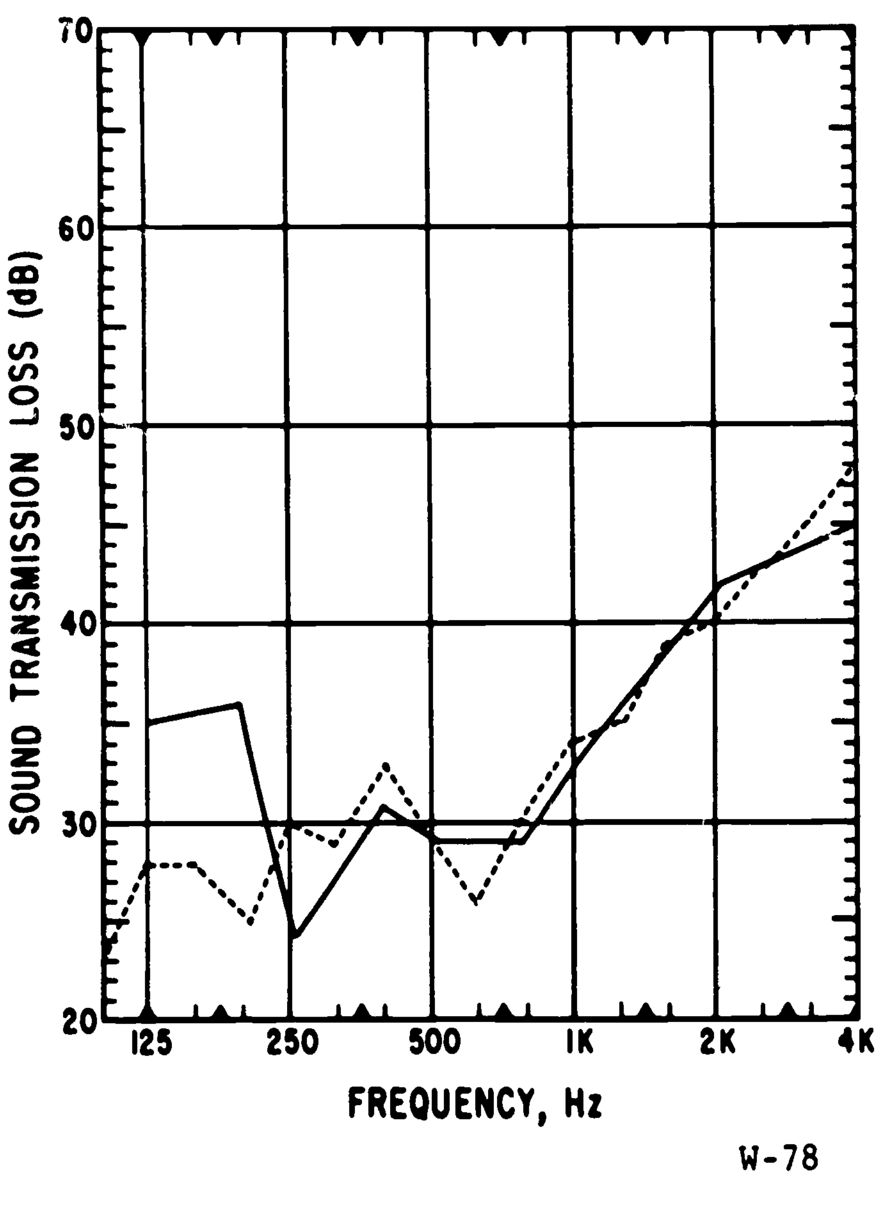
Total thickness: 2 in.

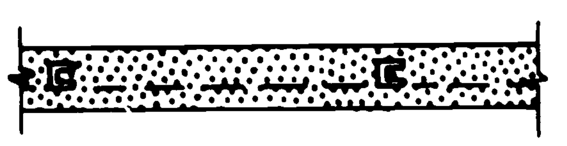
Area weight: approximately 10 lb/ft^2 (Not specified in reference)

(a) ———— STC = 31; Fire Rating: 1 1/4 hrs. (est.)

(b) -------- STC = 29

REMARKS: The STC value of (a) is based upon nine test frequencies.





TYPE: GYPSUM LATH AND PLASTER

TEST REF: (a) 2-(504, 510); (b) 2-(506, 511)

DESCRIPTION: (a) 3/8-in. gypsum lath, 13/16-in. sanded gypsum plaster applied to each side of lath.

Total thickness: 2 in.

Area weight: approximately 16.5 lb/ft^2

(b) Similar to (a) except plaster was 1 1/16 in. thick.

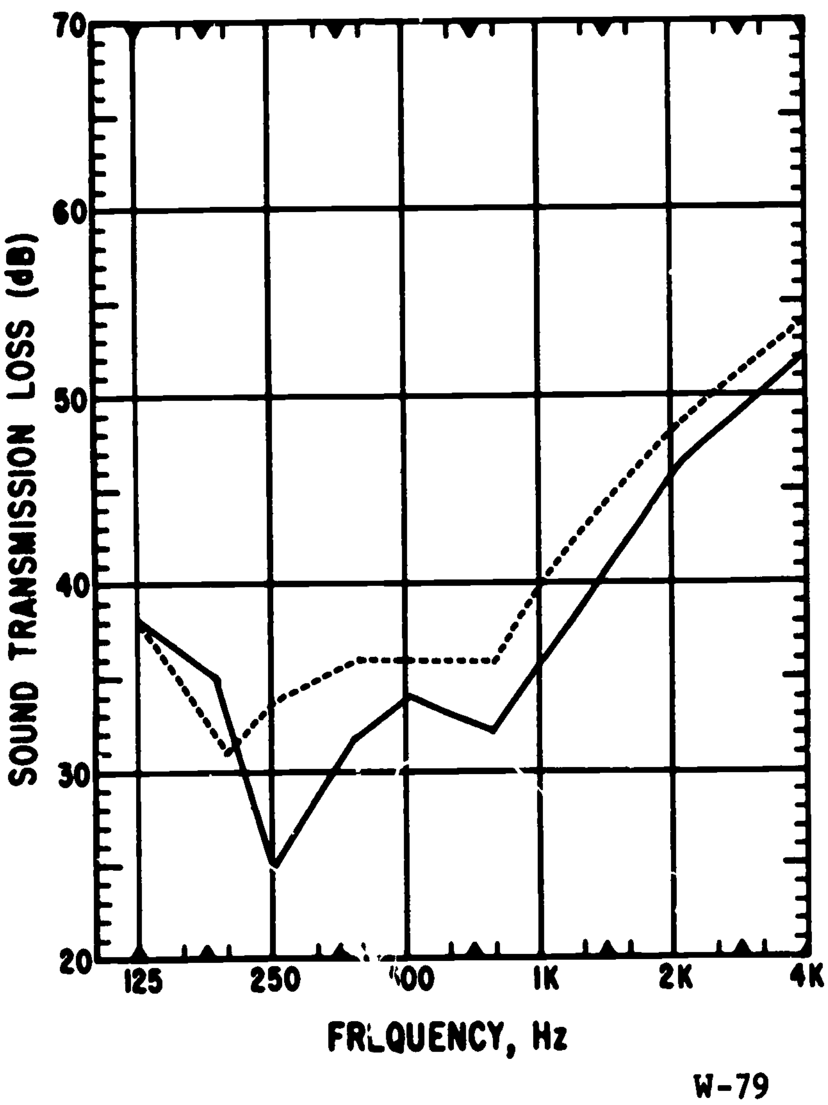
Total thickness: 2 1/2 in.

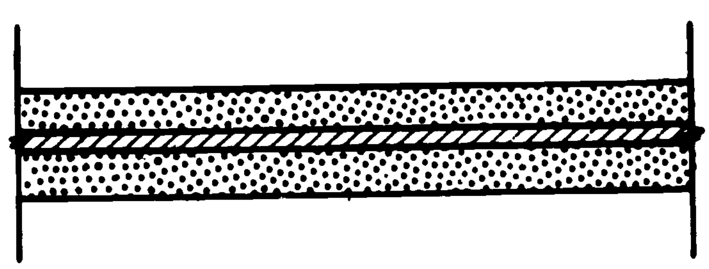
Area weight: approximately 20.0 lb/ft^2

(a) ———— STC = 34; Fire rating: 1 hr.

(b) ------------ STC = 38; Fire rating: 1 1/4 hrs. (est.)

REMARKS: The plotted curves represent the average of laboratory measurements of two nominally identical structures. The STC values are based upon nine test frequencies.





TYPE: SOLID GYPSUM CORE MOVABLE PARTITION

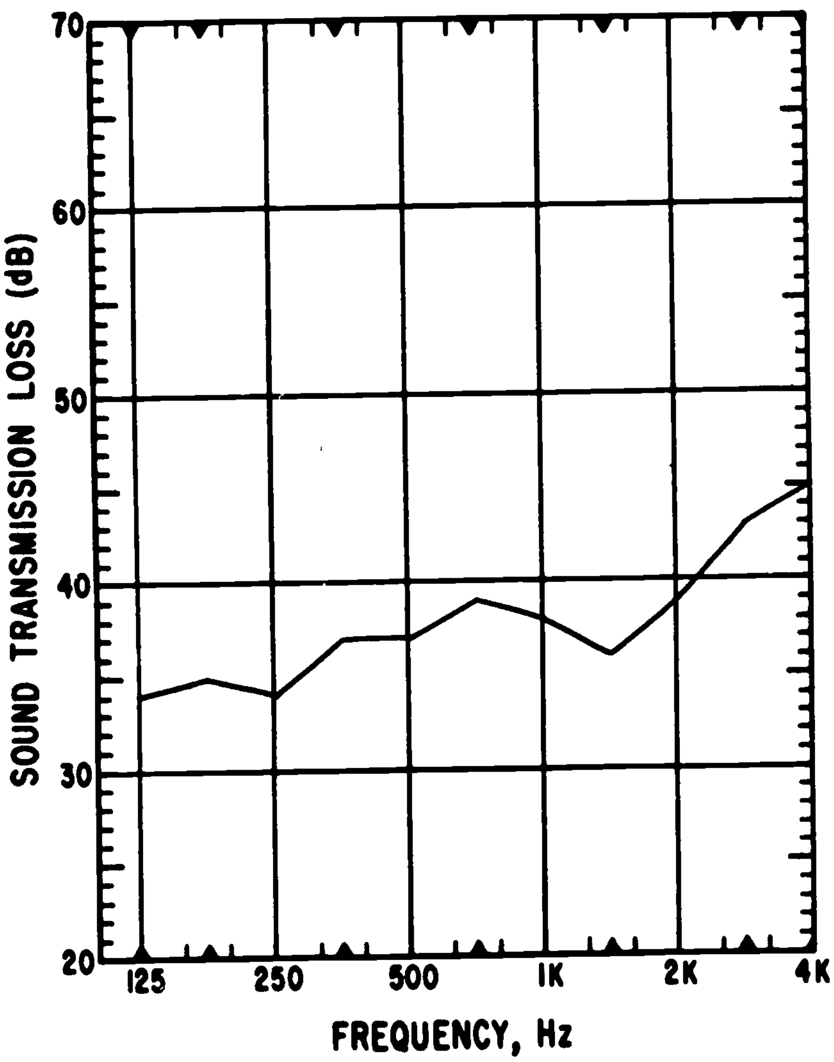
TEST REF: 7-(TL 64-213)

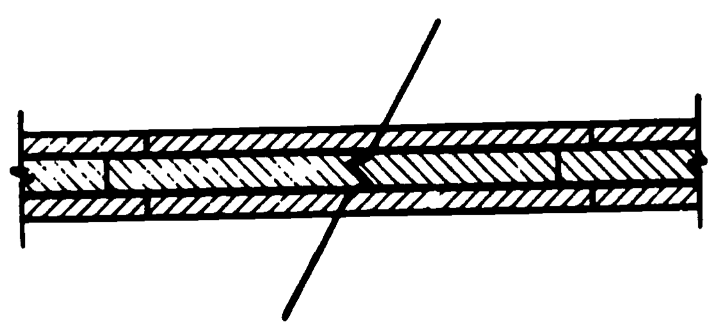
DESCRIPTION: 24-in.-wide panels constructed of 1- by 24-in. gypsum core board offset 1 1/2 in. at edges to form tongue and groove edge; 5/8-in. vinyl-faced gypsum wallboard laminated to both sides of core board. Panels inserted into two piece metal floor and ceiling tracks. Gypsum to gypsum screws at 1/4 and 1/2 points along vertical edges of face boards.

Total thickness: 2 1/4 in.

Area weight: 10.2 lb/ft^2

STC = 36; Fire Rating: 1 hr.





TYPE: SOLID GYPSUM CORE PARTITION WITH LEAD

TEST REF: (a) 15-(Fig. 7); (b) 15-(Fig. 7)

DESCRIPTION: (a) 1-in. gypsum core board with 5/8-in. gypsum wallboard laminated to each side.

Total thickness: 2 1/4 in.

Area weight: approximately 10 lb/ft^2 (Not specified in reference)

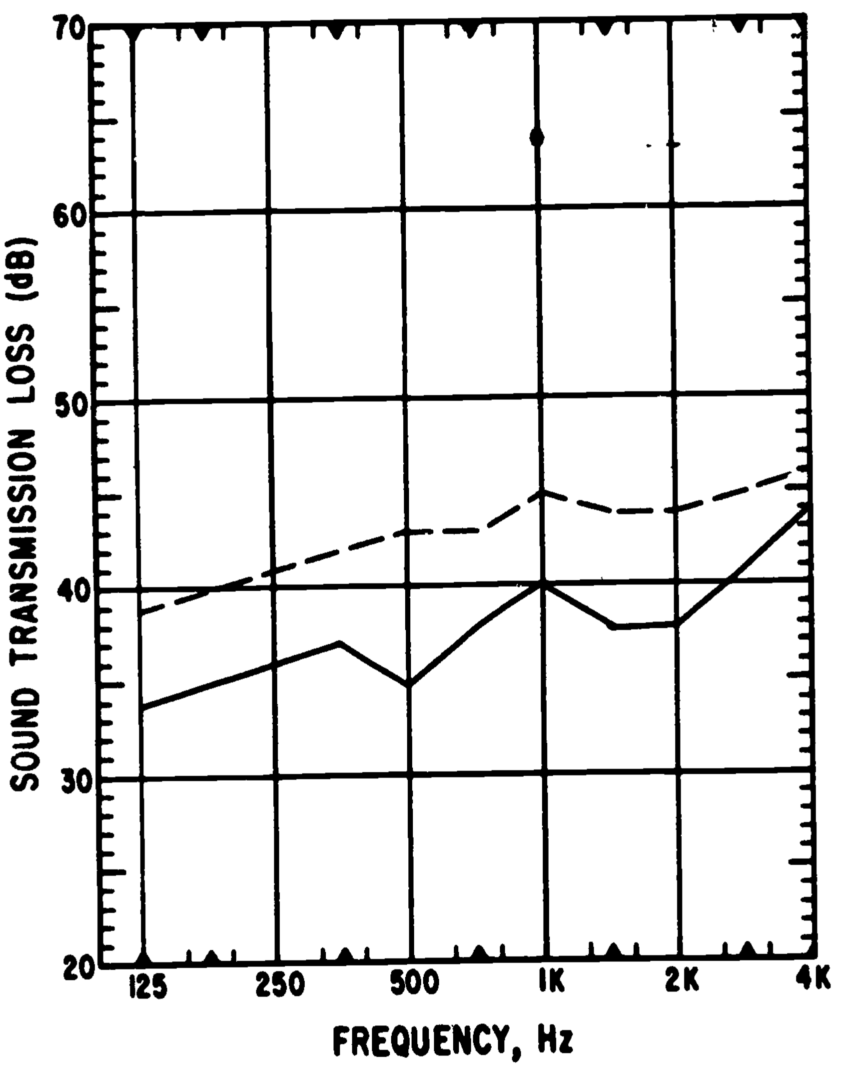
(b) Similar to (a) except on one side 1/2-in. gypsum wallboard with 1/8-in. lead, approximate area weight 7 lb/ft^2, replaced the 5/8-in. gypsum board.

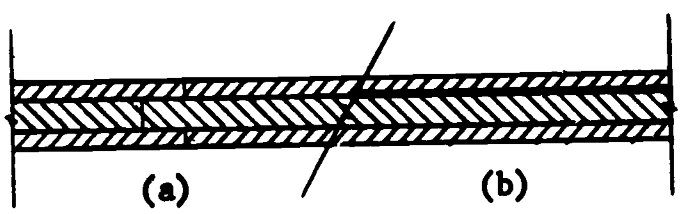
Total thickness: 2 1/4 in.

Area weight: approximately 17 lb/ft^2 (Not specified in reference)

(a)———— STC = 38; Fire Rating: 1 hr.

(b)- - - - - STC = 44; Fire Rating: 45 min. (est.)





TYPE: HOLLOW-CORE MOVABLE GYPSUM PARTITION

TEST REF: (a) 7-(TL 64-186); (b) 7-(TL 64-212)

DESCRIPTION: (a) 24-in.-wide panels constructed of 5/8-in. gypsum core board strips, 7 1/2 in. and 4 3/8 in. wide, offset 1 1/2 in. at edges to form tongue and groove; 5/8-in., vinyl-faced, gypsum wallboard laminated to both sides of core board strips. Panels inserted into two piece metal floor and ceiling tracks. Gypsum to gypsum screws at 1/4 points along vertical edges of face boards.

Total thickness: 1 7/8 in.

Area weight: 7.7 lb/ft^2

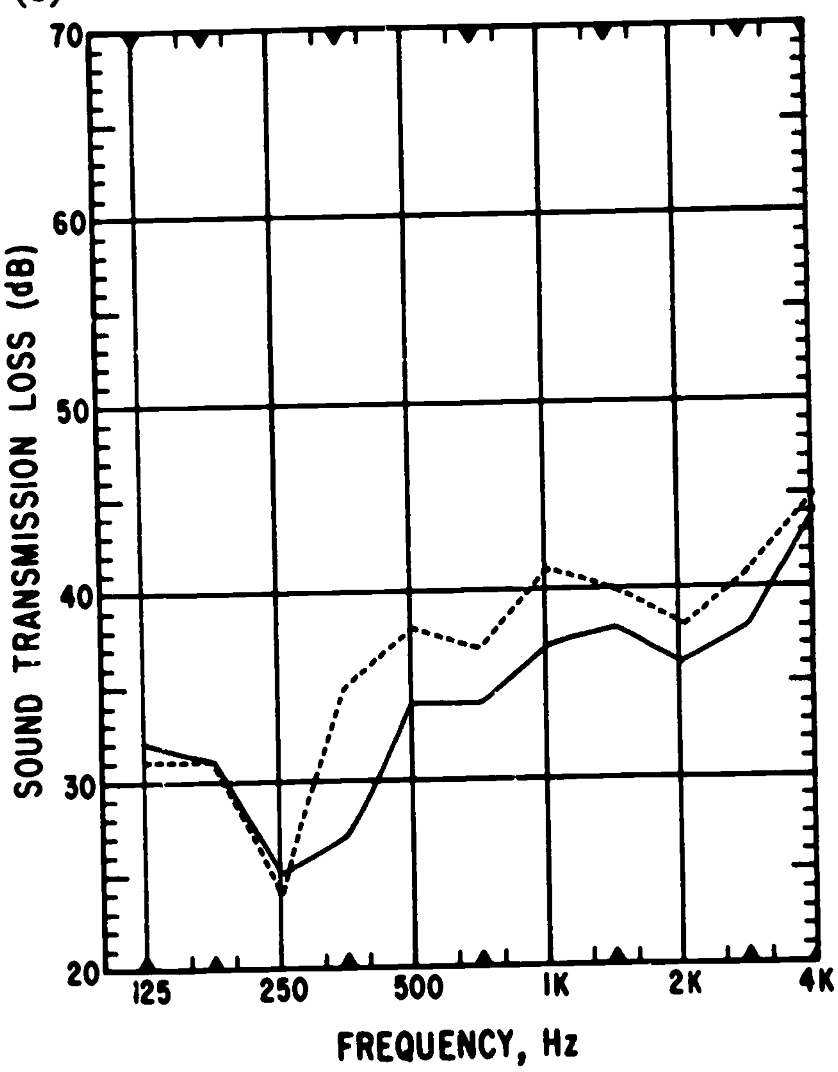
(b) Similar to (a) except the core board strips were 1 in. thick.

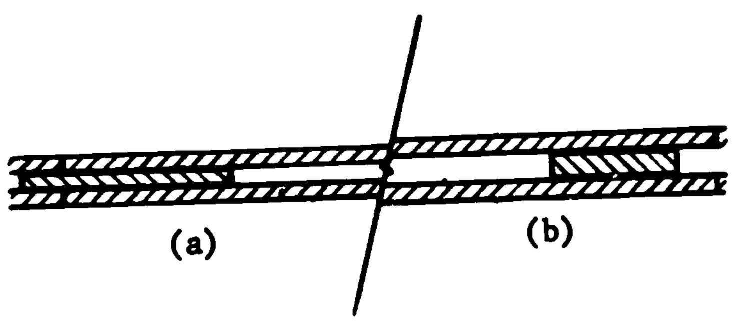
Total thickness: 2 1/4 in.

Area weight: 8.3 lb/ft^2

(a) ———— STC = 33; Fire Rating: 1 hr. (est.)

(b) ------------ STC = 37; Fire Rating: 1 hr.





TYPE: GYPSUM RIBS, DOUBLE LAYER GYPSUM BOARD

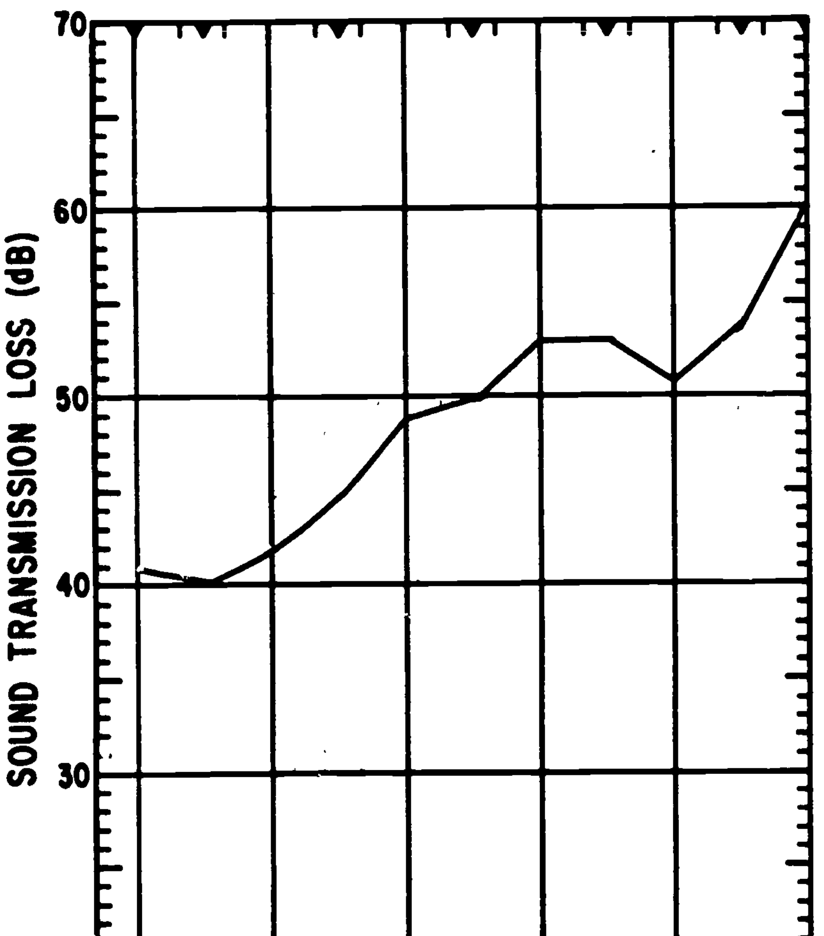
TEST REF: 7-(TL 63-15)

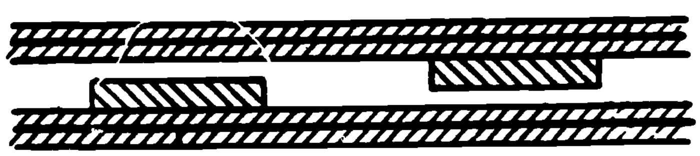
DESCRIPTION: 1- by 6-in. gypsum ribs vertically laminated 24 in. on centers to 5/8-in. gypsum wallboard such that board joints are covered, with bottom and top of ribs 6 in. from floor and ceiling. Ribs screwed 24 in. on centers at each board joint. Gypsum wallboard screwed 24 in. on centers, with ribs facing inside and staggered 12 in., to outside faces of 1 5/8-in. metal runners at floor and ceiling. Second layer of 5/8-in. gypsum wallboard laminated to both sides with joints staggered. All exposed joints taped and finished.

Total thickness: 4 1/8 in.

Area weight: 13.9 lb/ft^2

STC = 51; Fire Rating: 2 hrs.





TYPE: DOUBLE PANEL: CORE BOARD, GYPSUM BOARD

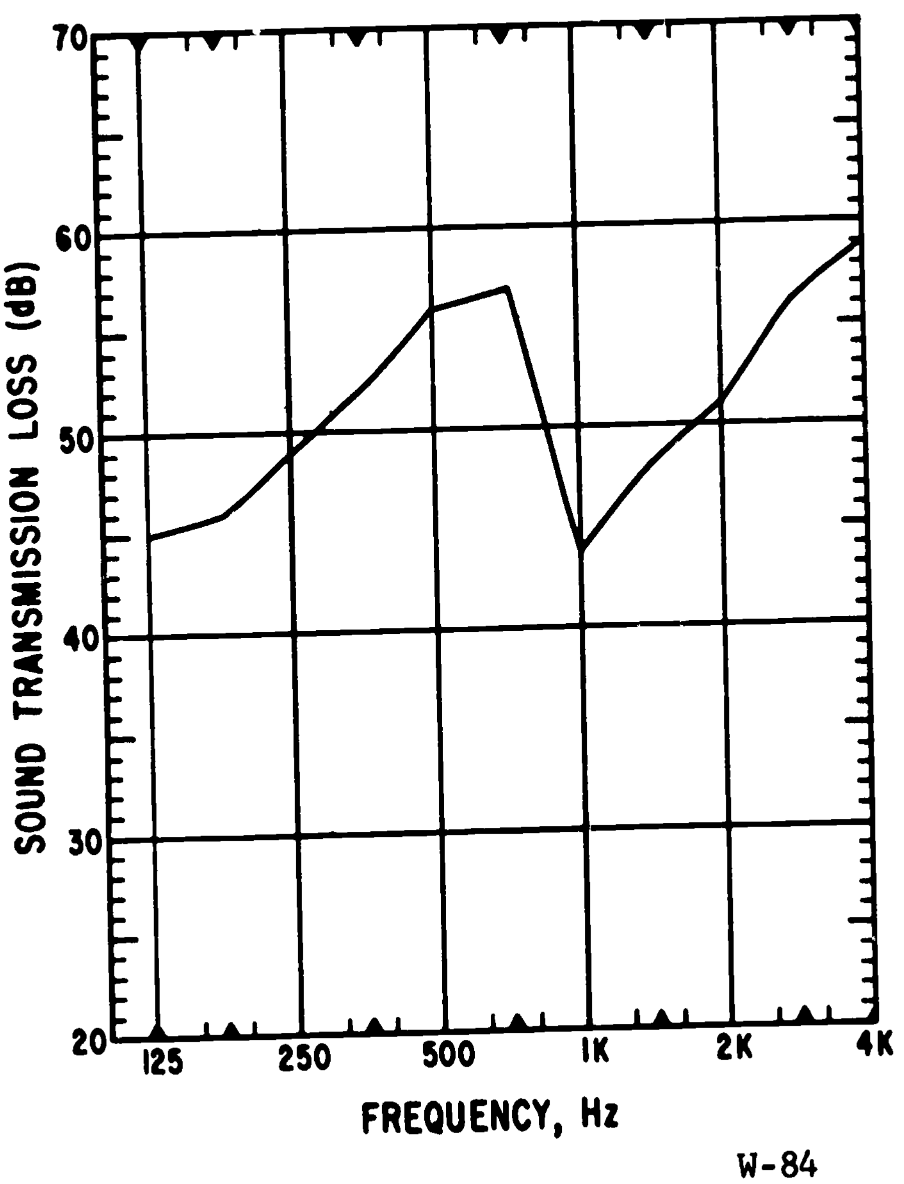
TEST REF: 7-(TL 64-60)

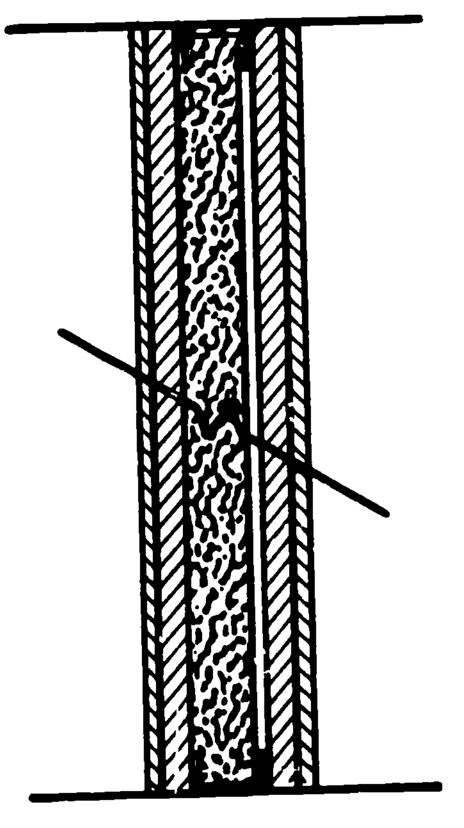
DESCRIPTION: 1-in. tongue-and-groove gypsum core board attached to both sides of 2 1/2-in. metal channel runners at floor and ceiling, 1/2-in. gypsum wallboard laminated to each core board. 2-in. mineral wool batts glued to inside surface of core board. All exposed joints taped and finished.

Total thickness: 5 5/8 in.

Area weight: 14.3 lb/ft^2

STC = 45; Fire Rating: 2 hrs. (est.)





TYPE: DOUBLE WALL: HOLLOW-CORE MOVABLE GYPSUM PARTITION

TEST REF: (a) 7-(TL 64-189); (b) 7-(TL 65-72)

DESCRIPTION: (a) Double wall with 1 3/8-in. airspace. Each leaf consisted of 24-in.-wide panels of 5/8-in. gypsum core board strips, 7 1/2 in. and 4 3/8 in. wide, offset 1 1/2 in. at edges to form tongue and groove. 5/8-in., vinyl-faced, gypsum wallboard laminated to both sides of core board strips. Panels screwed 12 in. on centers to 1 1/4- by 1-in. angle floor and ceiling runners.

Total thickness: 5 1/8 in.

Area weight: 14.6 lb/ft^2

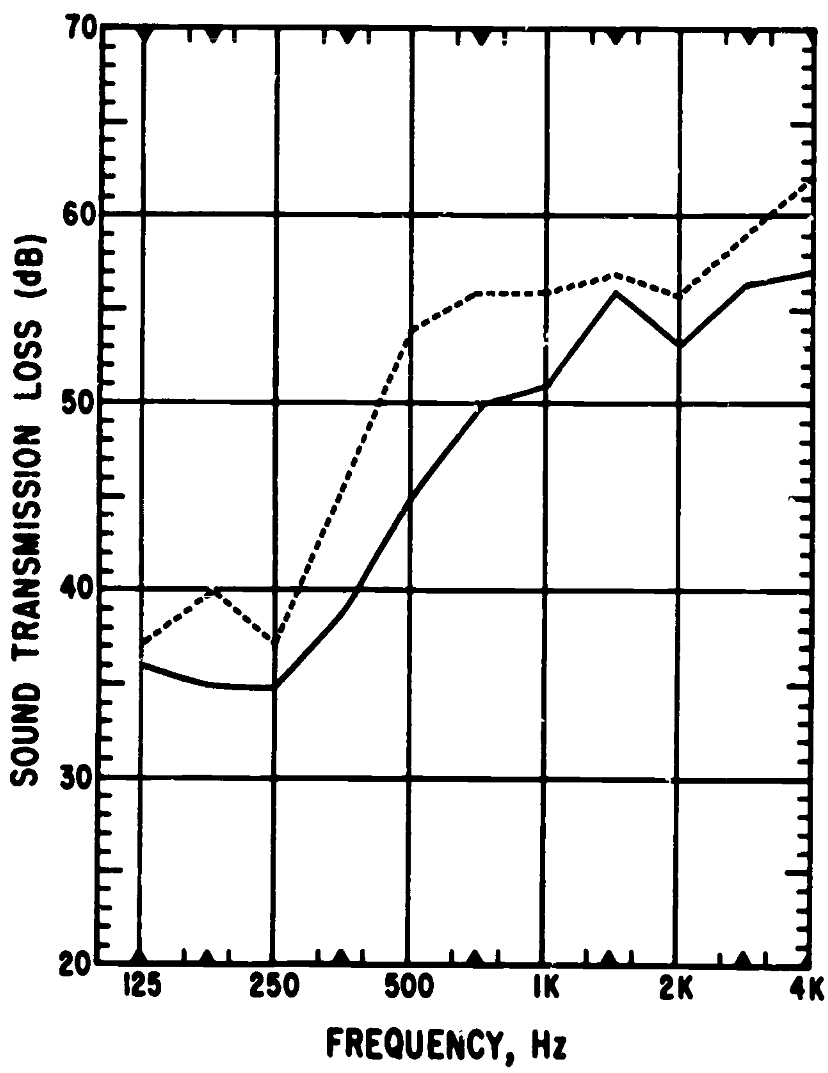
(b) Similar to (a) except the space between leaves was 2 1/8 in. and contained 2-in. mineral fiber blankets stapled to one leaf. 1/4-in. perimeter clearance closed with a non-setting resilient caulking compound. Vertical face layer joints sealed with joint compound.

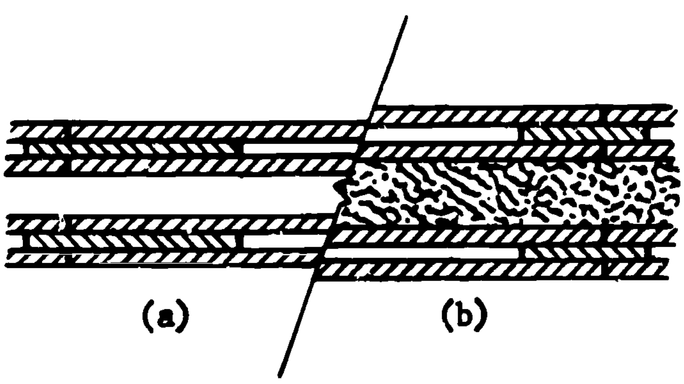
Total thickness: 6 in.

Area weight: 12.8 lb/ft^2

(a) ———— STC = 45; Fire Rating: 3 hrs. (est.)

(b) ·············· STC = 50





TYPE: GYPSUM BOARD WITH INSULATION

TEST REF: 9-(8-1090072d)

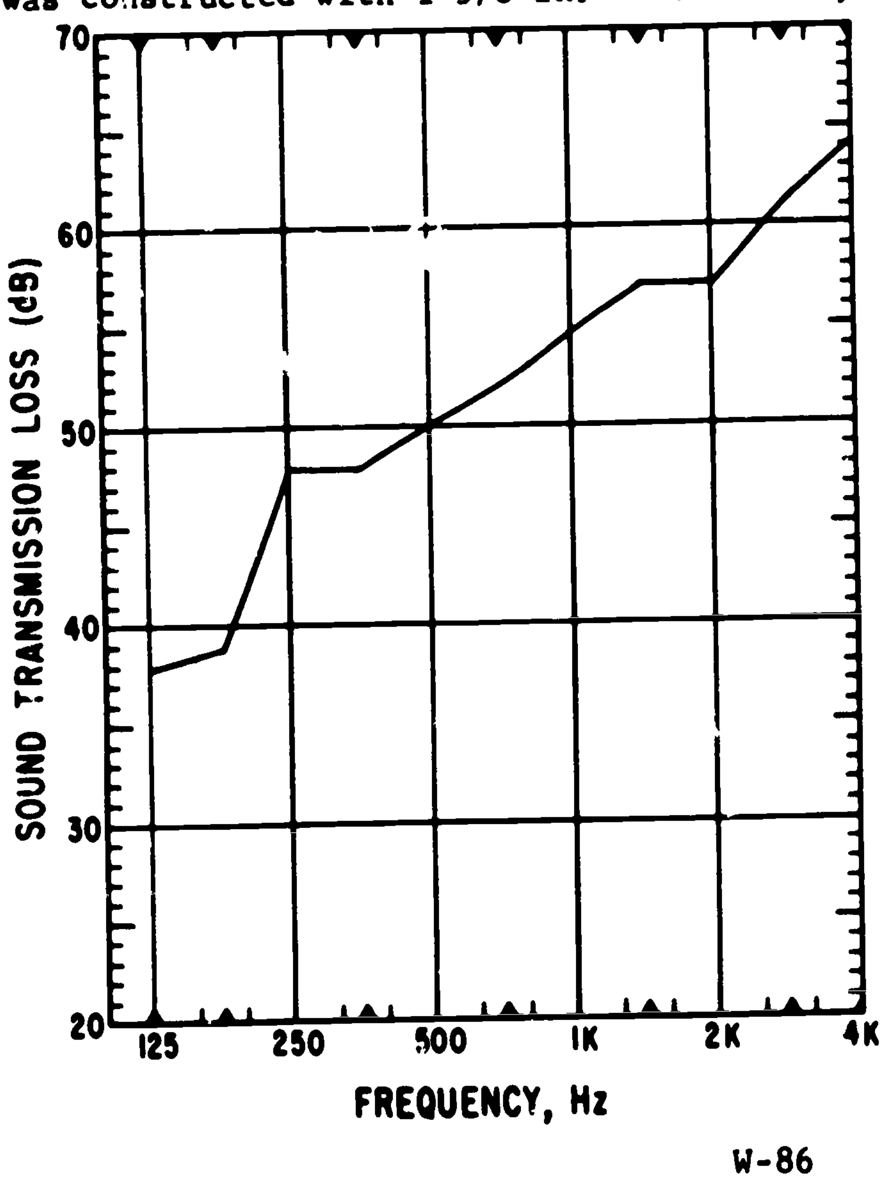
DESCRIPTION: A pair of 1- by 1 1/2-in. 22 gage steel angle runners, with a 3-in. separation, screwed 24 in. on centers through a 1/2-in. isolating resilient gasket to the ceiling and the floor. 1- by 24-in. tongue-and-groove gypsum core board units applied vertically, and screwed 23 in. on centers to the angles with joints staggered 12 in. on opposite sides. 1 1/2-in. mineral fiber blankets stapled to one inside surface of core boards. 1/2- by 48-in. gypsum lath laminated to core boards with joints offset 3 inches; laminating compound beads 1/2-in.-thick, 5/16-in.-wide, spaced 4 1/2 in. on centers. 1 1/2-in. screws through lath and core board 36 in. on centers along edges and 48 in. on centers in field. 1/16-in. plaster finish coat applied to both sides. The 1/4 and 1/8-in. clearances around the perimeter closed with a non-setting resilient caulking compound.

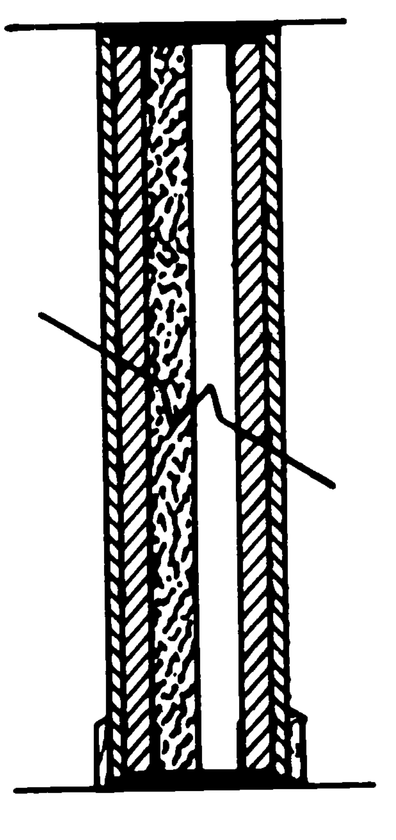
Total thickness: 6 1/8 in.

Area weight: 12.8 lb/ft^2

STC = 54; Fire Rating: 2 hrs. (est.)

REMARKS: The above test was conducted in the field. One adjoining wall was constructed with 1 5/8-in. metal studs, 1/2-in. gypsum lath and finish coat of plaster; the other wall was plastered masonry.





TYPE: GYPSUM BOARD PANELS WITH INSULATION

TEST REF: 9-(109006c)

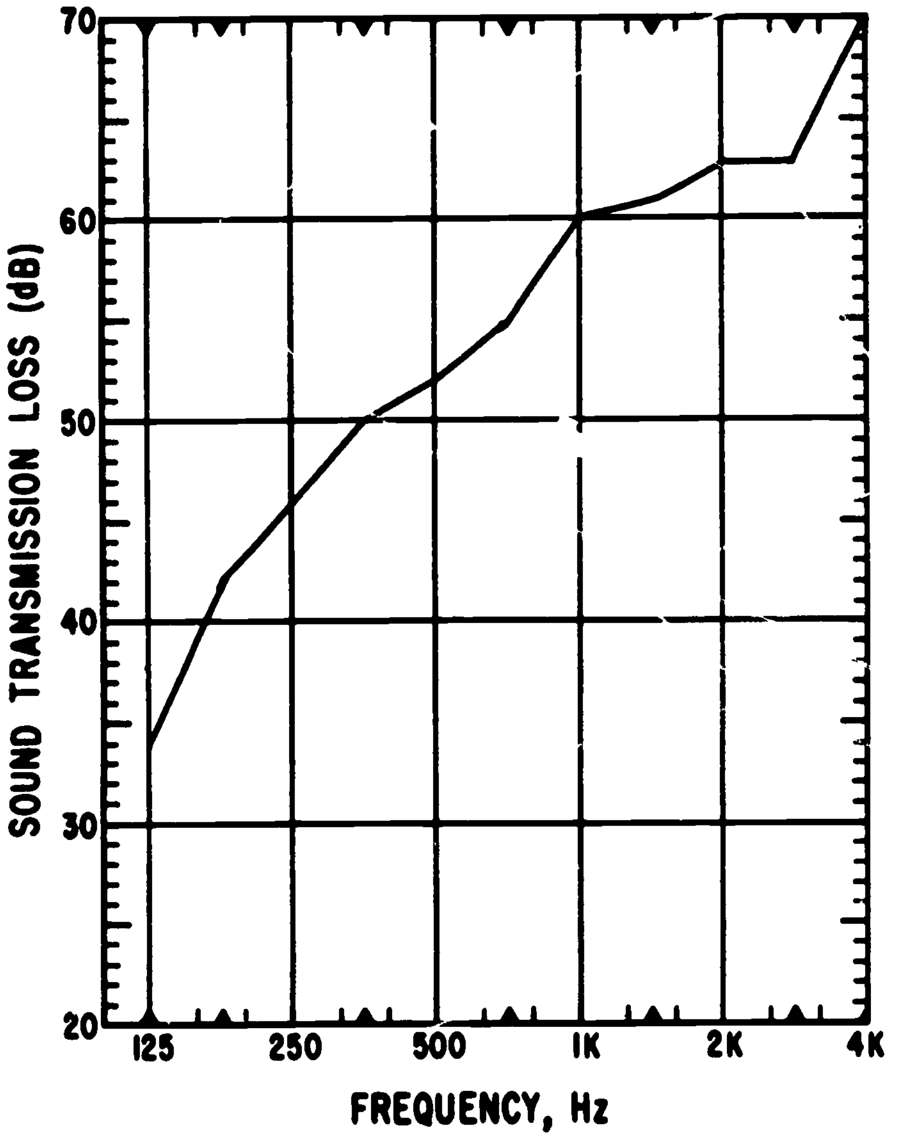
DESCRIPTION: A pair of 3/4- by 1-in. steel angle runners, with a 3-in. separation, set on continuous beads of non-setting resilient caulking compound at floor and ceiling. 1- by 24-in. gypsum core board units applied vertically, and screwed 12 in. on centers to the angles with joints staggered 12 in. on opposite sides. 1 1/2-in.-thick mineral fiber blankets stapled to one inside surface of core boards. 1/2-in. by 48-in. gypsum wallboard laminated to core board with joints of opposite faces staggered. The 1/4-in. clearances around the perimeter closed with a non-setting resilient caulking compound.

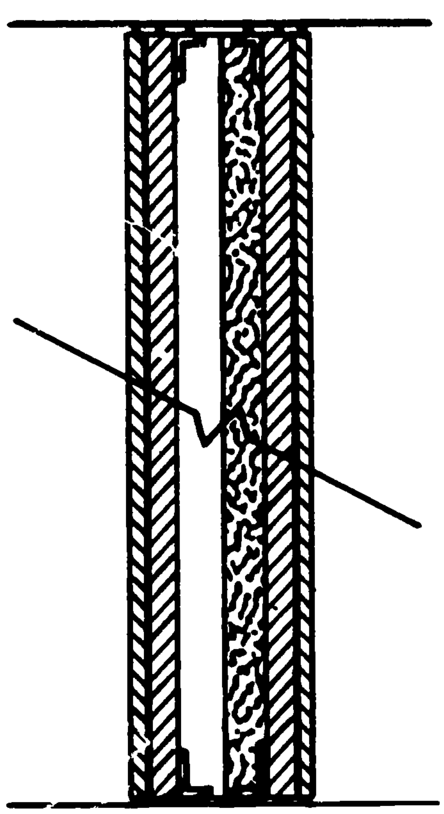
Total thickness: 6 in.

Area weight: 12.5 lb/ft^2

STC = 56; Fire Rating: 2 hrs. (est.)

REMARKS: The above test was conducted in the field.





AIRBORNE AND IMPACT SOUND INSULATION DATA OF FLOOR-CEILING CONSTRUCTIONS

TYPE: REINFORCED CONCRETE SLAB

TEST REF: (a) 3-(808); (b) 14; (c) 3-(808A); (d) 14

DESCRIPTION: (a) 4-in.-thick reinforced concrete slab, isolated from support structure. Concrete was reinforced with 6- by 6-in. number 6 AWG reinforcing mesh placed at the centerline horizontal plane of the slab. All surface cavities were sealed with a thin mortar mix.

(b) Field measurements of a nominally identical structure, as in (a), supported by masonry walls.

Total thickness: 4 in.

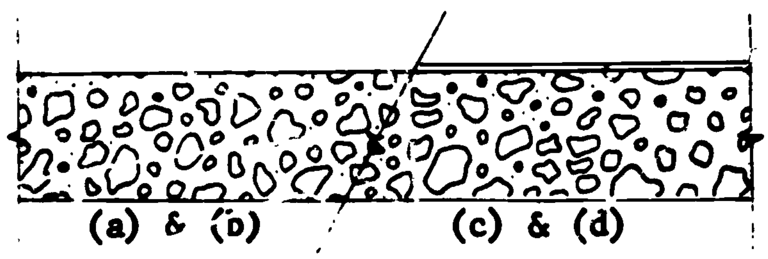
Area weight: 53 lb/ft^2

(c) Same as (a) except 1/8-in.-thick vinyl tile was adhered to concrete.

(d) Same as (b) except 1/8-in.-thick vinyl tile was adhered to concrete.

Total thickness: 4 1/8 in.

Area weight: 54 lb/ft^2

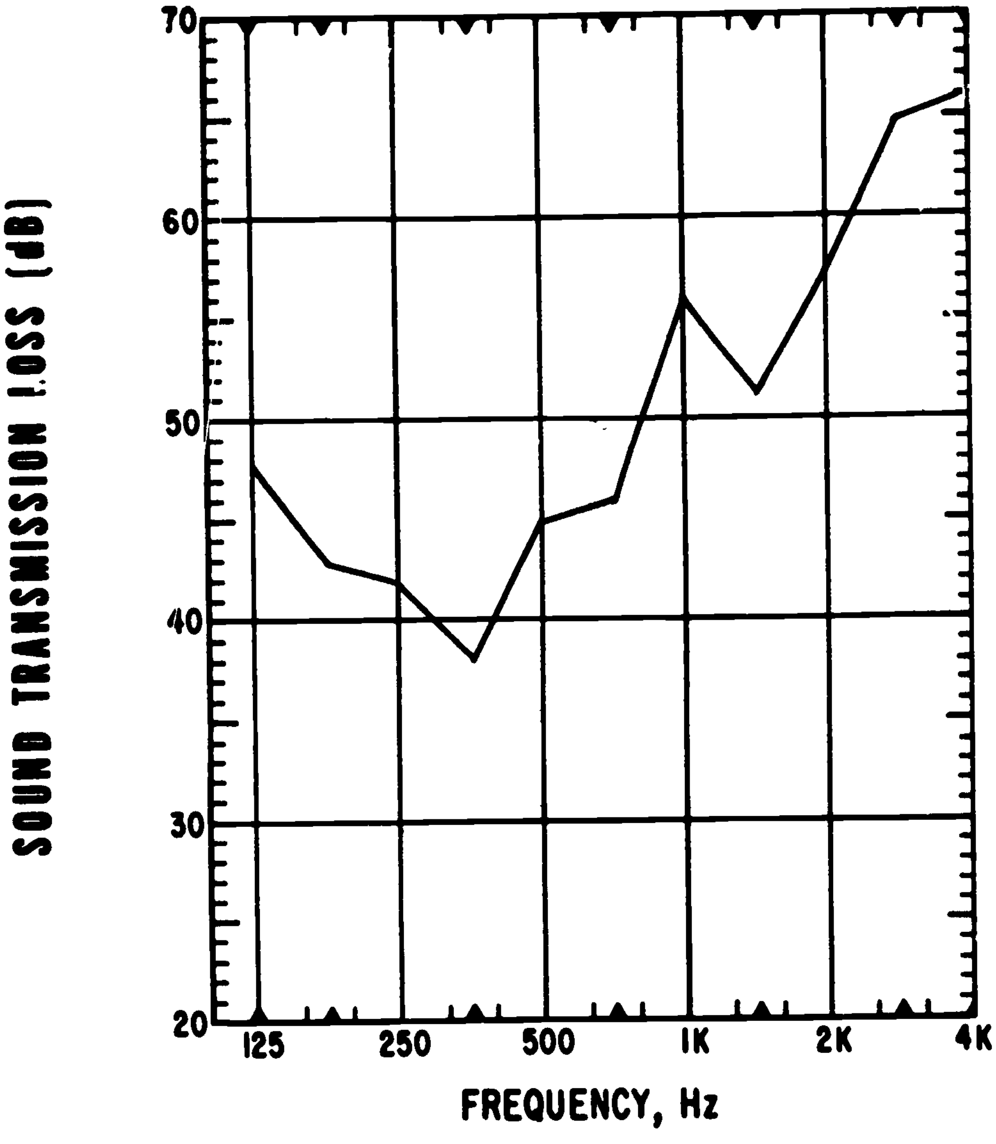


(a) ———————— STC = 44; IIC = 25; Fire Rating: 1 hr. (est.)

(b) ·················· IIC = 25

(c) — — — — — IIC = 29

(d) ·—·—·—·— IIC = 28



*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: REINFORCED CONCRETE WITH FLOOR COVERINGS

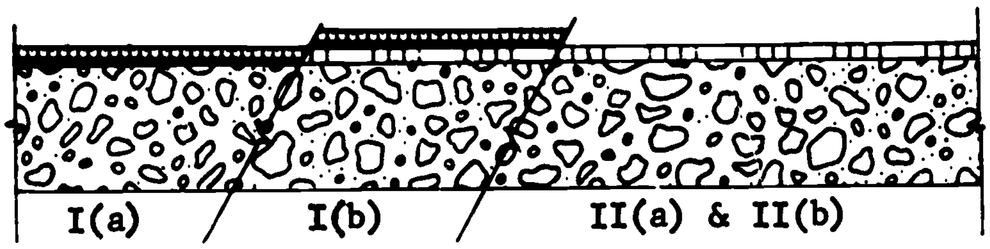
TEST REF: I(a) 3-(808D); I(b) 3-(808C); II(a) 3-(808B); II(b) 14

DESCRIPTION: I(a) 4-in.-thick reinforced concrete slab with carpeting and pad. The carpeting was of 1/4-in. wool loop pile with 1/8-in. woven jute backing, 0.49 lb/ft^2; the foam rubber pad was 1/4 in. thick and weighed 0.53 lb/ft^2.

I(b) Same as I(a) except the carpet and pad were placed on 1/2-in.-thick oak blocks, 1.8 lb/ft^2, adhered to concrete.

II(a) Same as I(b) without carpet and pad.

II(b) Field measurements of a nominally identical structure, as in II(a), supported by masonry walls.



I(a) ———— IIC = 80

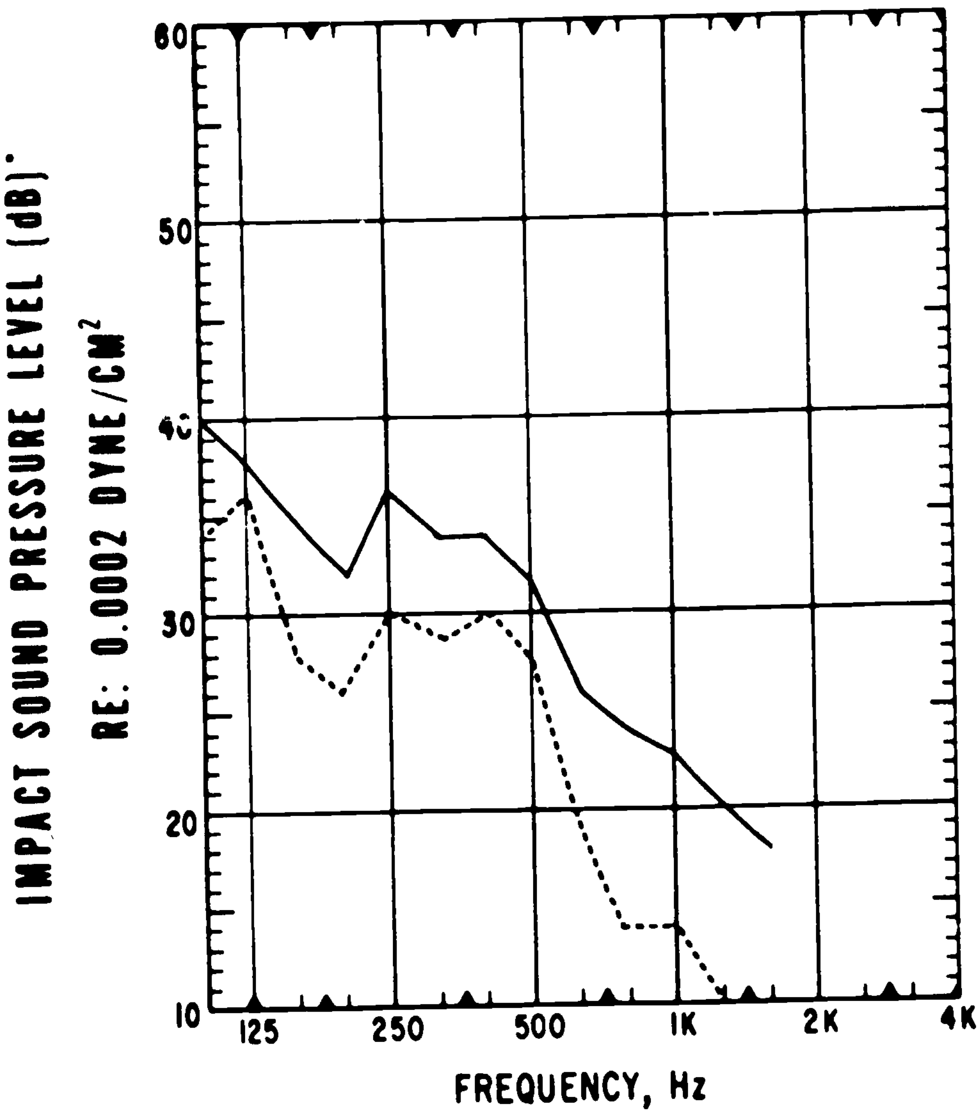
I(b) ··········· IIC = 84

II(a) ———— IIC = 45

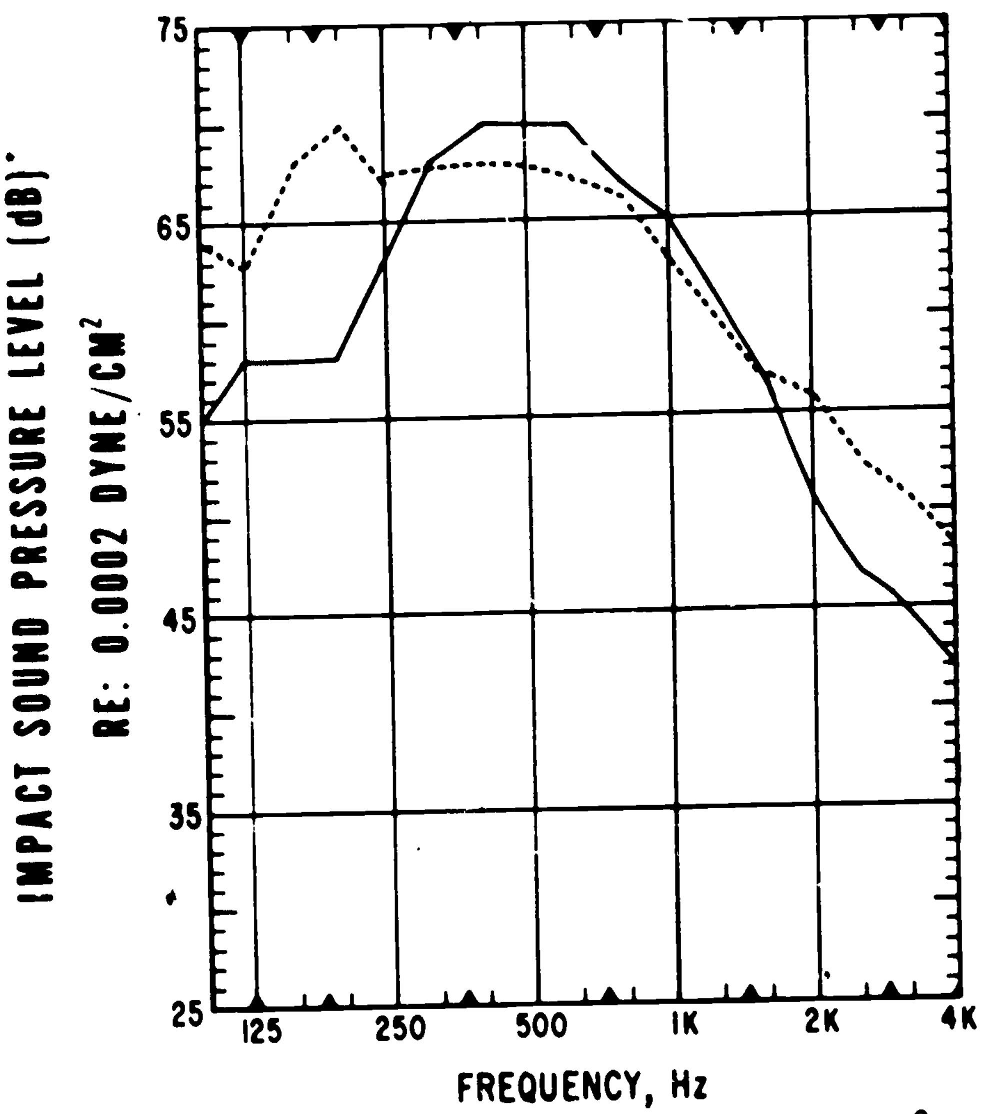
II(b) ··········· IIC = 45

REMARKS: See preceding report. Fire rating and STC are commensurate with those given in F-1

I



II



*1/3-octave band data normalized to $A_c = 10m^2$

TYPE: REINFORCED CONCRETE SLAB, WOOD BLOCKS WITH UNDERLAYMENTS

TEST REF: 3-(809, 809A-H)

DESCRIPTION: I(a) 4-in. reinforced concrete slab with 1/2- by 9- by 9-in. oak blocks, 1.8 lb/ft^2, set in mastic.

I(b) 1/4-in. polystyrene closed-cell foam, approximate density 2 lb/ft^3, between kraft liner board facings.

I(c) 1/8-in. polystyrene closed-cell foam, approximate density 4.5 lb/ft^3, between liner board facings.

I(d) 1/4-in. rigid polyurethane, approximate density 2.5 lb/ft^3, between liner board facings.

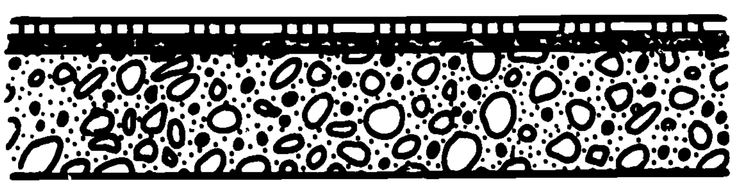
I(e) 1/4-in. semi-rigid polyurethane foam, approximate density 2.2 lb/ft^3, without liner board facings.

II(a) 1/2-in. wood fiber board, approximate density 21 lb/ft^3.

II(b) 1/8-in. molded corrugated pulp material of sulfate fibers, approximate area weight 0.05 lb/ft^2.

II(c) 1/4-in. cork, approximate density 24 lb/ft^3.

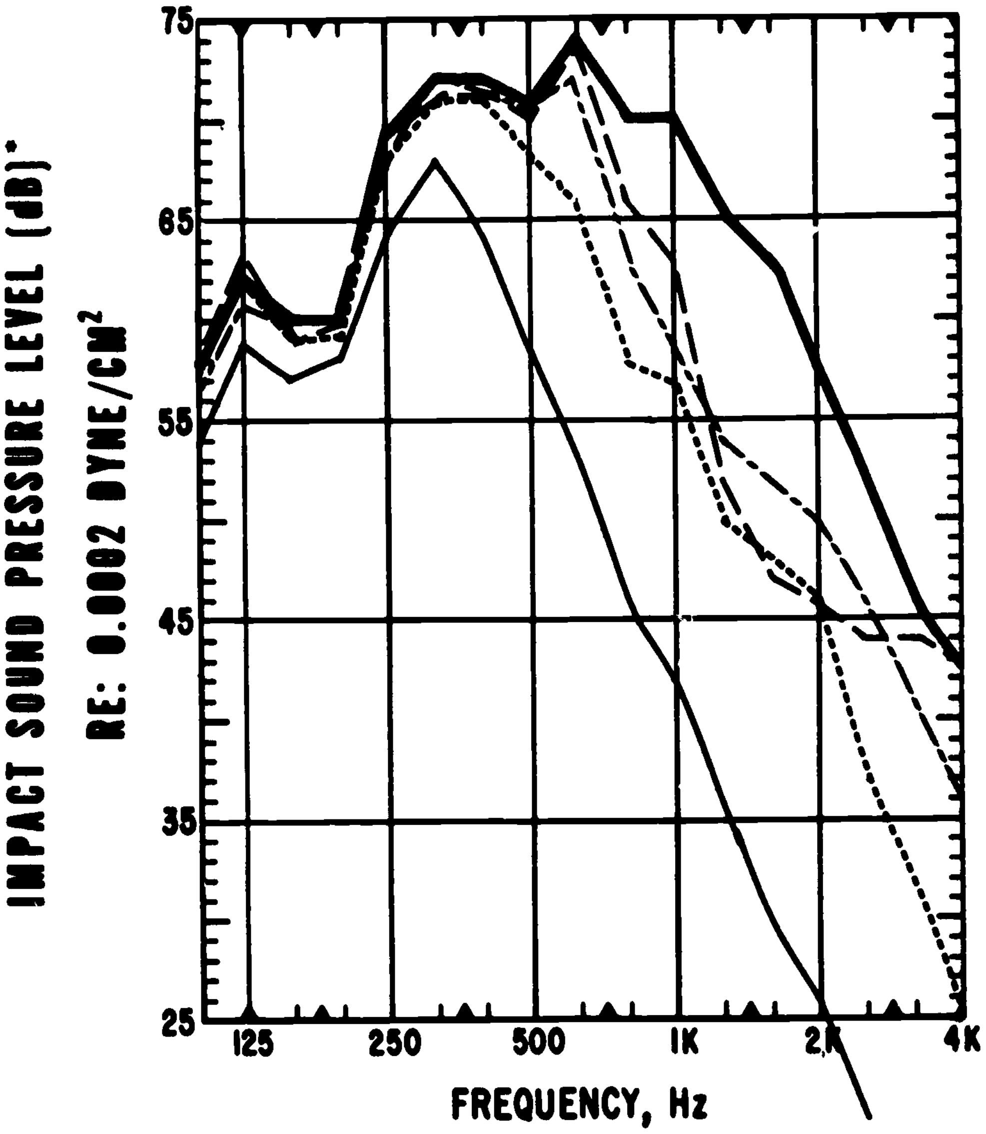
II(d) 1/8-in. cork.



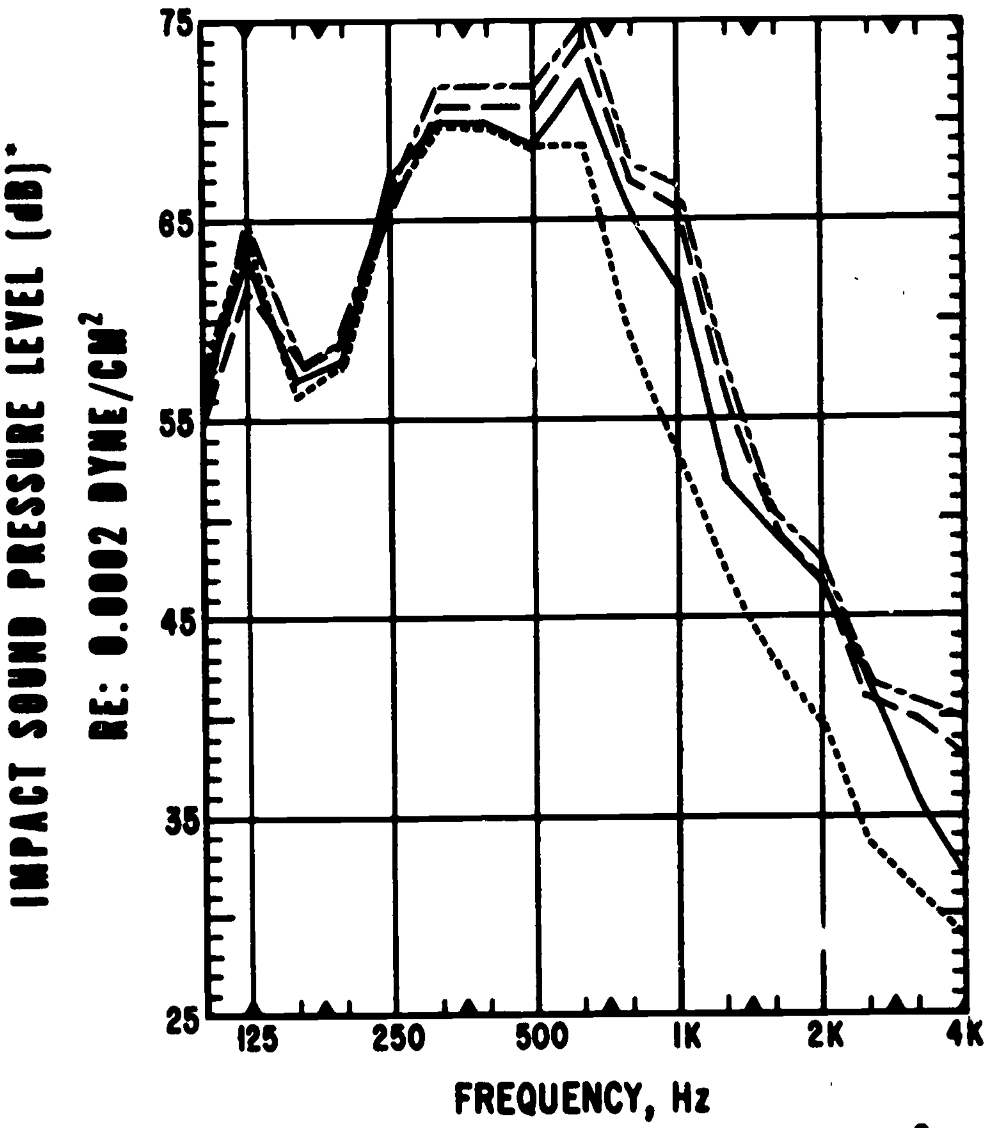
I(a) ———— IIC = 41
I(b) ········ IIC = 48
I(c) – – – – IIC = 43
I(d) –·–·–·– IIC = 45
I(e) ———— IIC = 52

II(a) —— —— IIC = 45
II(b) ········ IIC = 48
II(c) – – – – IIC = 43
II(d) –·–·–·– IIC = 42

REMARKS: See preceding reports. Fire rating and STC are commensurate with those given in F-1.



I



II

*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: REINFORCED CONCRETE SLAB

TEST REF: 1-(S5)

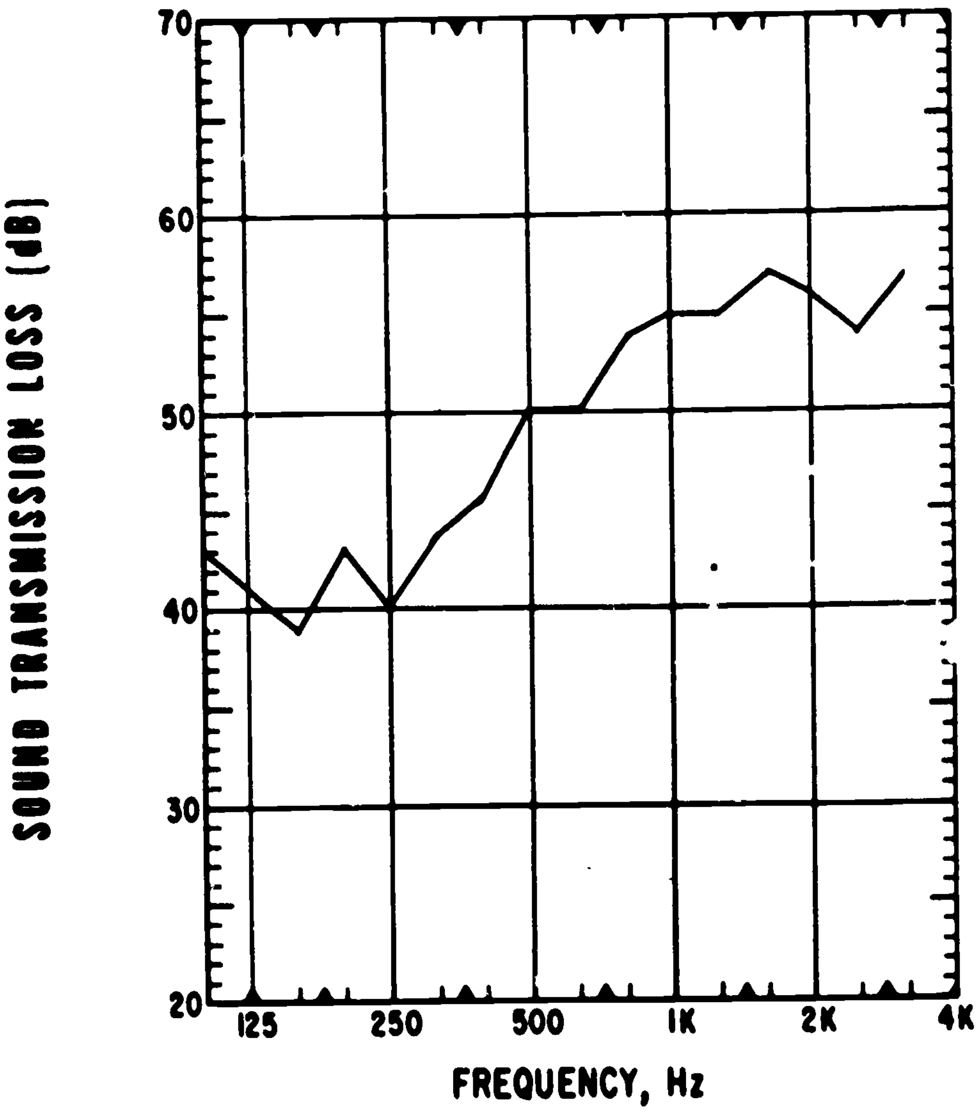
DESCRIPTION: 5-in.-thick reinforced concrete. On the floor side, linoleum on bitumen-felt underlayment. On the ceiling side, 1/2-in.-thick papered fiber board.

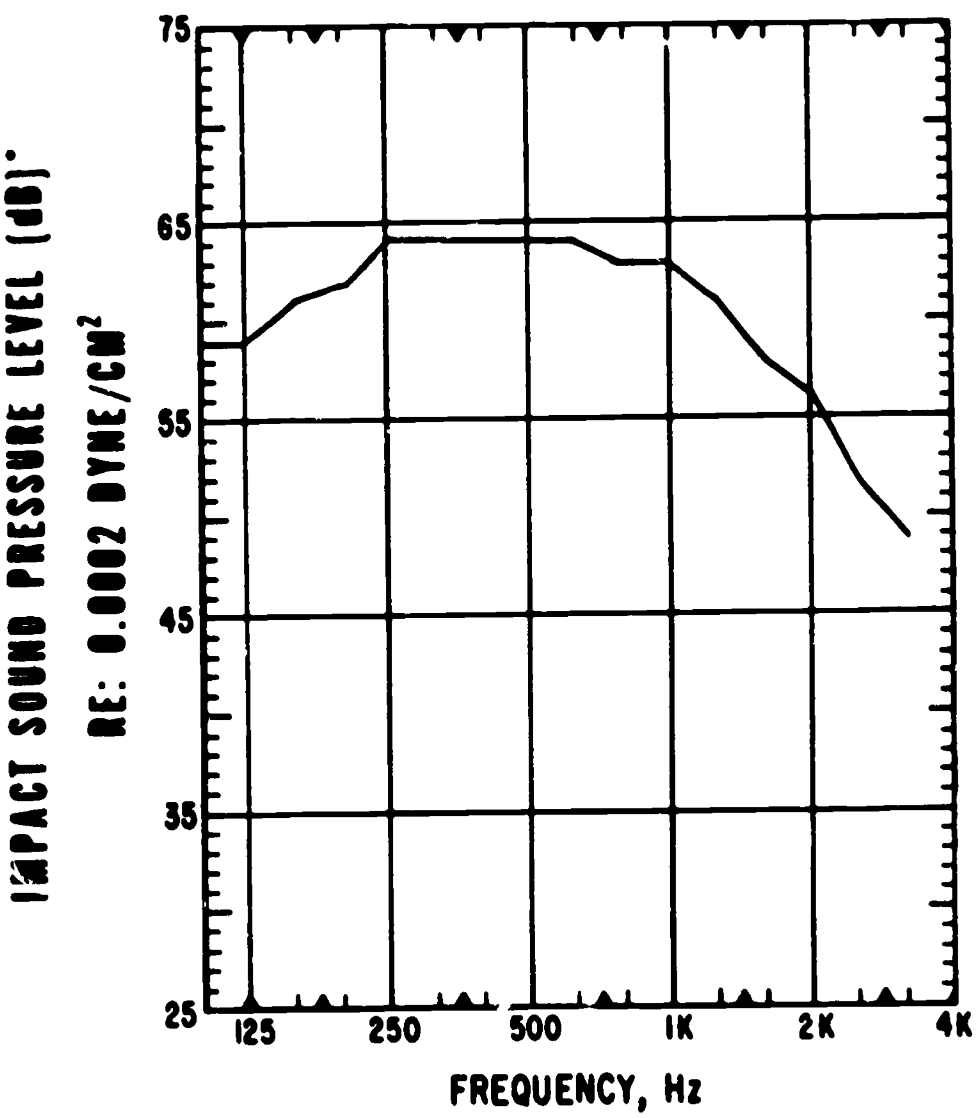
Total thickness: 6 in.

Area weight: 64 lb/ft^2

STC = 51; IIC = 47; Fire Rating: 2 hrs. (est.)

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

TYPE: REINFORCED CONCRETE SLAB

TEST REF: (a) 1-(S7); (b) 1-(S8); (c) 1-(S9)

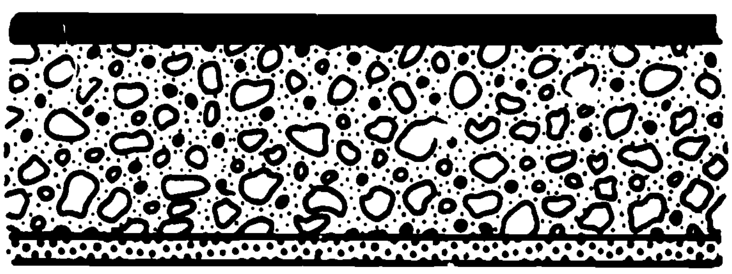
DESCRIPTION: (a) 6-in.-thick reinforced concrete slab. On the floor side, 5/8-in.-thick mastic asphalt. On the ceiling side, approximately 3/4-in. layer of plaster.

(b) Similar to (a), except for a thin layer of asphalt-felt paper between the concrete slab and the mastic asphalt.

(c) Similar to (a), except for a thin layer of cork between the concrete slab and the mastic asphalt.

Total thickness: approximately 7 1/2 in.

Area weight: 85 lb/ft^2

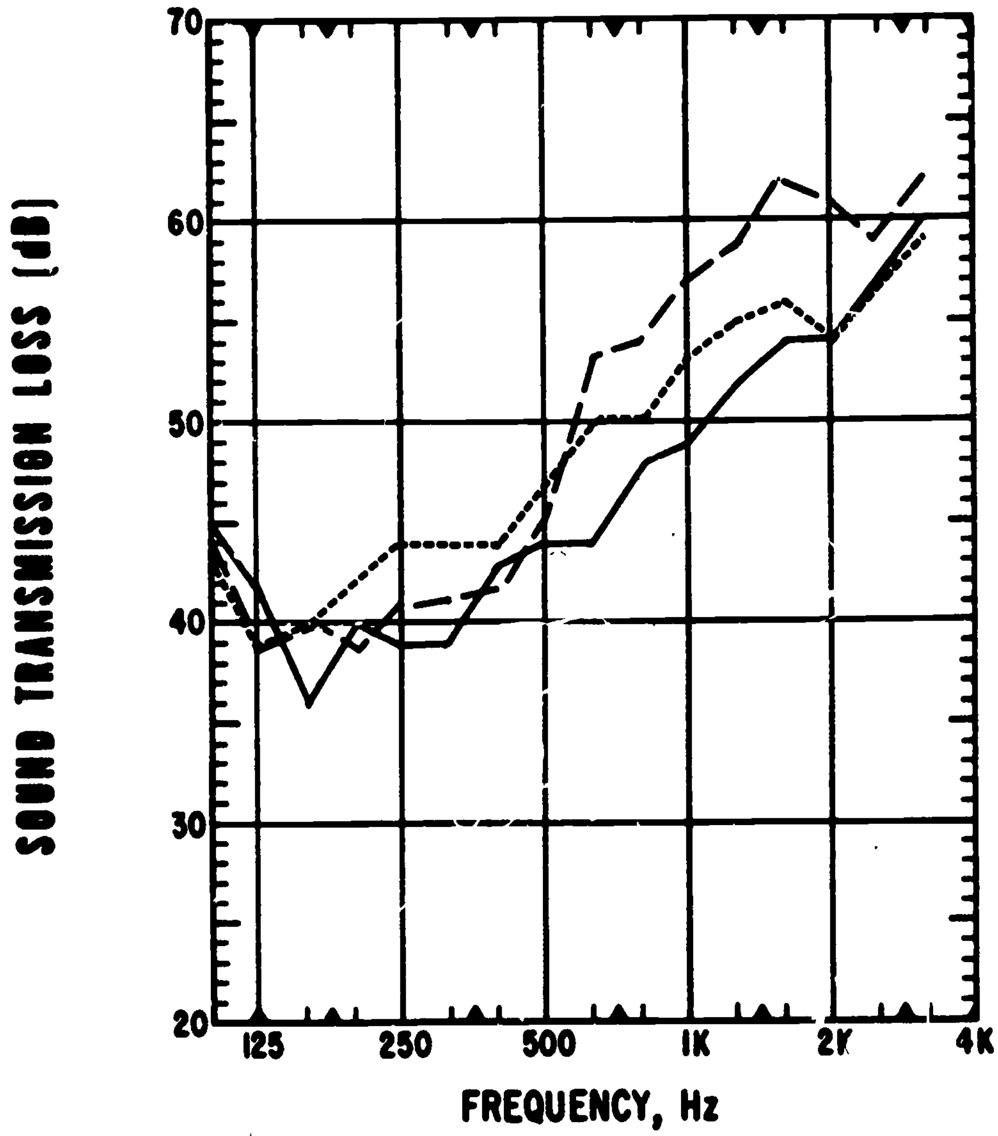


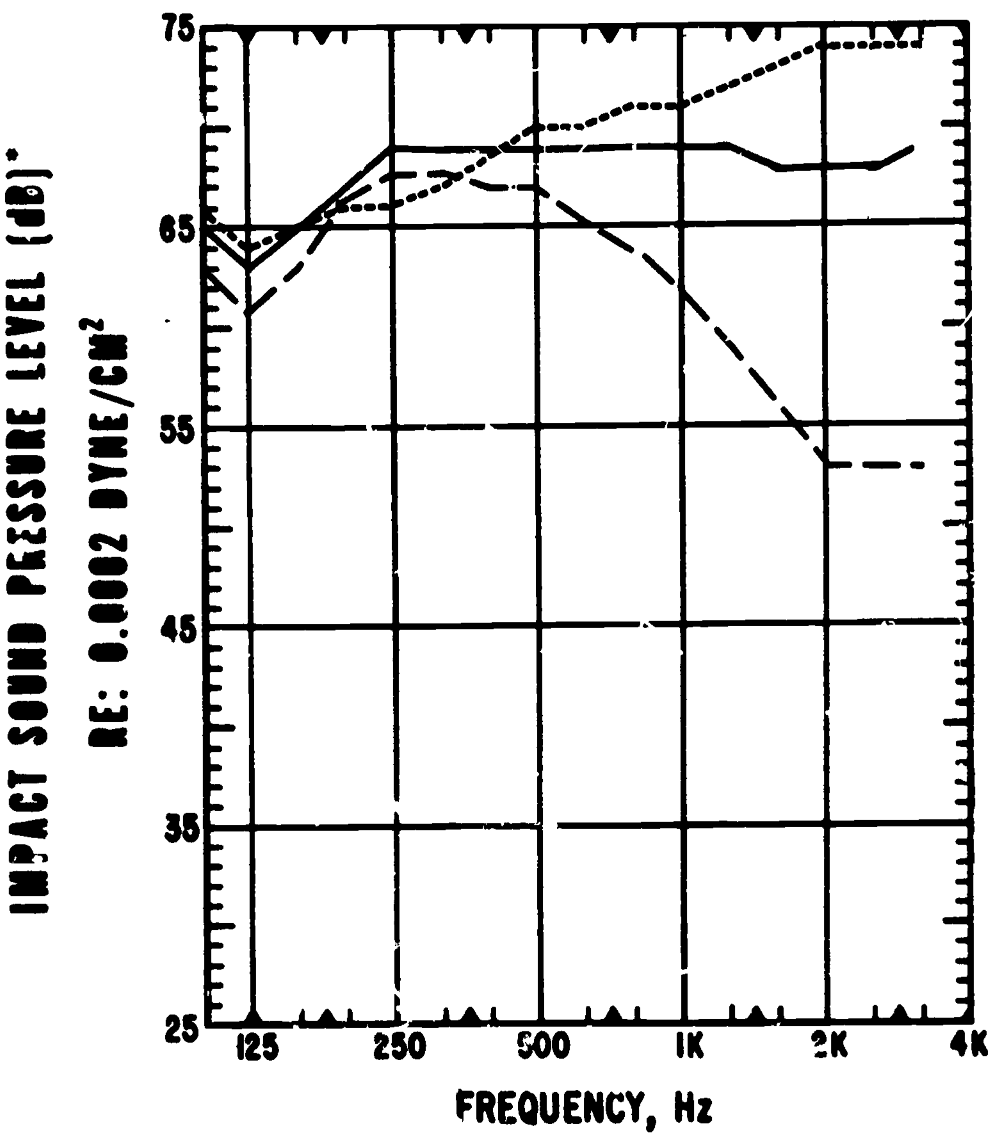
(a) ———— STC = 47; IIC = 31; Fire Rating: 3 hrs. (est.)

(b) ·········· STC = 49; IIC = 26

(c) - — — — — STC = 47; IIC = 46

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

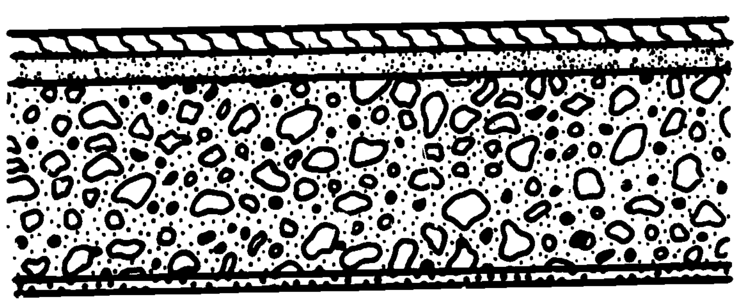
TYPE: REINFORCED CONCRETE SLAB

TEST REF: 1-(S2-1; S3-1, 2; S4-1, 2)

DESCRIPTION: 6-in. reinforced concrete slab; on the floor side, 7/8-in.-thick sand-cement screed and 5/8-in.-thick composition flooring; on the ceiling side, 1/2-in. plaster.

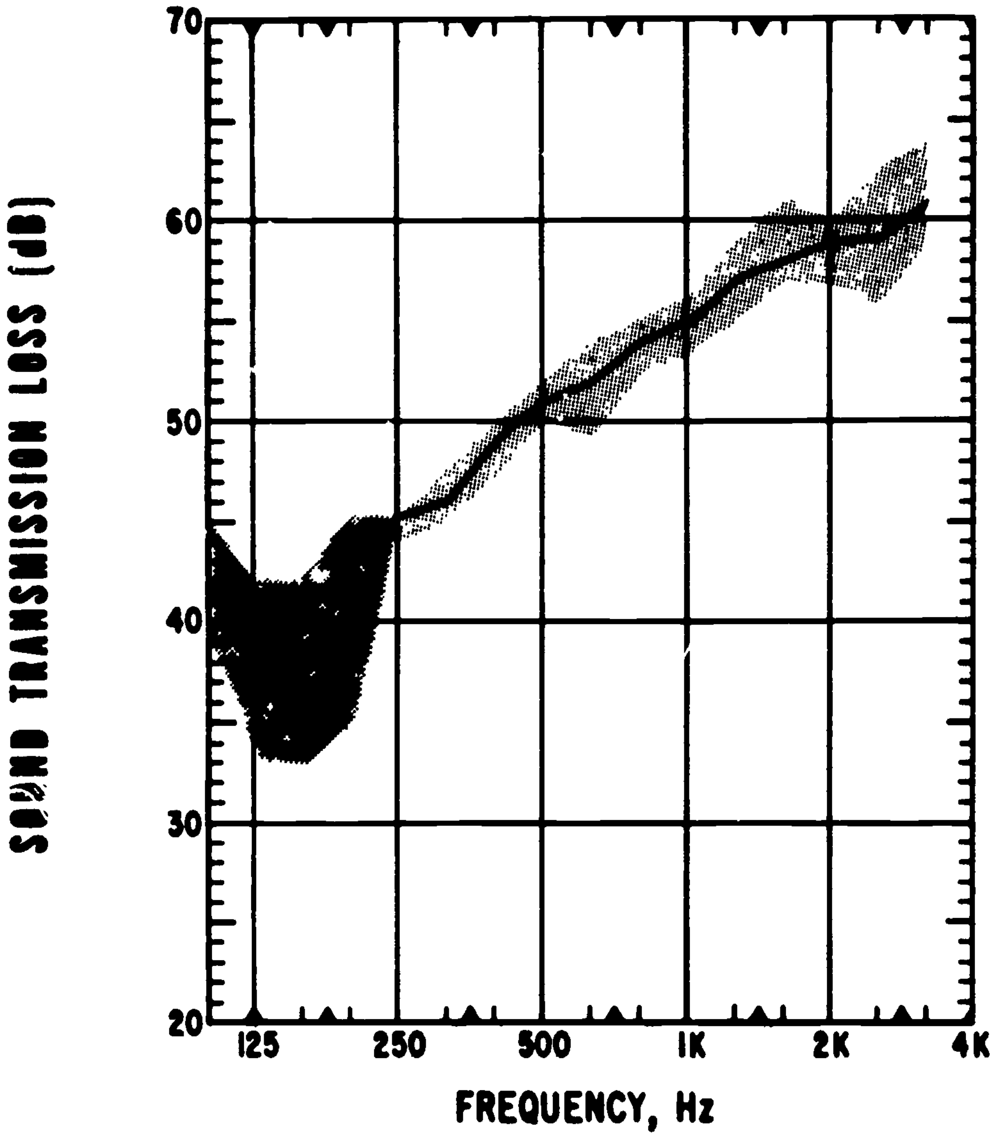
Total thickness: 8 in.

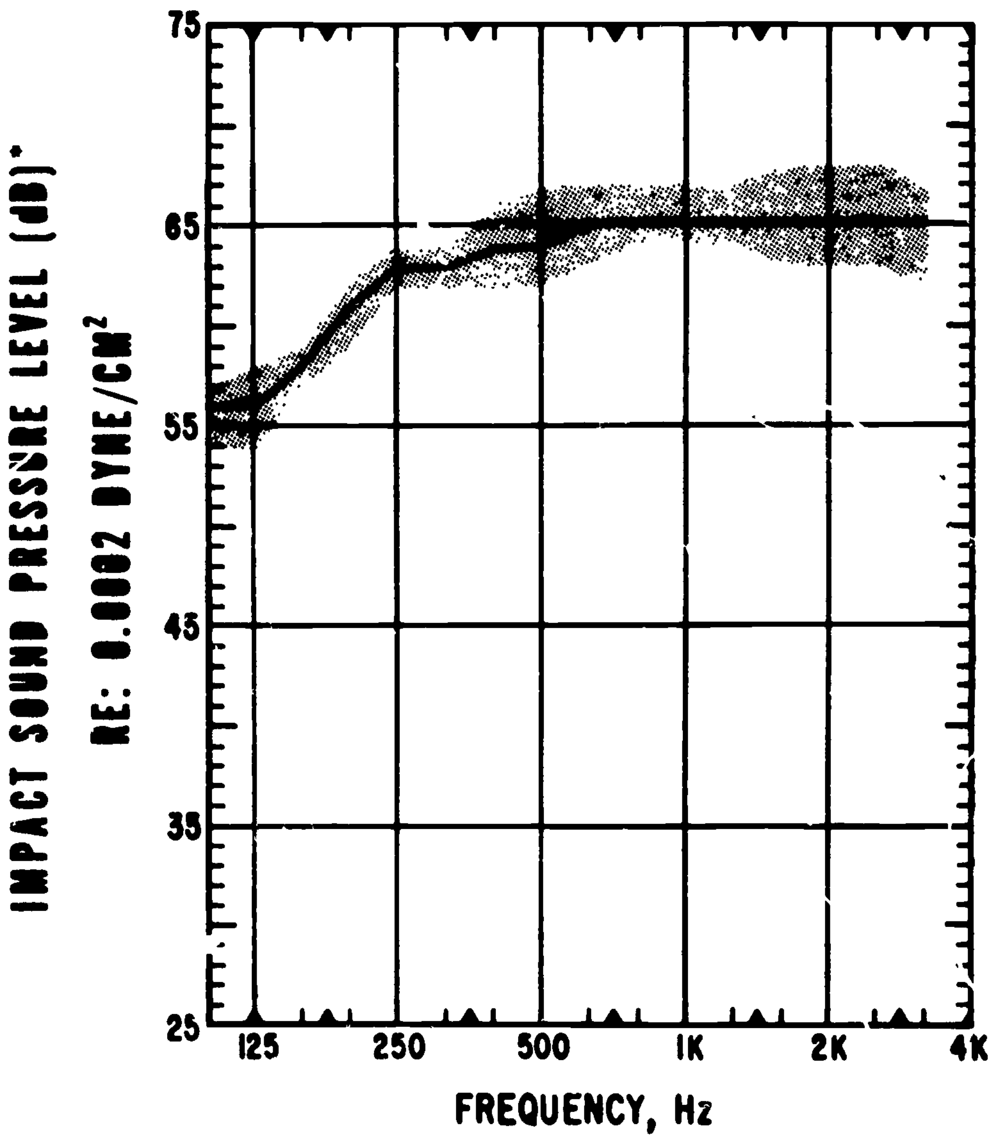
Area weight: 95 lb/ft^2



STC = 54; IIC = 35; Fire Rating: 3 hrs. (est.)

REMARKS: The plotted curve is the average of field measurements of five nominally identical structures. The shaded area indicates the spread of the measurements.





*1/3-octave band data normalized to T_o = 0.5 sec.

TYPE: REINFORCED CONCRETE SLAB

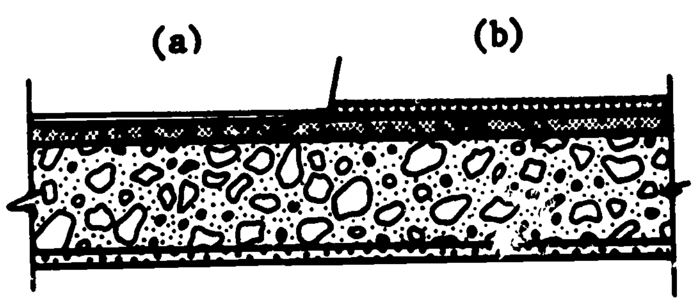
TEST REF: (a) 11(b)-(Fig. 37a, 37d); (b) 11(b)-(Fig. 36f); 17-(3a)

DESCRIPTION: (a) 4 3/8-in.-thick reinforced concrete slab. On the floor side, 3/4-in.-thick sand-cement screed with 1/8-in. linoleum floor covering. On the ceiling side, 3/8-in. layer of plaster.

(b) Similar to (a) except the floor was covered with coco mat carpeting.

Total thickness: approximately 5 1/2 in.

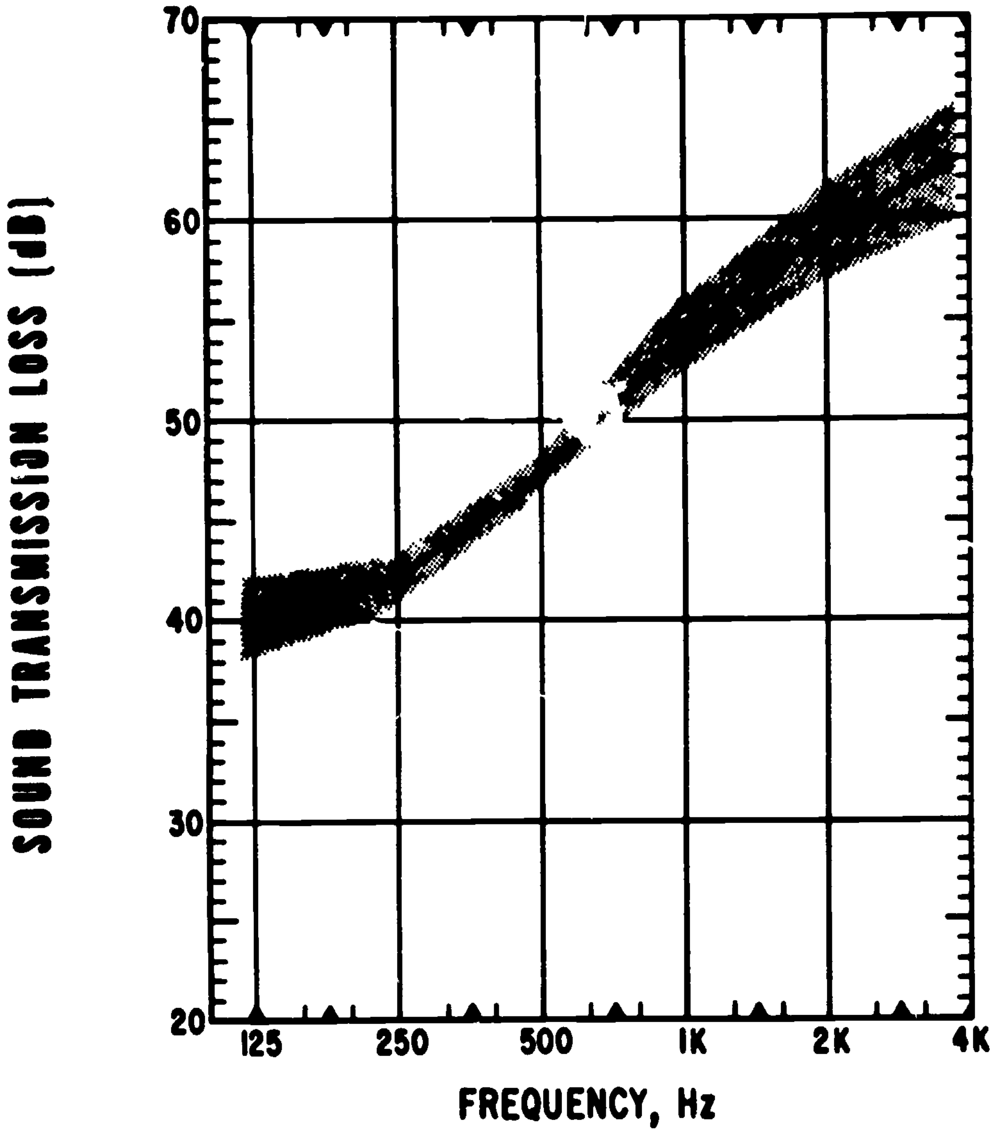
Area weight: approximately 61 lb/ft^2

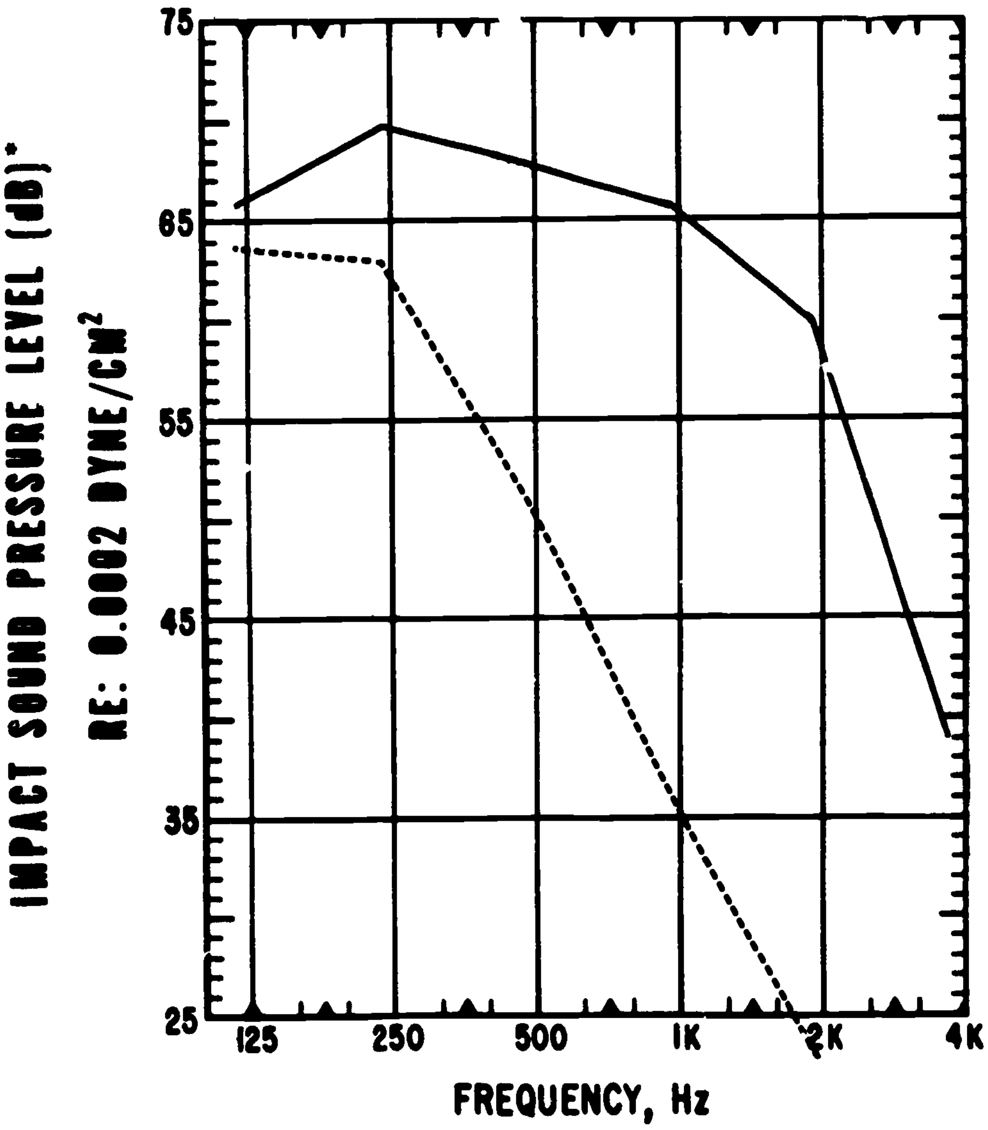


(a) ———— STC = 51; IIC = 48; Fire Rating: 2 hrs. (est.)

(b) ------------ STC = 51; IIC = 58

REMARKS: The airborne STL measurements were made without floor coverings; however, these provide little additional airborne sound insulation and the data are applicable to the above structures. The plotted curve for the airborne sound insulation represents the average of field measurements of six nominally identical structures. The shaded area indicates the spread of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

TYPE: CONCRETE SLAB

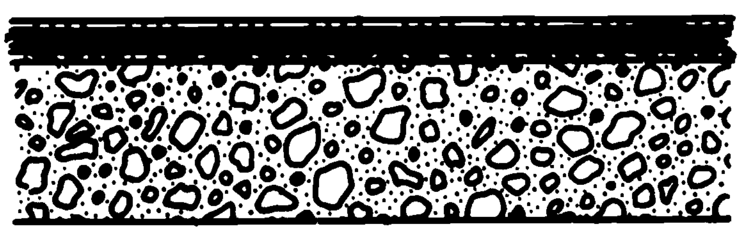
TEST REF: (a) 8-(308-1-65); (b) 8-(308-2-65)

DESCRIPTION: (a) 5-in.-thick concrete slab. On the floor side, 1/4-in.-thick medium density cork, 11-12 lb/ft^3, adhered to concrete, 5/8-in.-thick plywood subfloor glued to cork, 5/16-in.-thick wood oak flooring adhered to subfloor. No ceiling finish.

Total thickness: 6 1/4 in.

Area weight: approximately 70 lb/ft^2 (Not specified in reference.)

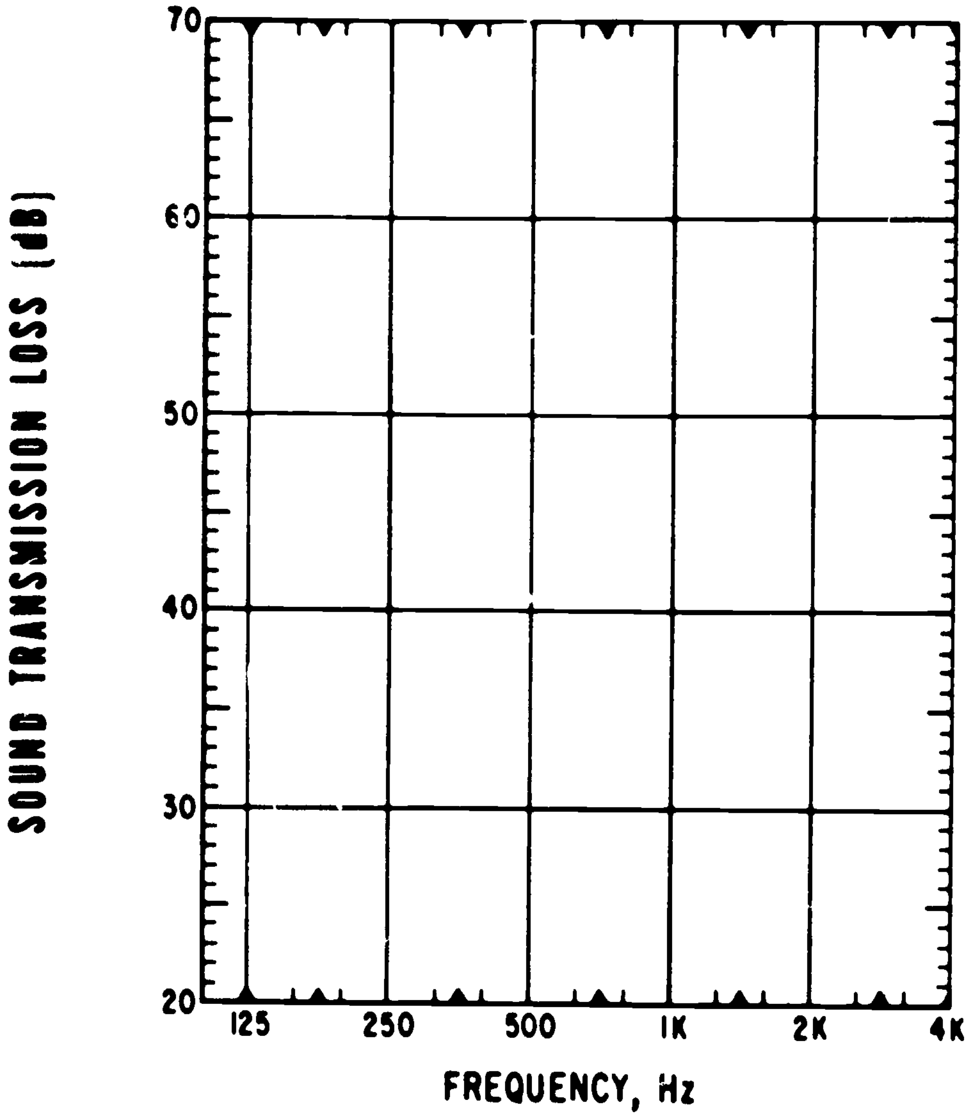
(b) Similar to (a) except the density of the cork was 8.5 lb/ft^3.

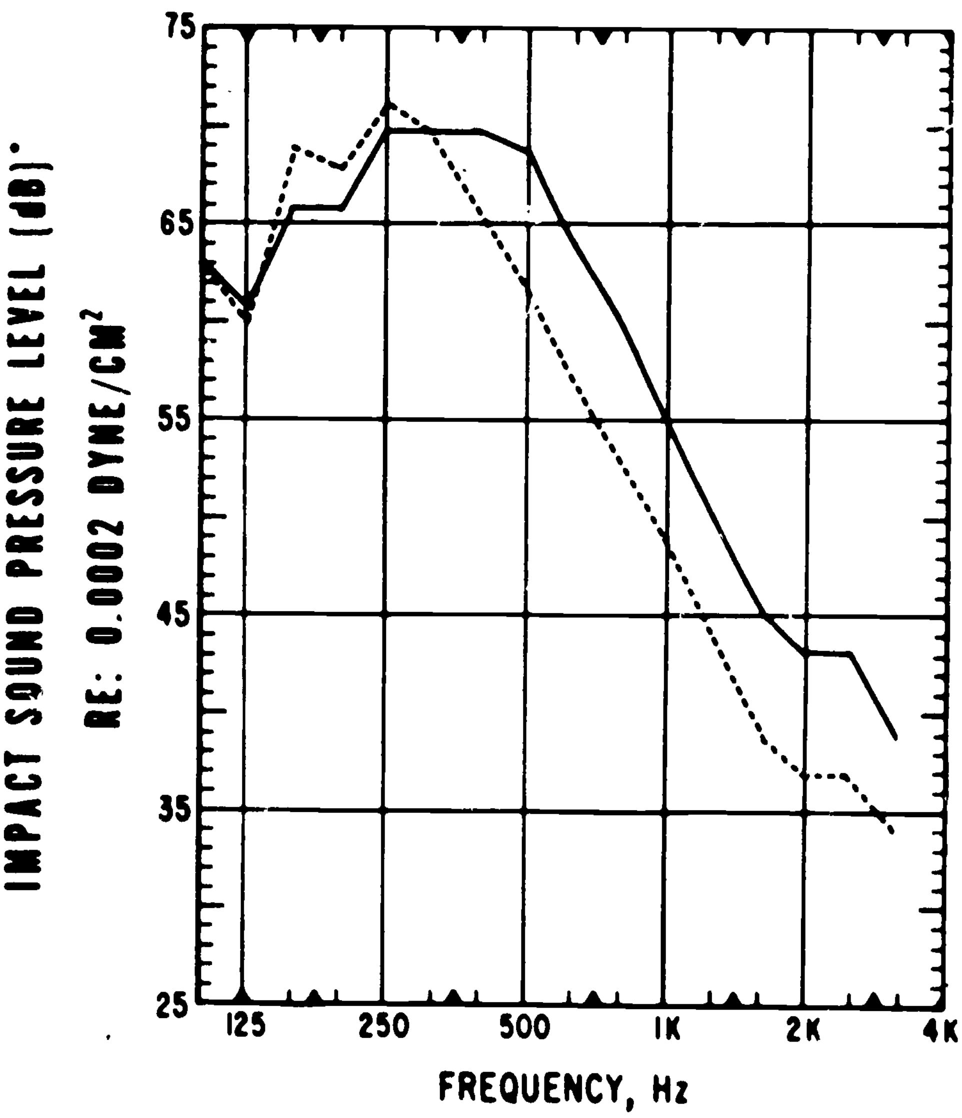


(a) ———— STC = 48-50 (est.); IIC = 47; Fire Rating: 2 hrs. (est.) - combustible

(b) ------- STC = 48-50 (est.); IIC = 49

REMARKS: Airborne STL measurements of this structure are not available; therefore, the STC has been estimated from measurements of similar constructions.





*1/3-octave band data normalized to A = $10m^2$

TYPE: REINFORCED CONCRETE SLAB

TEST REF: 11(a)-(IV-C-27)

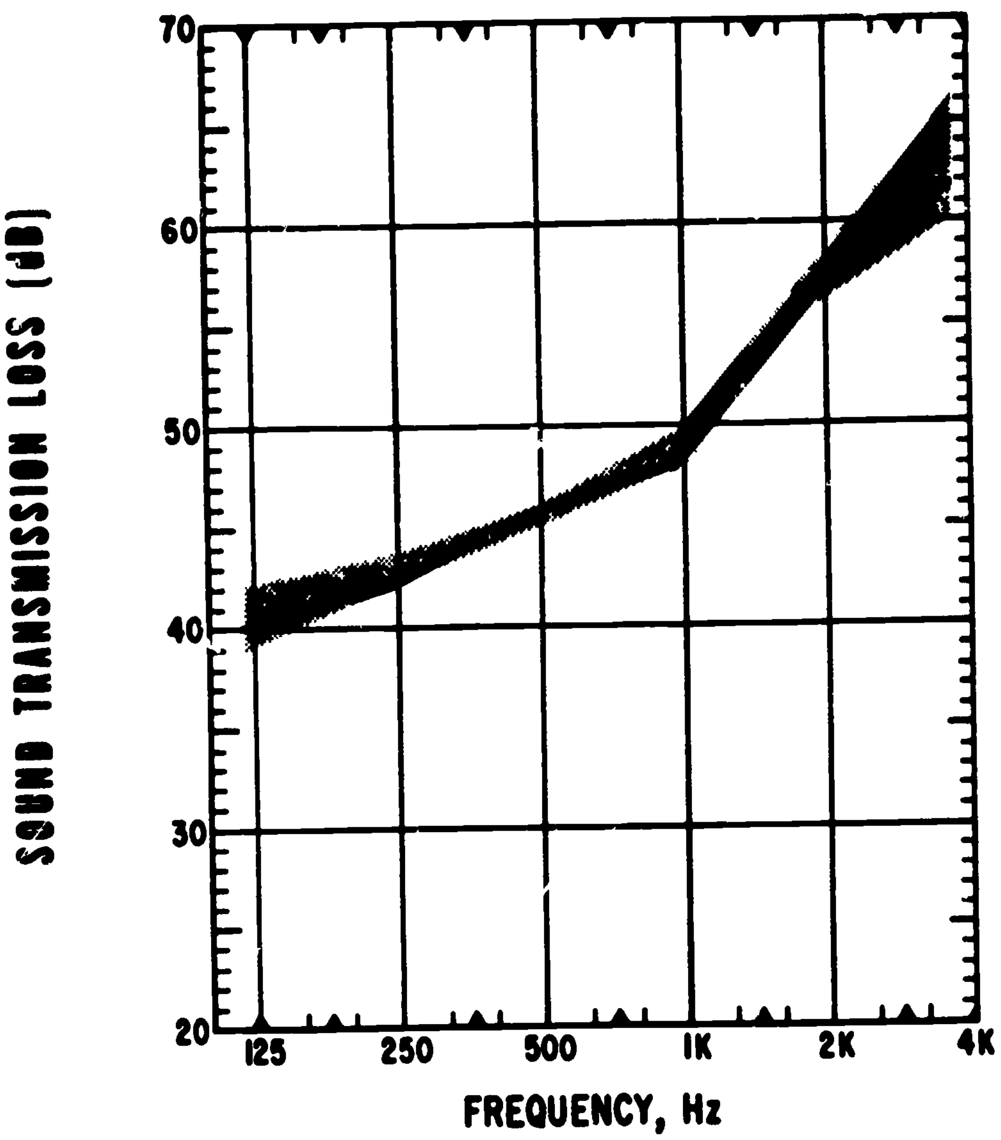
DESCRIPTION: 4 3/8-in.-thick reinforced concrete slab. On the floor side, 1/2-in.-thick layer of bitumen with 1/2-in.-thick soft wood fiber board which was covered with a thin layer of bitumen with sand and a 3/4-in.-thick sand-cement screed. On the ceiling side, 3/8-in. layer of plaster.

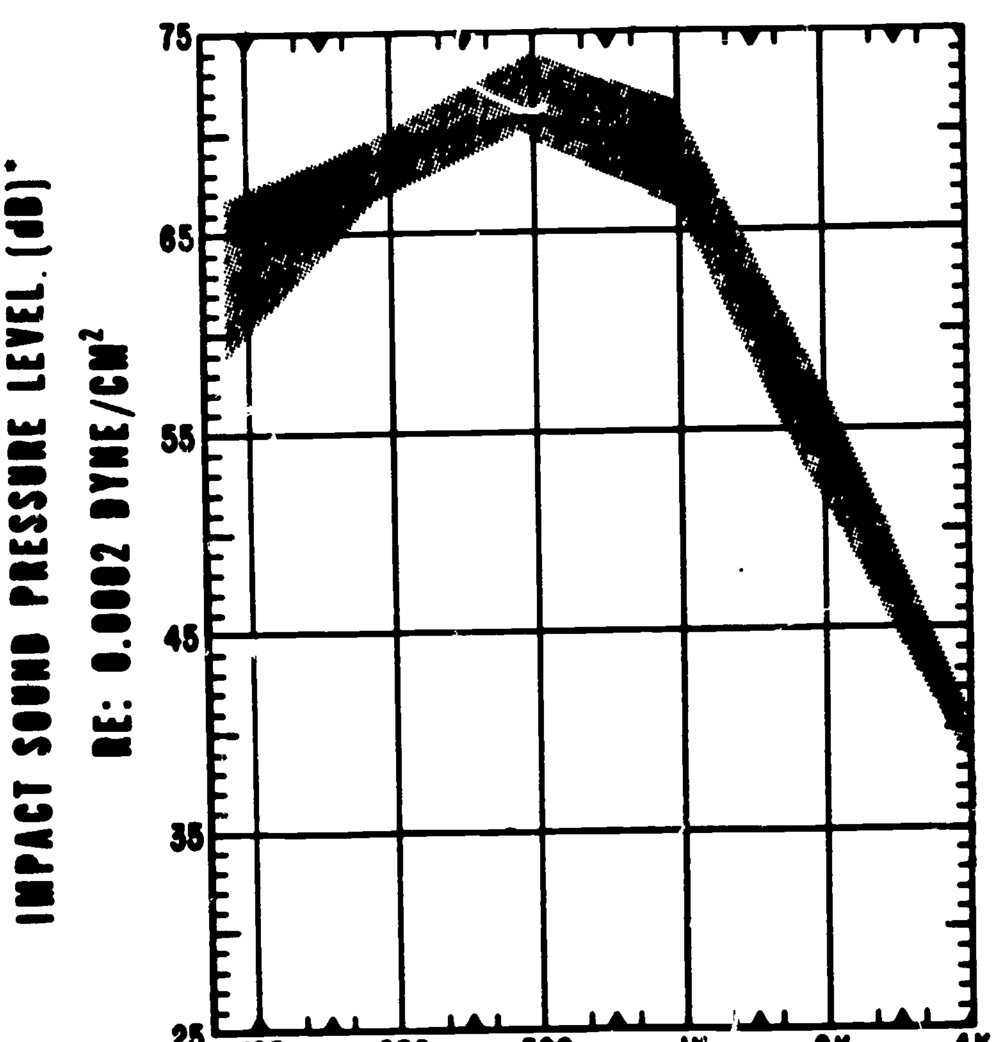
Total thickness: 6 5/8 in.

Area weight: approximately 65 lb/ft^2

STC = 49; IIC = 48; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

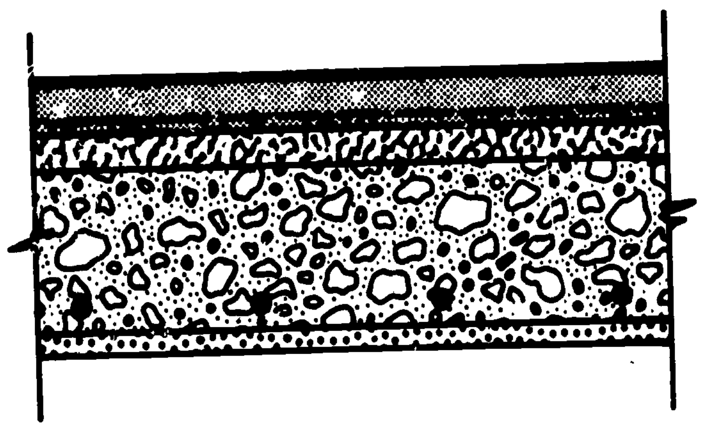
TYPE: REINFORCED CONCRETE SLAB, FLOATING FLOOR

TEST REF: 1-(S27-1,2,4; S29-1,4; S30-2,3,4; S31, S32, S33-1,2,3; S34)

DESCRIPTION: 5-in.-thick reinforced concrete. On the floor side, 1 1/2-in.-thick wire mesh reinforced sand-cement screed floating on 1/2-in.-thick bitumen-bonded glass-wool quilt covered with building paper. On the screed, 1/2-in.-thick pitch-mastic with a linoleum floor covering. On the ceiling side, 1/2-in. layer of plaster.

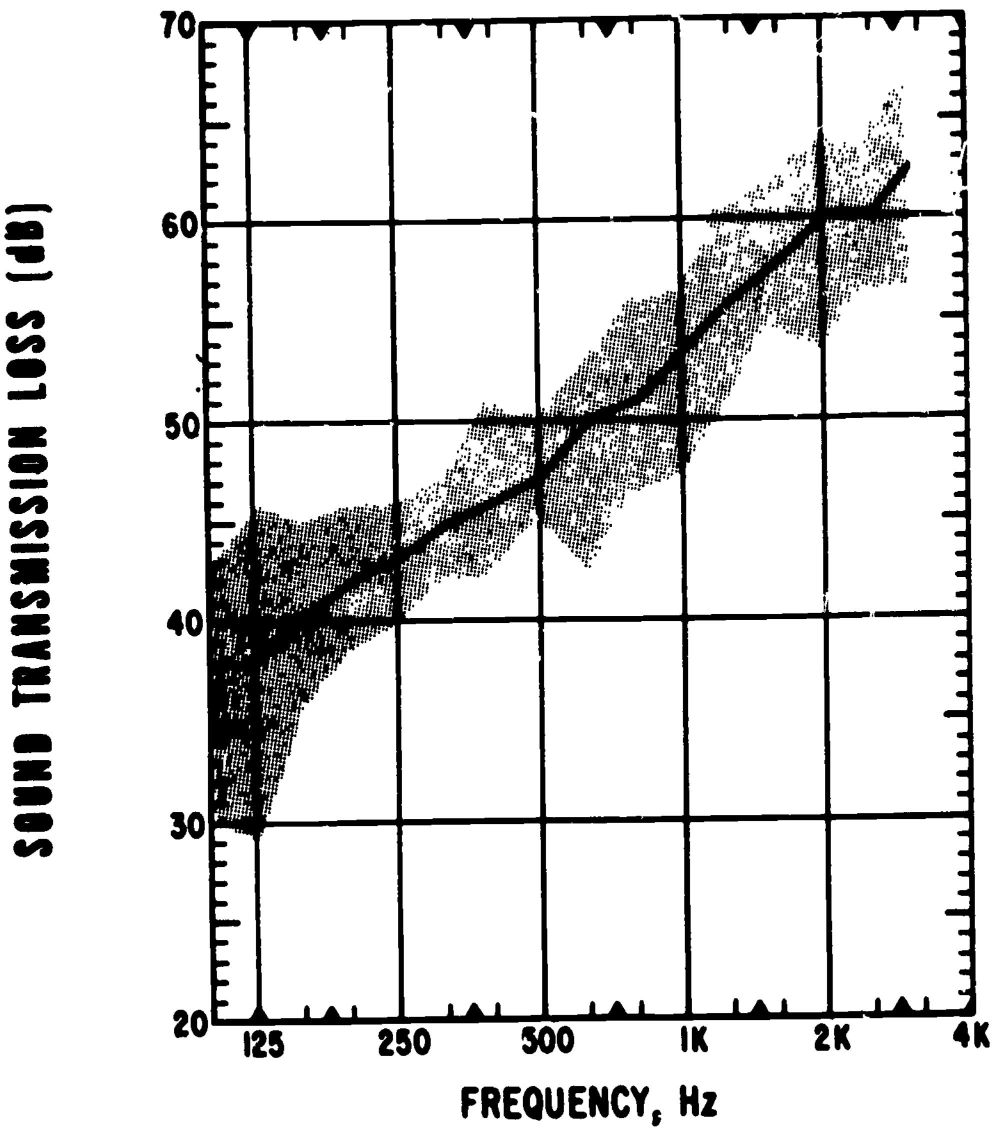
Total thickness: 8 1/4 in.

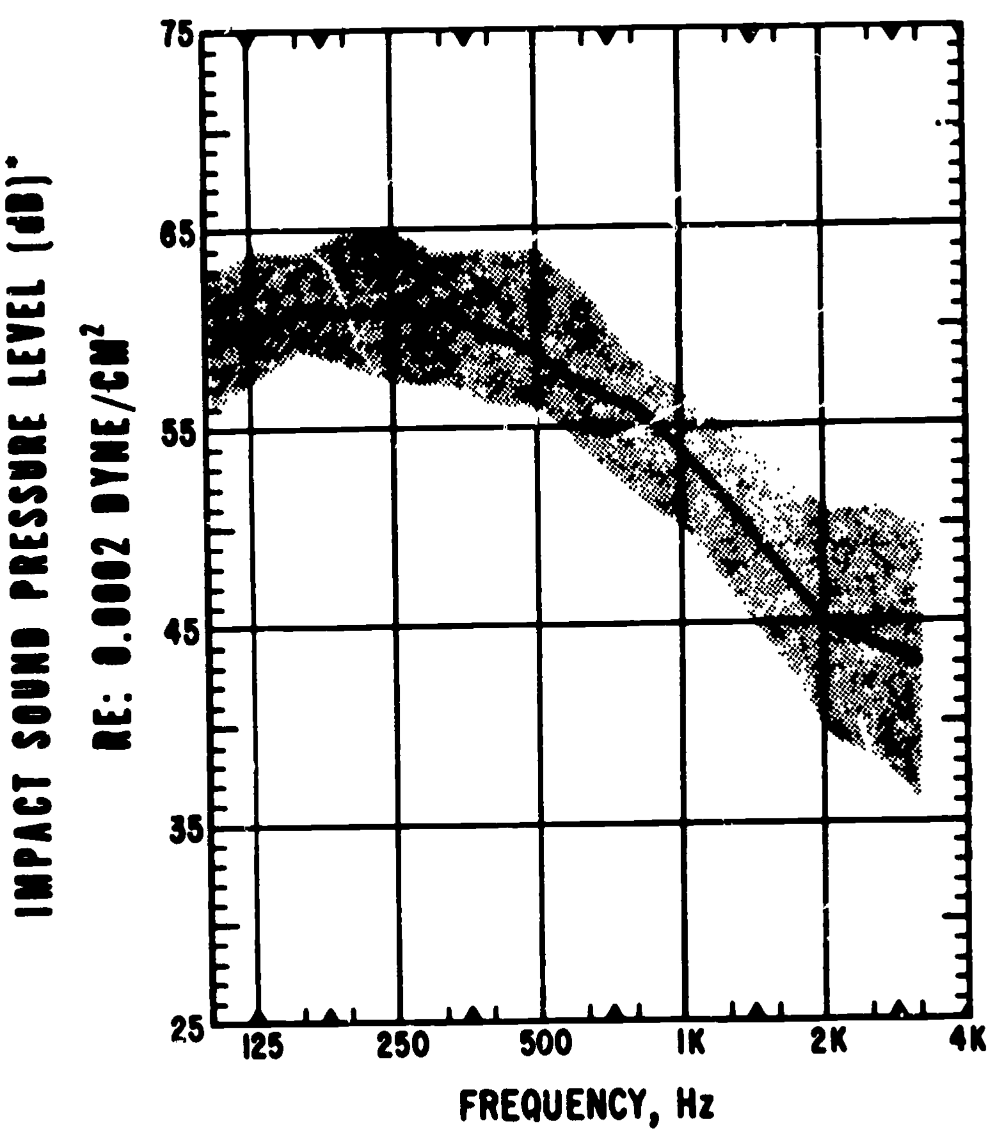
Area weight: 90 lb/ft^2



STC = 51; IIC = 53; Fire Rating: 2 1/2 hrs. (est.)

REMARKS: The plotted STL curve represents the average of field measurements of 21 nominally identical structures, and the plotted ISPL curve is the average of 17 structures. The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to T_o = 0.5 sec.

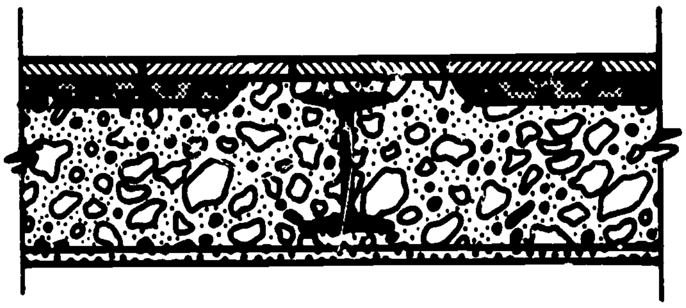
TYPE: CONCRETE WITH STEEL "I" BEAMS

TEST REF: 1-(S11-3, 4; S12; S13-2, 3, 4; S14-1, 2, 3; S15; S16-1, 3; S17; S18-4; S19-1, 3; S21-1, 3; S22-2)

DESCRIPTION: 4 1/2-in.-thick concrete and filler-joist structural floor. The filler-joists were 3- by 4-in. steel "I" beams spaced 30 in. on centers. On the floor side, 1-in.-thick clinker concrete to which 7/8-in.-thick wood flooring was nailed 15 in. on centers; linoleum cemented to wood flooring. On the ceiling side, 1/2-in. layer of plaster.

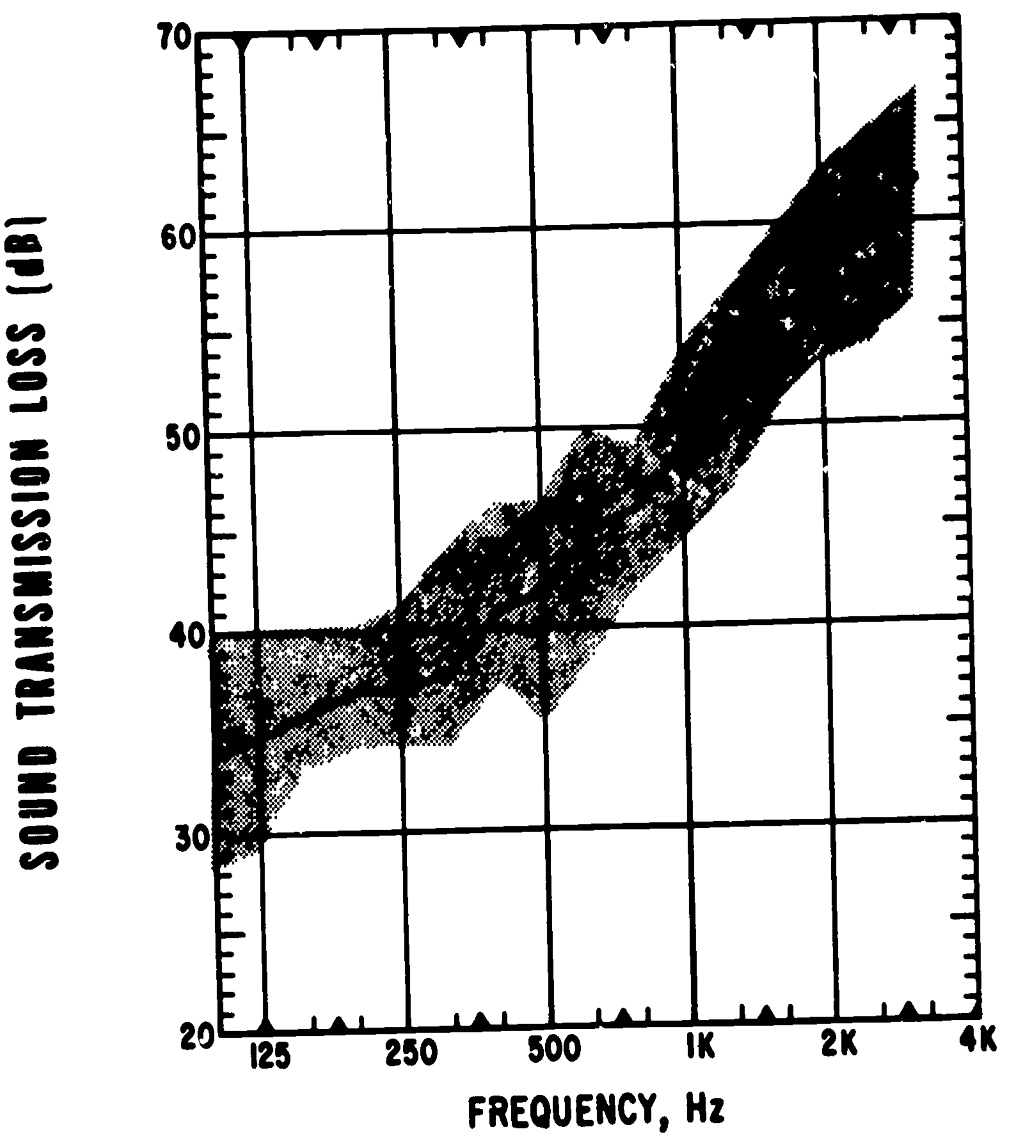
Total thickness: 7 in.

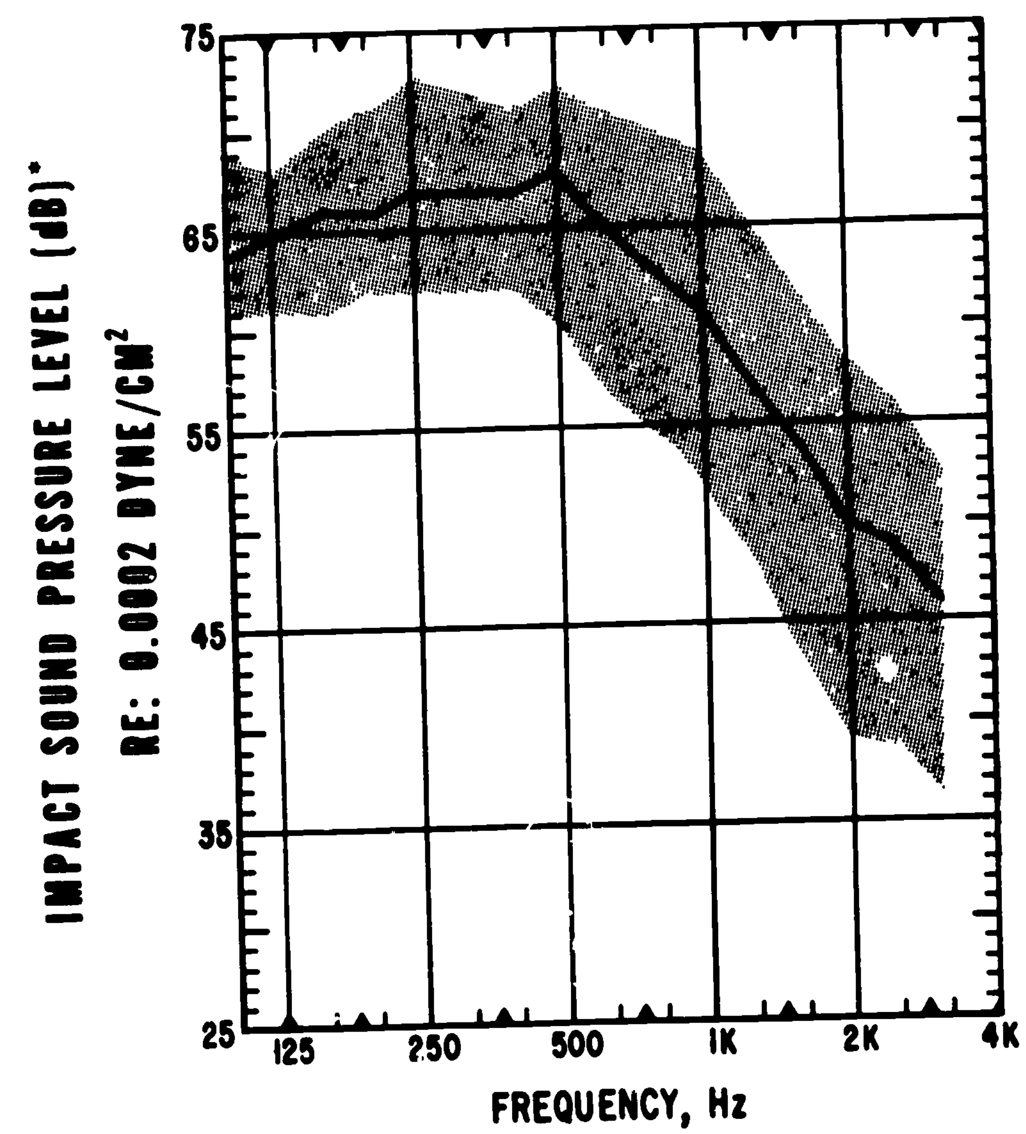
Area weight: 70 lb/ft^2



STC = 46; IIC = 47; Fire Rating: 4 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of 26 nominally identical structures. The shaded areas indicate the spread of the measurements.





*1/3-octave band data normalized to T_0 = 0.5 sec.

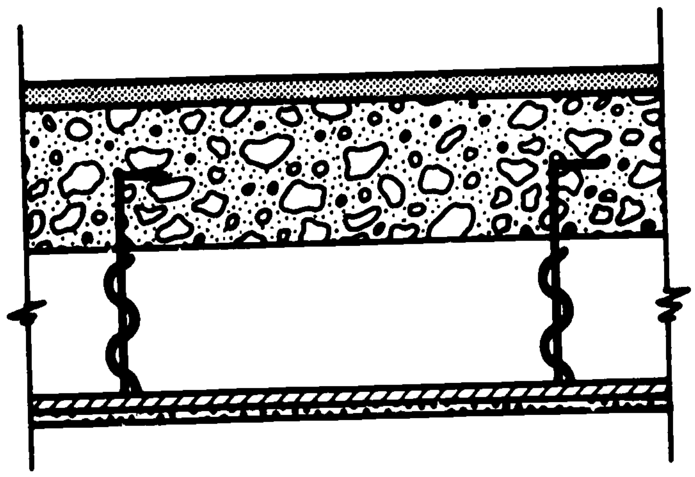
TYPE: REINFORCED CONCRETE, SUSPENDED CEILING

TEST REF: 11(a)-(IV-B-22)

DESCRIPTION: 4 3/8-in.-thick reinforced concrete slab. On the floor side, 3/4-in.-thick sand-cement screed. On the ceiling side, brick wire mesh, suspended 4 in. with wire hangers, held 7/8-in. gypsum plaster.

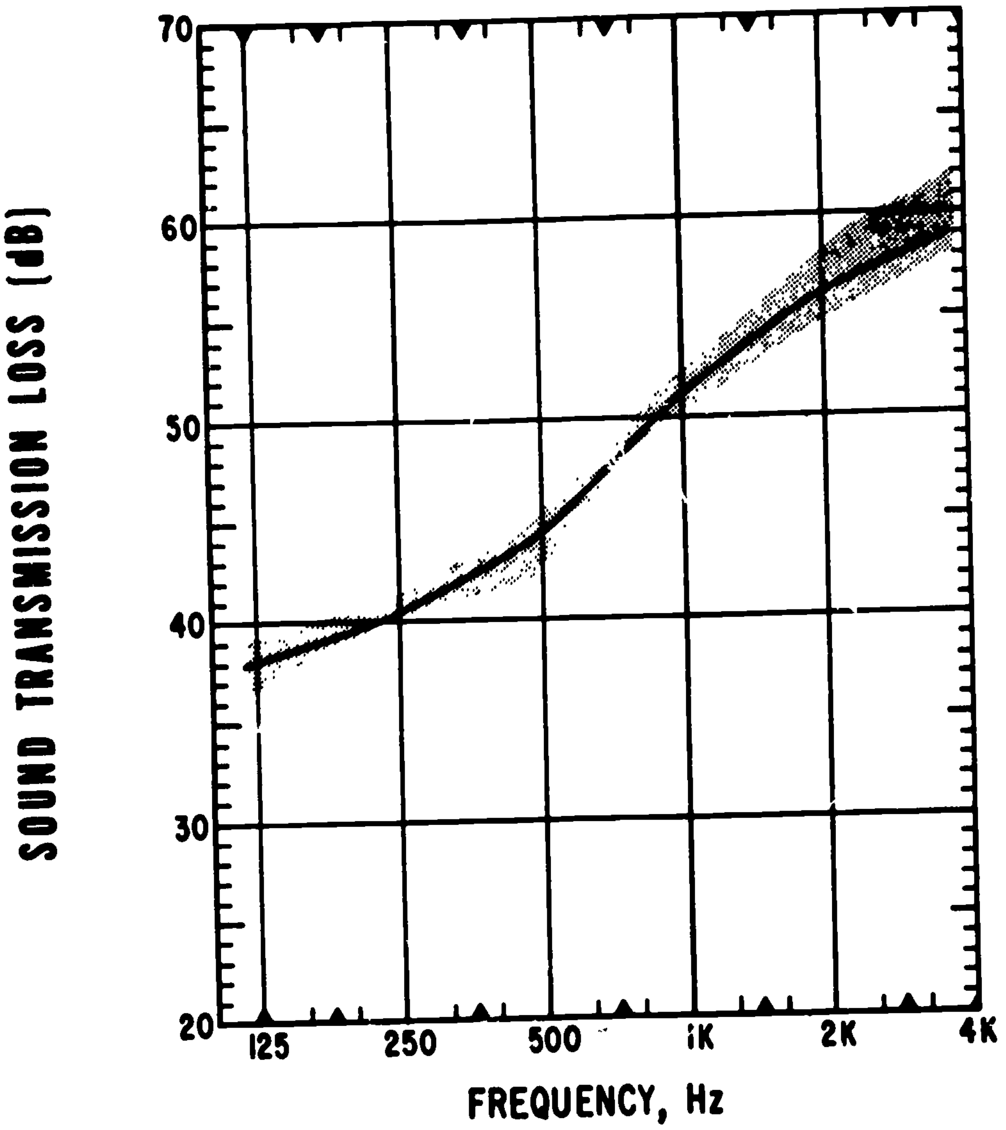
Total thickness: 10 in.

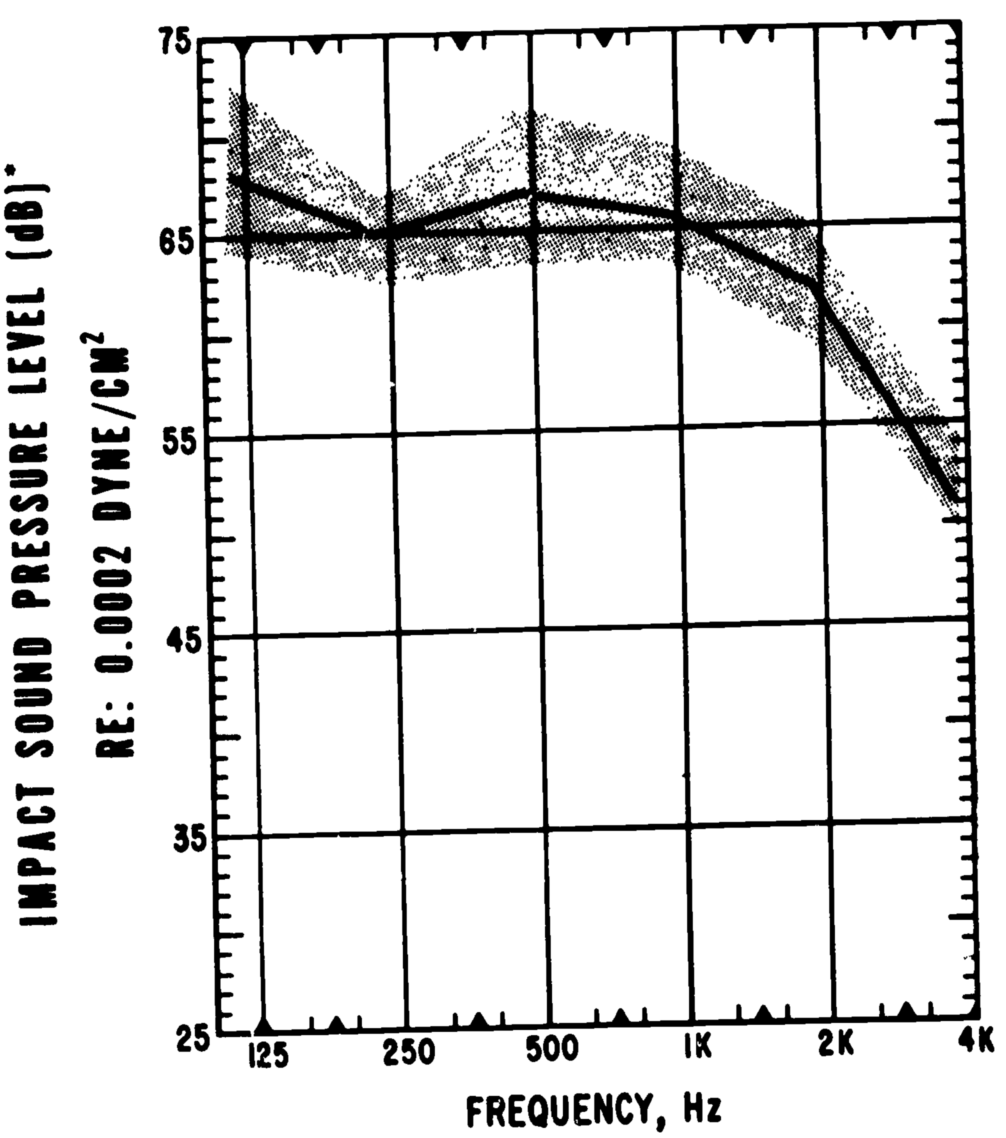
Area weight: approximately 62 lb/ft^2 (Not specified in reference.)



STC = 48; IIC = 47; Fire Rating: 3 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

TYPE: REINFORCED CONCRETE SLAB, FLOATING FLOOR

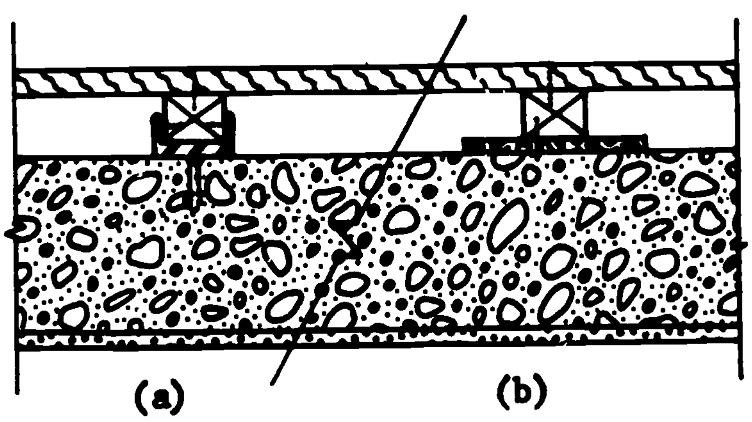
TEST REF: (a) 1-(S166); (b) 1-(S167)

DESCRIPTION: (a) 5 1/2-in.-thick reinforced concrete slab. On the floor side, 3/4-in.-thick tongue-and-groove wood flooring nailed to 1 1/2- by 2-in. wooden battens which were held in asbestos-lined metal clips anchored to concrete slab. On the ceiling side, 1/2-in. layer of plaster.

(b) Similar to (a) except wooden battens were nailed to 1/2- by 4- by 6-in. cork pads set in mastic on the concrete slab.

Total thickness: 9 1/4 in.

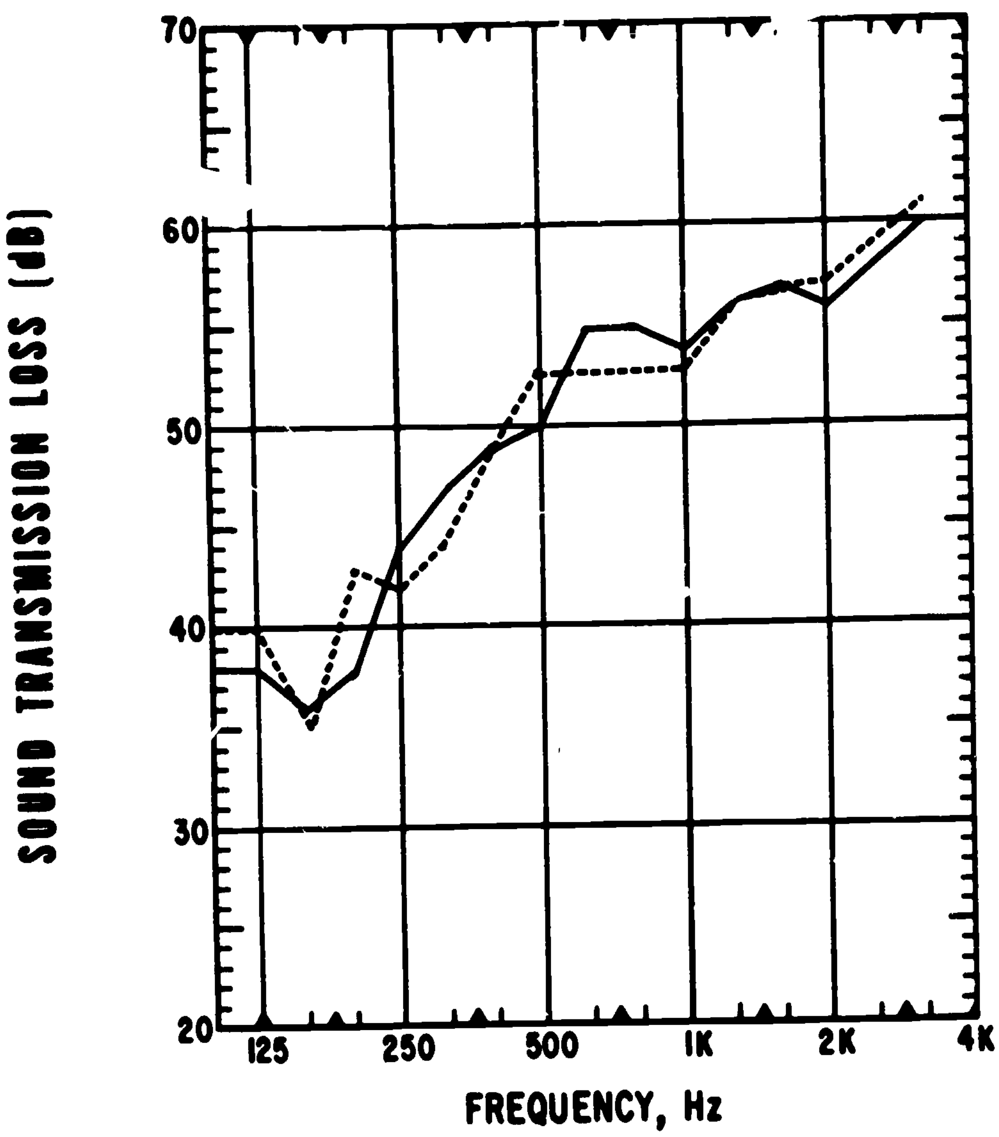
Area weight: 75 lb/ft^2

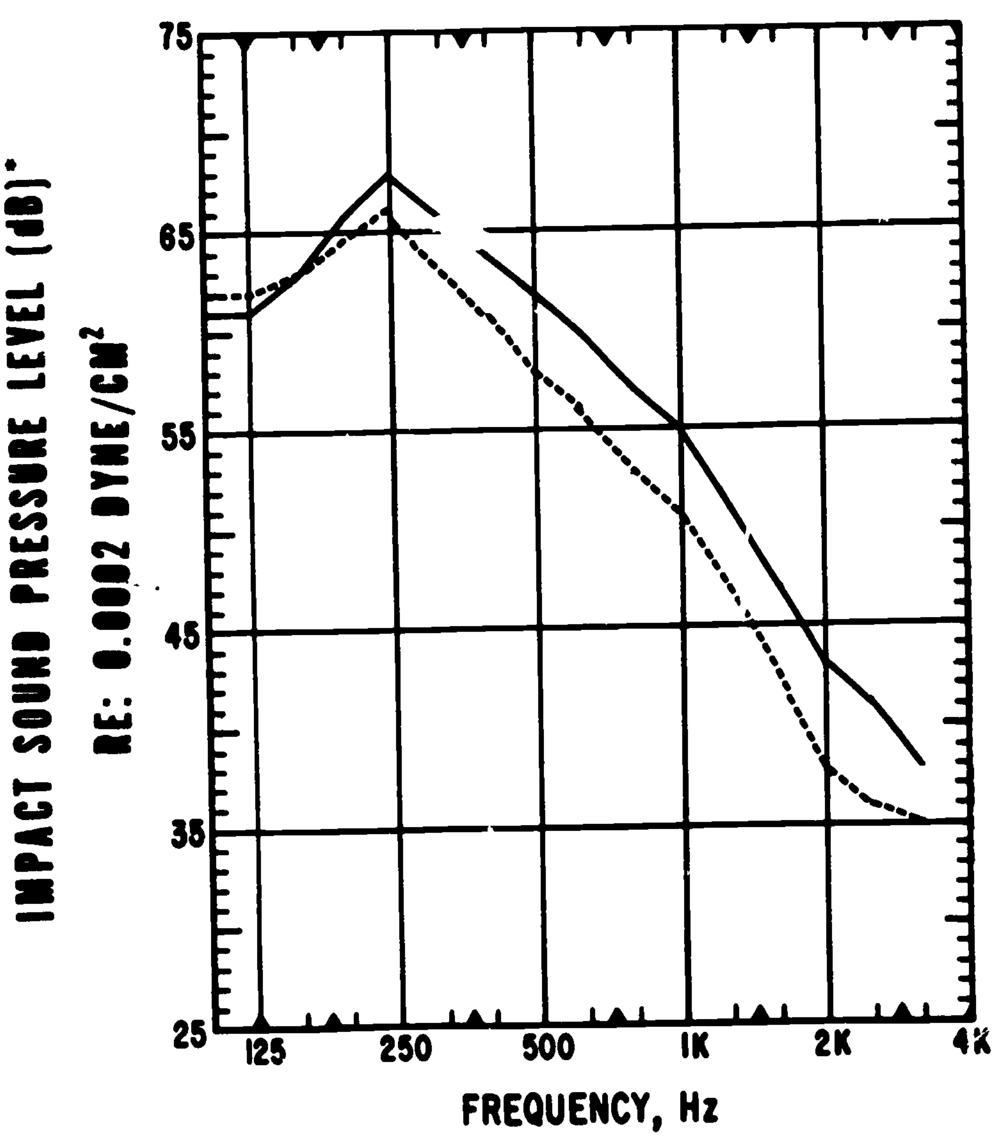


(a) ———— STC = 54; IIC = 51; Fire Rating: 3 hrs. (est.)

(b) ············ STC = 53; IIC = 53

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

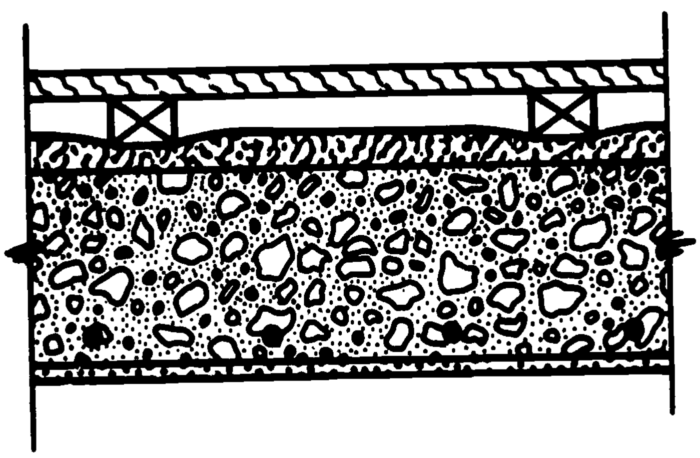
TYPE: REINFORCED CONCRETE SLAB, FLOATING FLOOR

TEST REF: 1-(S53)

DESCRIPTION: 6-in.-thick reinforced concrete slab. On the floor side, 3/4-in.-thick tongue-and-groove wood flooring nailed to 1 1/2- by 2-in. wooden battens, 16 in. on centers, floating on 1-in.-thick glass-wool quilt. On the ceiling side, 1/2-in. layer of plaster.

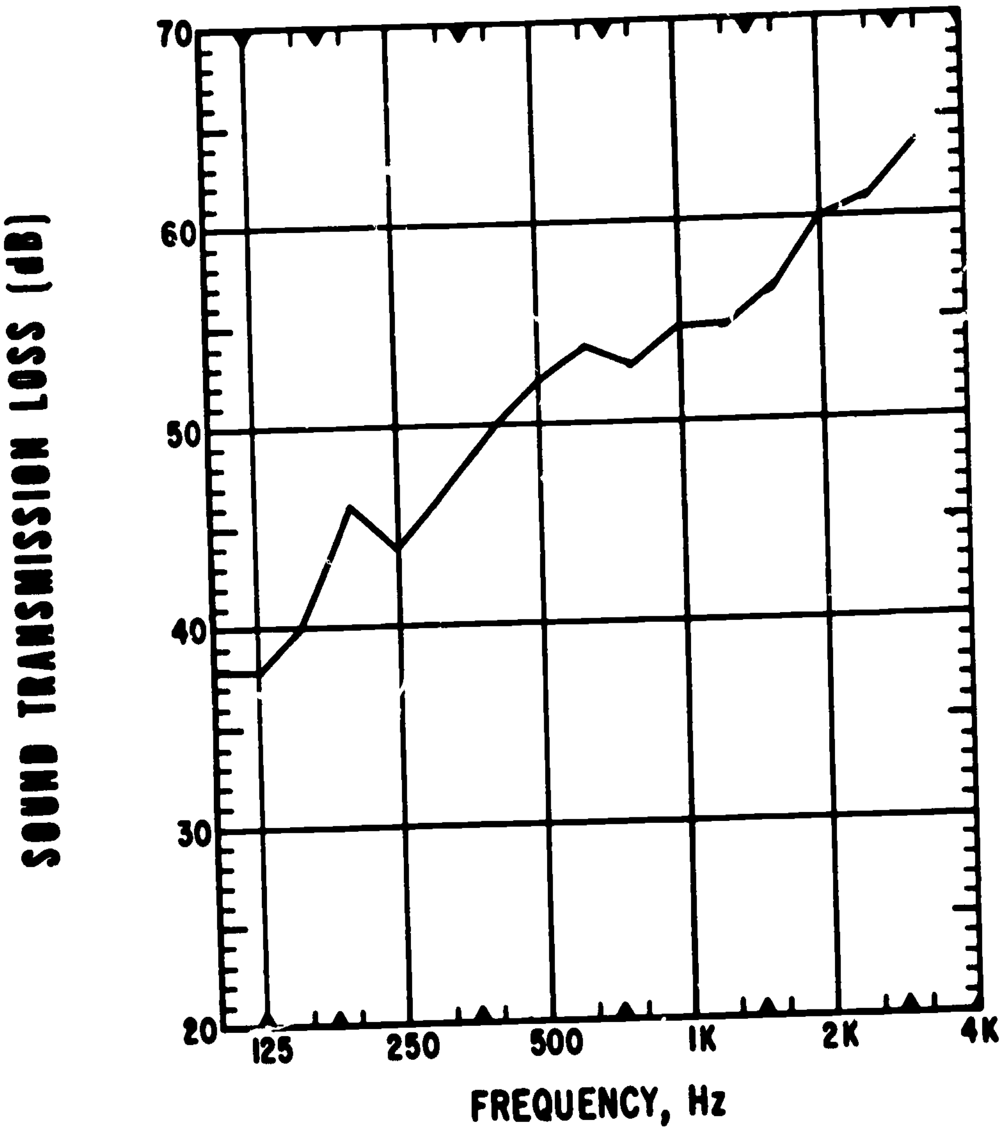
Total thickness: 9 1/2 in.

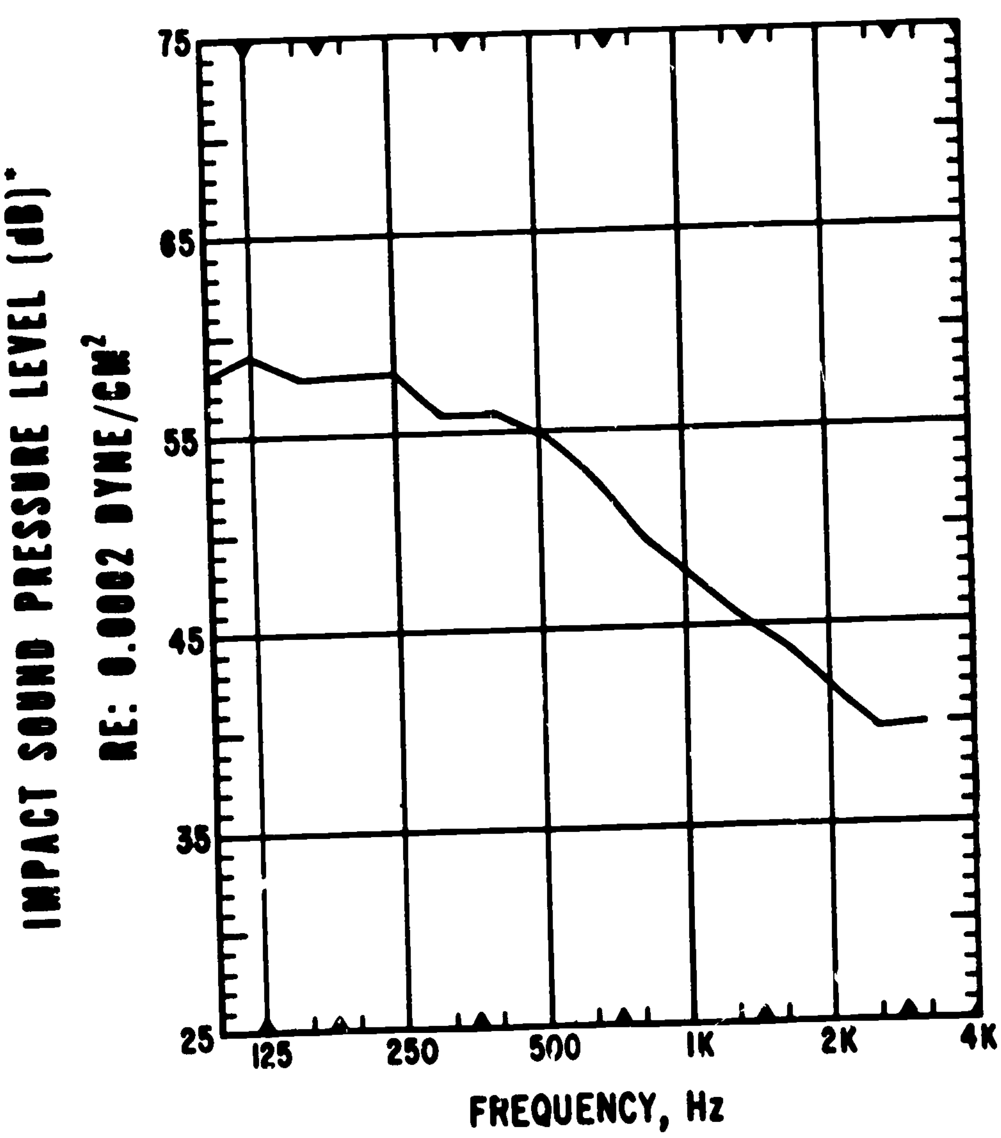
Area weight: 83 lb/ft^2



STC = 55; IIC = 57; Fire Rating: 3 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of two nominally identical structures.





*1/3-octave band data normalized to $T_0 = 0.5$ sec.

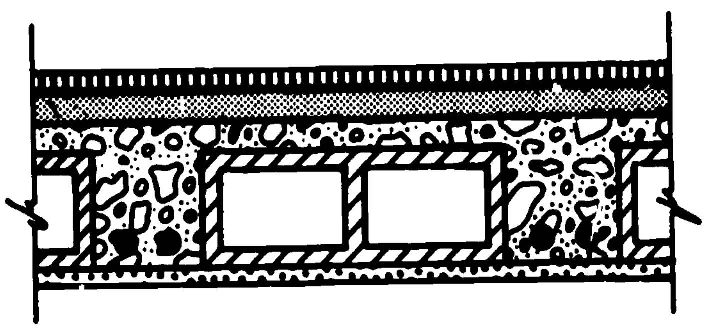
TYPE: REINFORCED CONCRETE WITH HOLLOW BLOCKS

TEST REF: 1-(S57)

DESCRIPTION: 6-in. reinforced concrete slab with 12- by 5-in. hollow blocks spaced 16 in. on centers. On the floor side, 1 1/2-in. sand-cement screed with a 5/8-in.-thick pitch-mastic floor finish on felt underlayment. On the ceiling side, approximately 3/4-in. plaster.

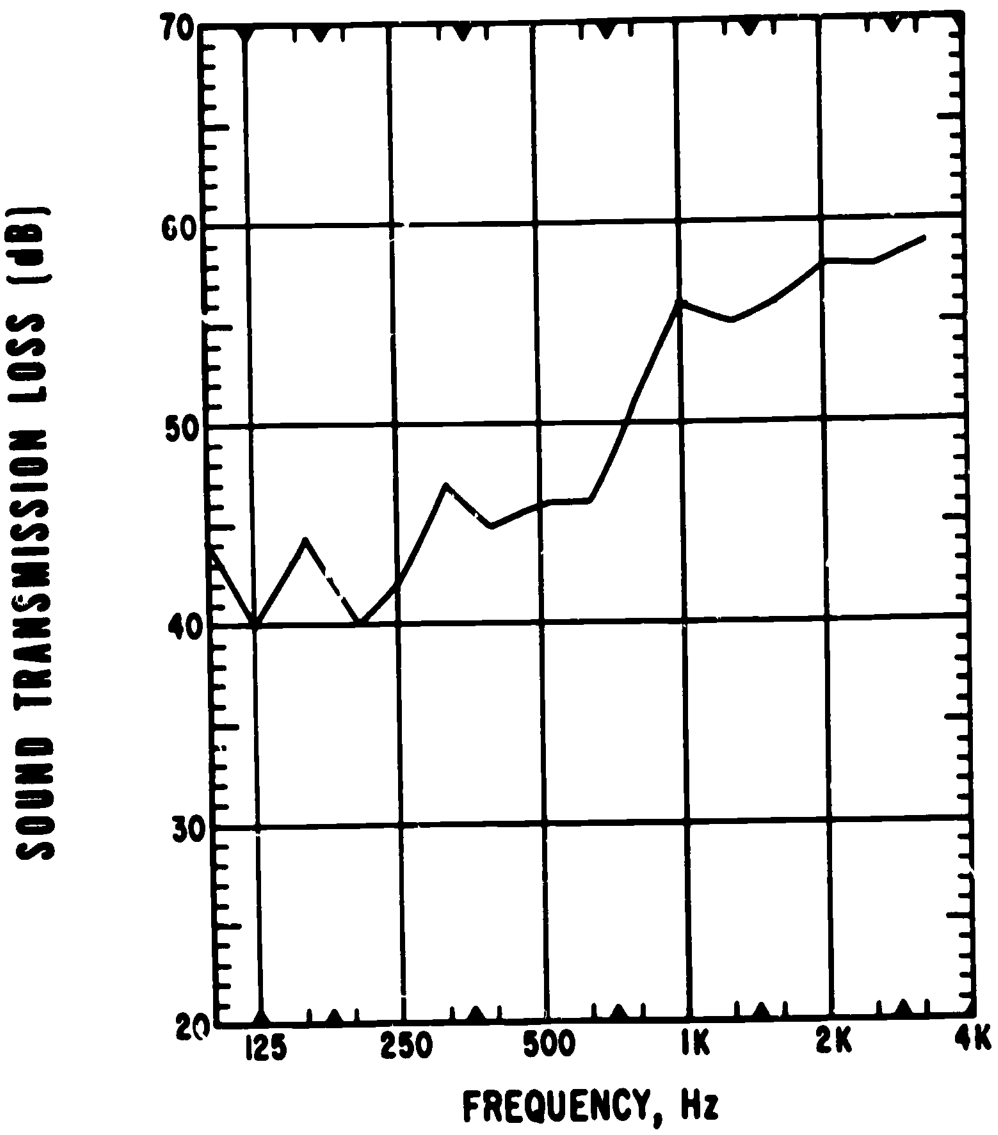
Total thickness: 8 1/2 in.

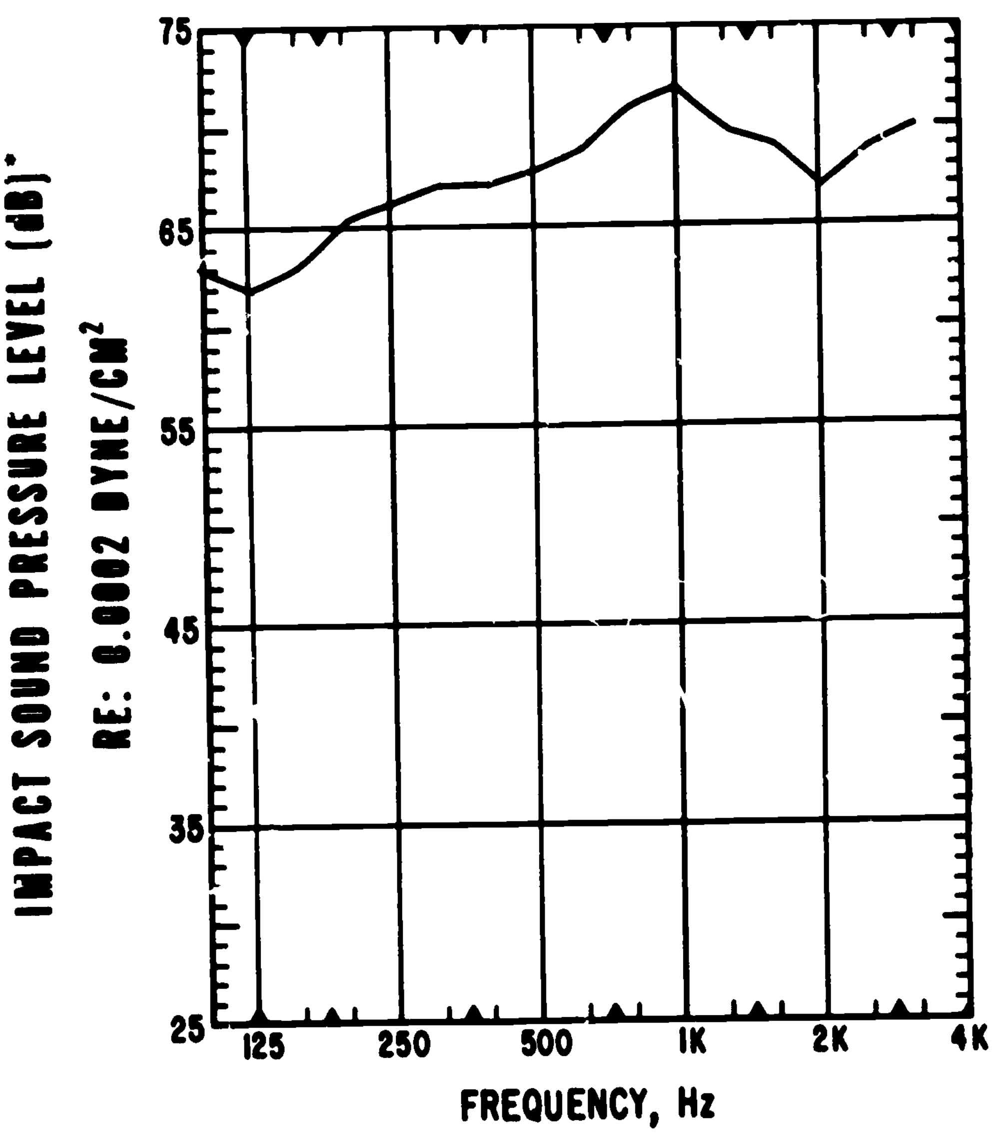
Area weight: 70 lb/ft^2



STC = 49; IIC = 30; Fire Rating: 2 hrs. (est.)

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

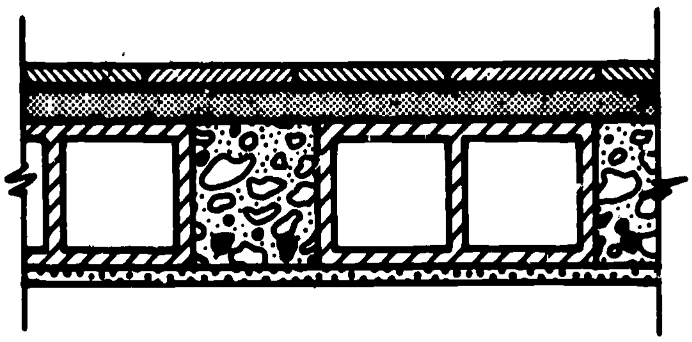
TYPE: CONCRETE WITH HOLLOW BLOCKS

TEST REF: 1-(S59)

DESCRIPTION: 5- by 10-in. hollow masonry blocks, 14 in. on centers, with spaces between blocks filled with 5-in.-thick reinforced concrete. On the floor side, 7/8-in.-thick wood blocks adhered to 1 1/2-in.-thick sand-cement screed. On the ceiling side, 3/4-in. layer of plaster.

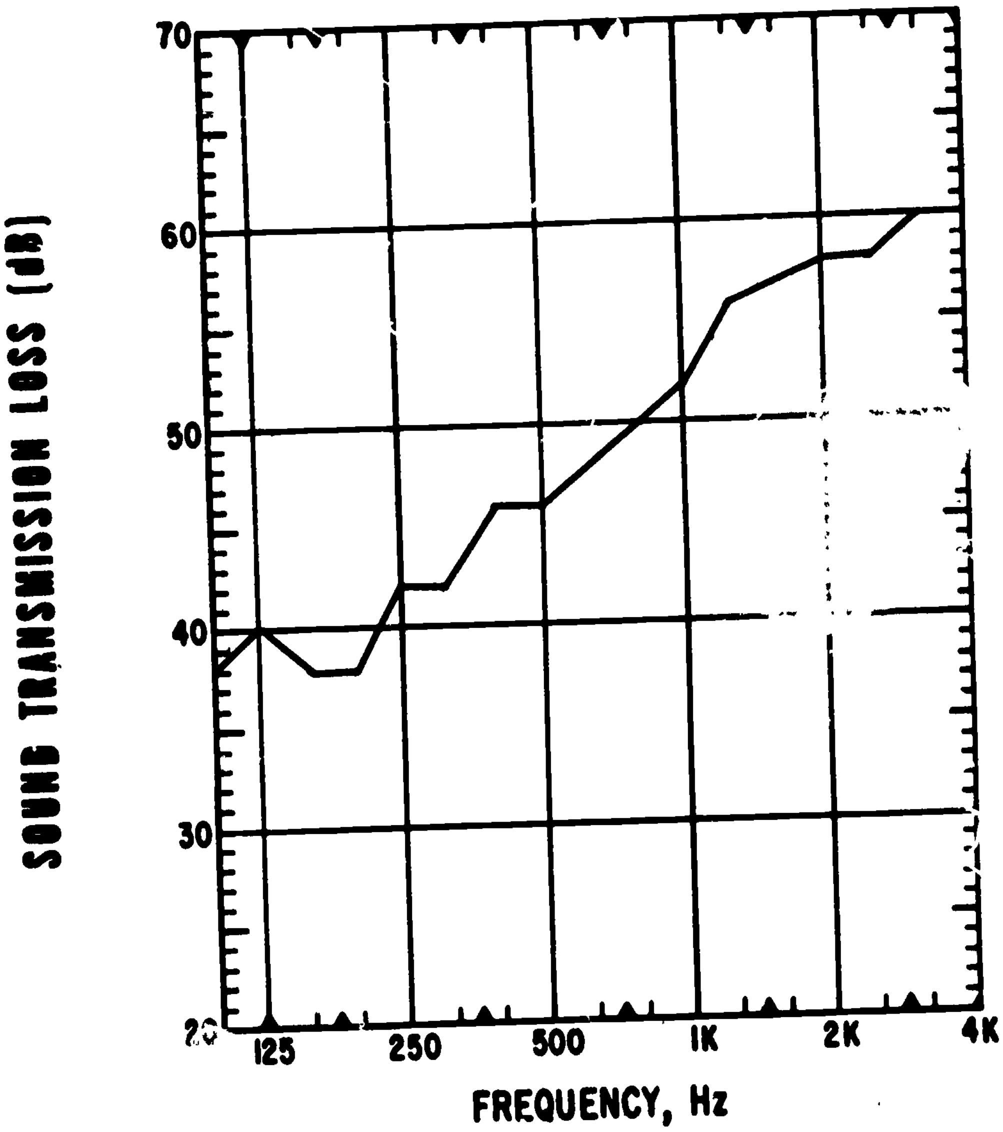
Total thickness: 8 1/8 in.

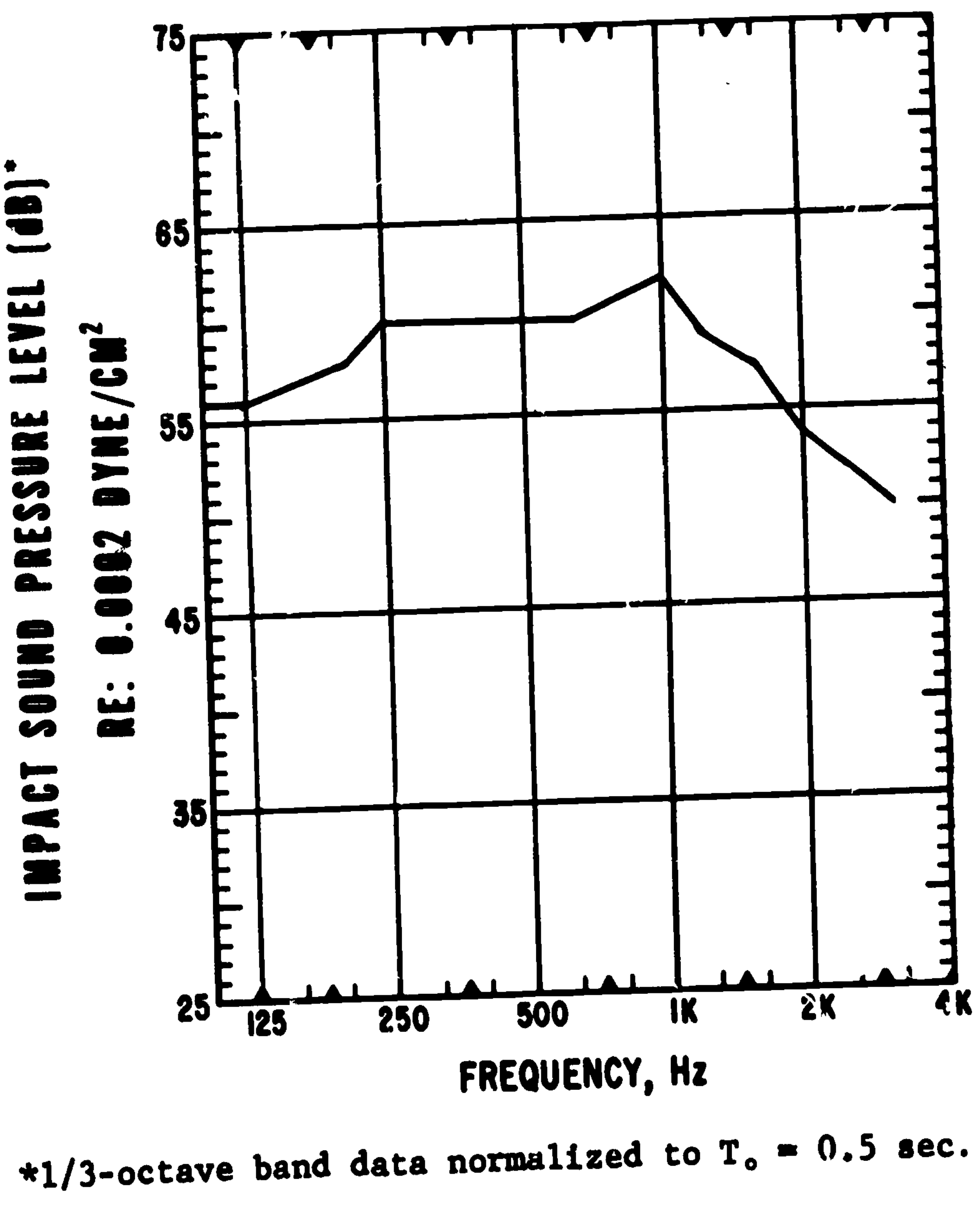
Area weight: 65 lb/ft^2



STC = 50; IIC = 48; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of two nominally identical structures.





*1/3-octave band data normalized to T_o = 0.5 sec.

TYPE: CONCRETE WITH HOLLOW BLOCKS, FLOATING FLOOR

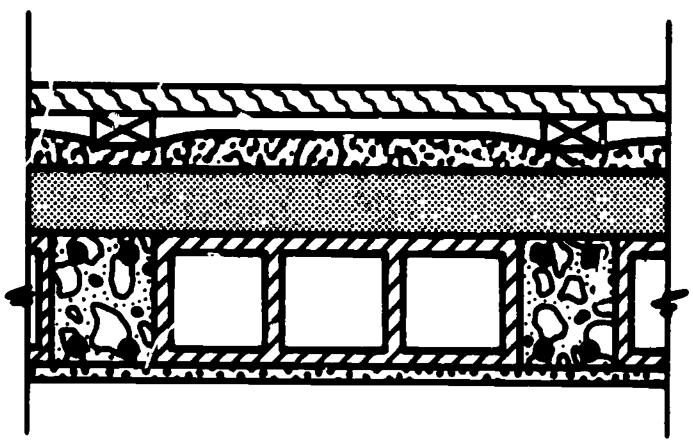
TEST REF: (a) 1-(S77-1,4); (b) 1-(S77-2,3)

DESCRIPTION: (a) 4- by 12 1/2-in. hollow masonry blocks, 15 1/2 in. on centers, with spaces between blocks filled with 4-in.-thick reinforced concrete. On the floor side, 2-in.-thick sand-cement screed; 1-in.-thick wood flooring nailed to 1- by 2-in. wooden battens, spaced 15 1/2 in. on centers, floating on glass-wool quilt, approximately 1 in. thick. On the ceiling side, 3/4-in. layer of plaster.

(b) Similar to (a) with linoleum floor covering.

Total thickness: 9 1/4 in.

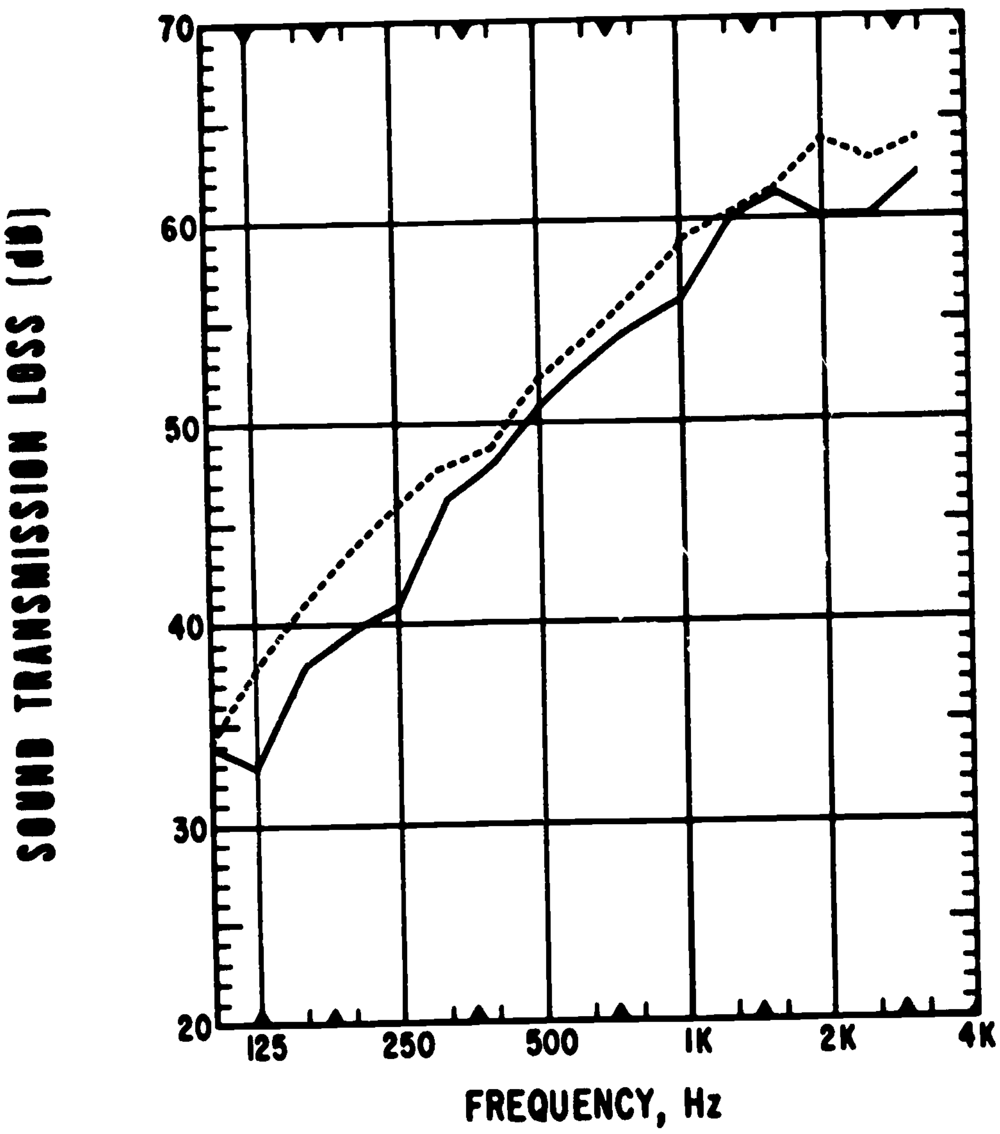
Area weight: 57 lb/ft^2

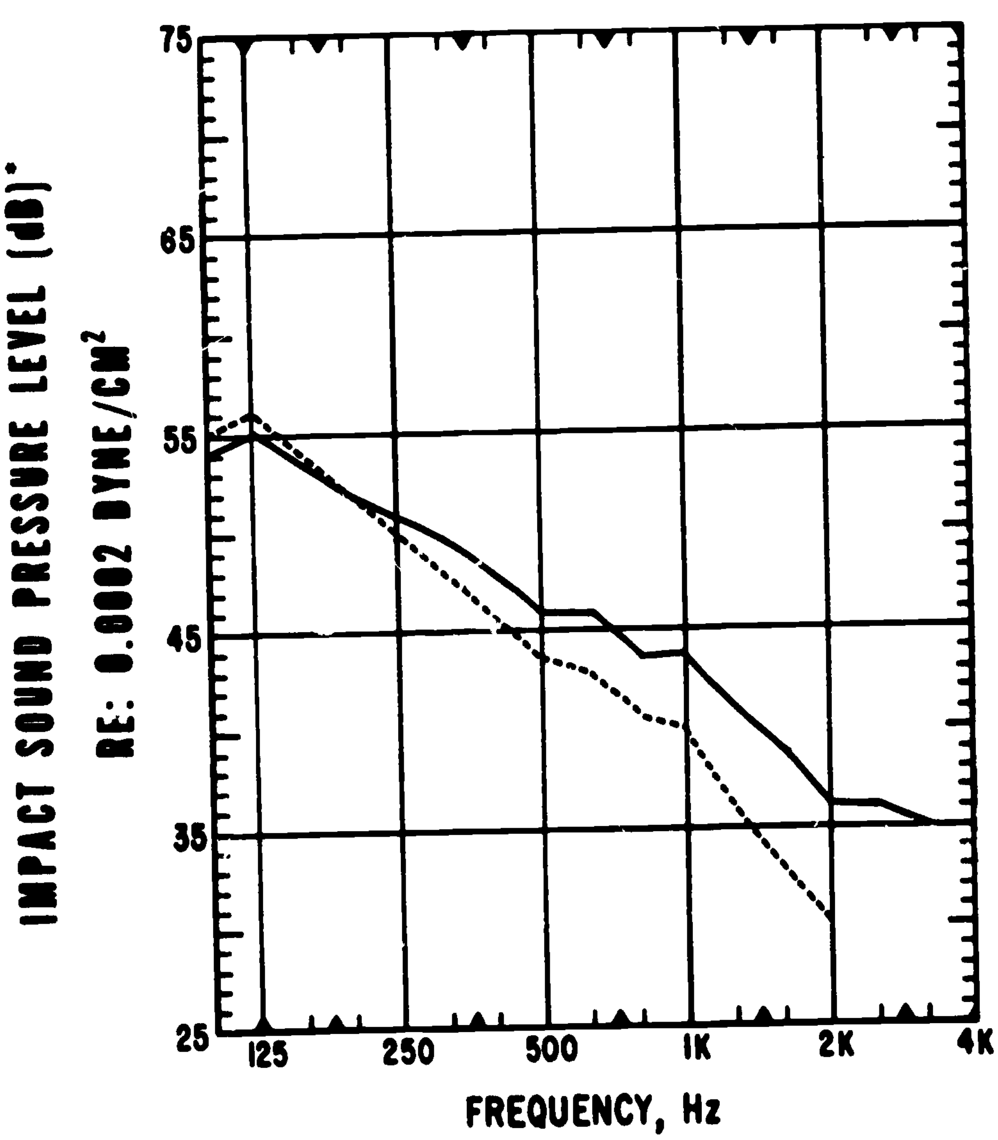


(a) ———— STC = 53; IIC = 62; Fire Rating: 2 hrs. (est.)

(b) ------------ STC = 54; IIC = 64; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curves are the average values of field measurements of two nominally identical structures of type (a) and (b).





*1/3-octave band data normalized to T_o = 0.5 sec.

TYPE: CONCRETE WITH HOLLOW BLOCKS, FLOATING FLOOR

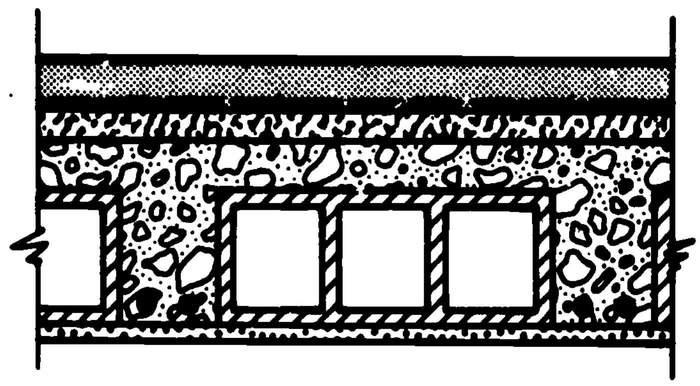
TEST REF: (a) 1-(S66-1,2,4; S67-1,2,4; S68-1,2,4); (b) 1-(S66-3, S67-3, S68-3)

DESCRIPTION: (a) 5 1/2-in.-thick reinforced concrete with hollow 4- by 12-in. blocks embedded 14 1/2 in. on centers. On the floor side, 1 1/2-in.-thick wire mesh reinforced sand-cement screed floating on 1-in.-thick bitumen-bonded glass-wool quilt covered with building paper; thermoplastic tile floor covering. On the ceiling side, 1/2-in. layer of plaster.

(b) Similar to (a) except the glass-wool quilt was not bitumen-bonded.

Total thickness: 8 1/2 in.

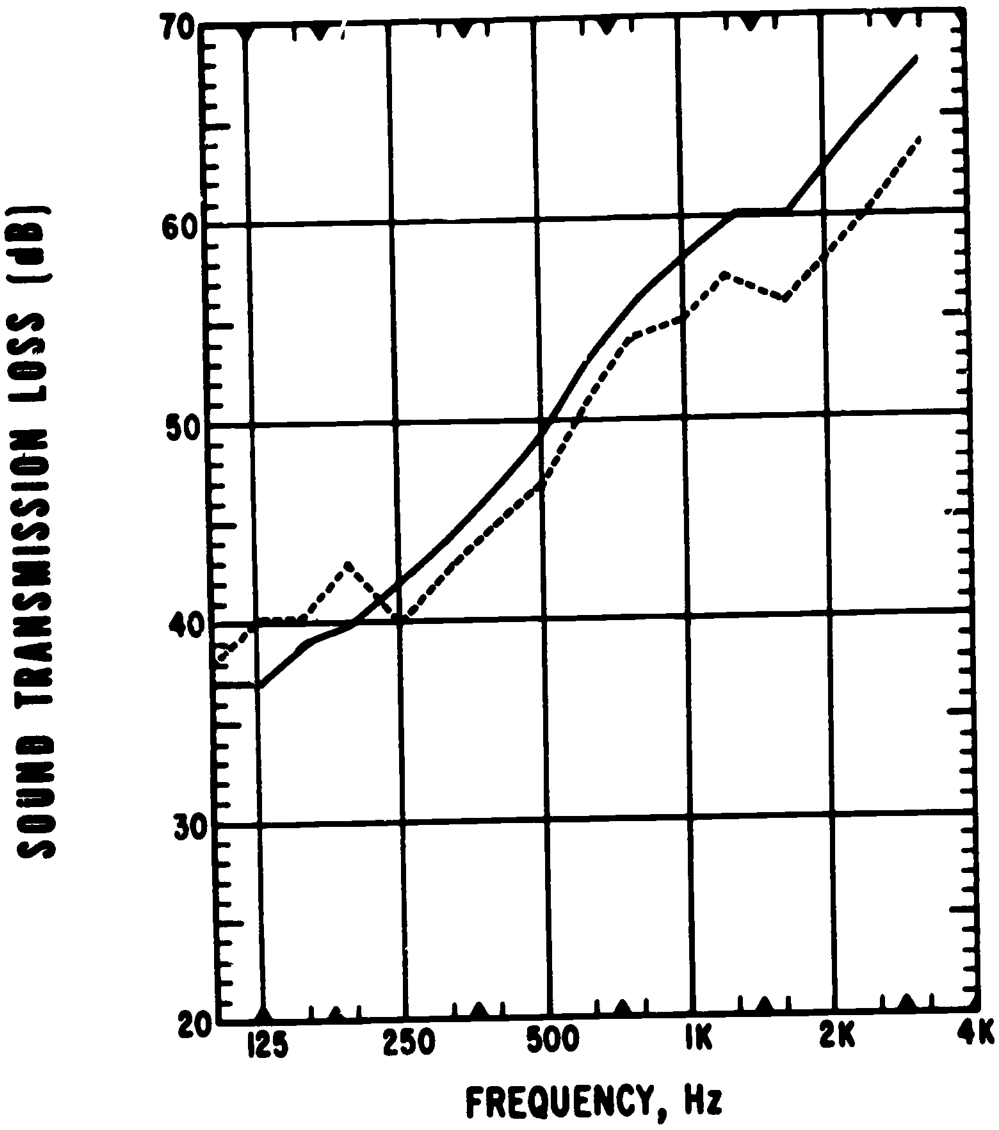
Area weight: 65 lb/ft^2

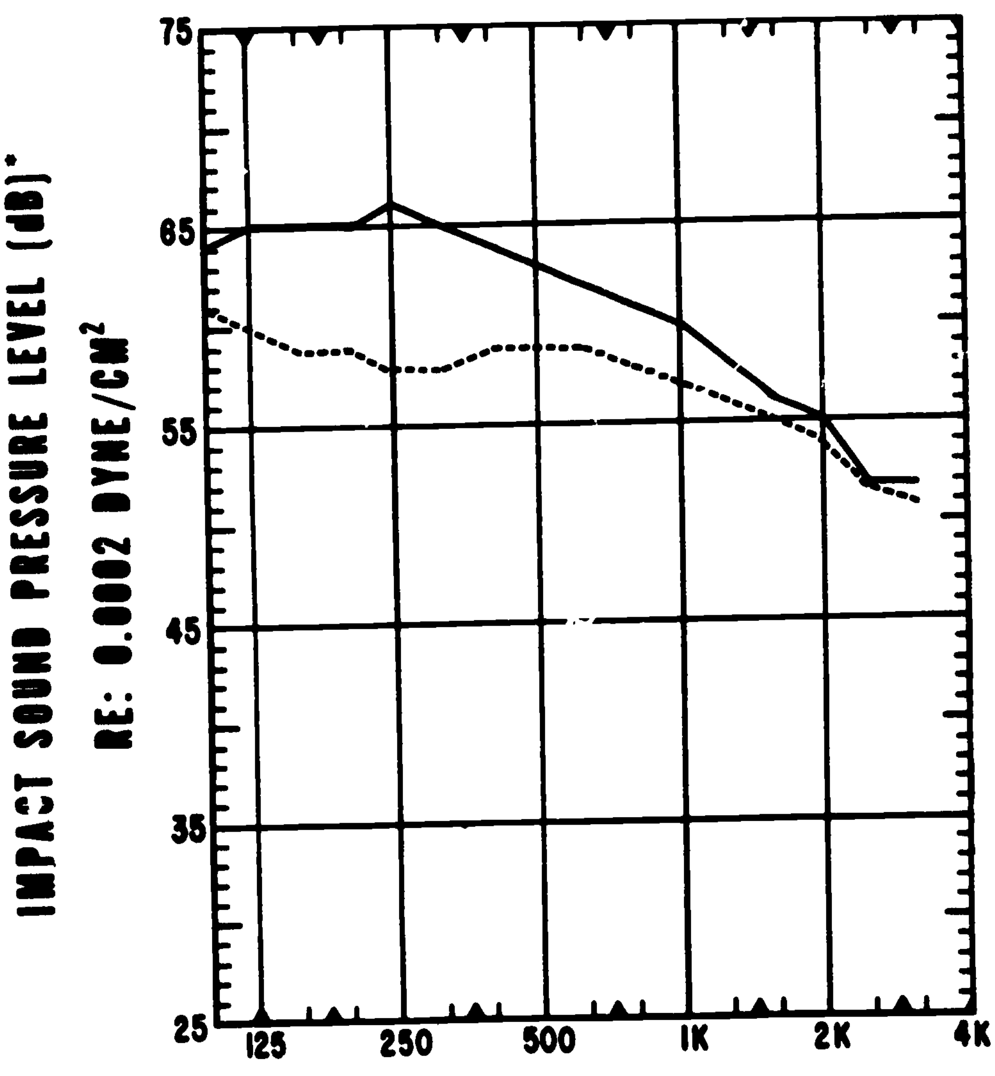


(a) ———— STC = 52; IIC = 47; Fire Rating: 2 hrs. (est.)

(b) ············ STC = 50; IIC = 49; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curves are the average of field measurements of nine nominally identical structures of type (a), and three of type (b).





*1/3-octave band data normalized to $T_0 = 0.5$ sec.

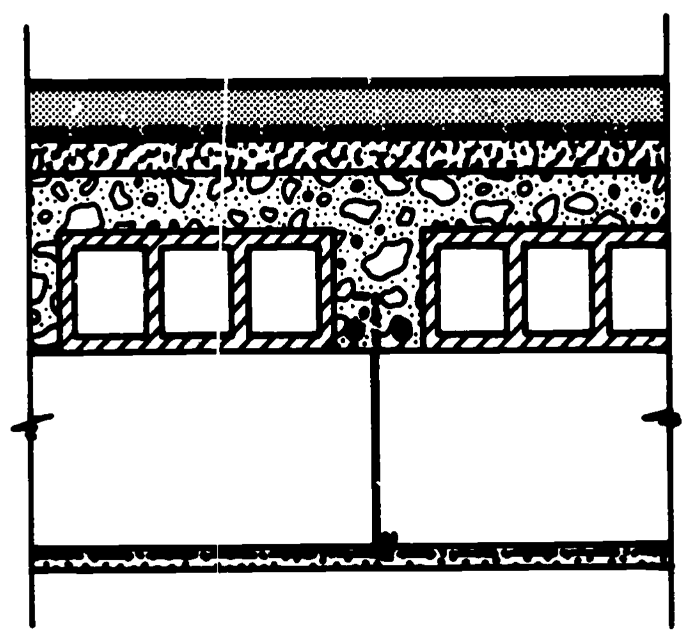
TYPE: CONCRETE WITH HOLLOW BLOCKS, FLOATING FLOOR, SUSPENDED CEILING

TEST REF: 1-(S110, S111, S112)

DESCRIPTION: 5 1/2-in.-thick reinforced concrete with 4- by 12-in. hollow masonry blocks embedded 15 in. on centers. On the floor side, 1 1/2-in.-thick wire mesh reinforced sand-cement screed floating on 1-in.-thick bitumen-bonded glass-wool quilt covered with building paper; thermoplastic tile floor covering. On the ceiling side, 1/2-in. layer of plaster on ribbed expanded metal lath attached to 1/4- by 1 1/4-in. steel bars suspended 6 in. from the concrete slab by 1/4-in. steel rods, spaced 48 in. on centers.

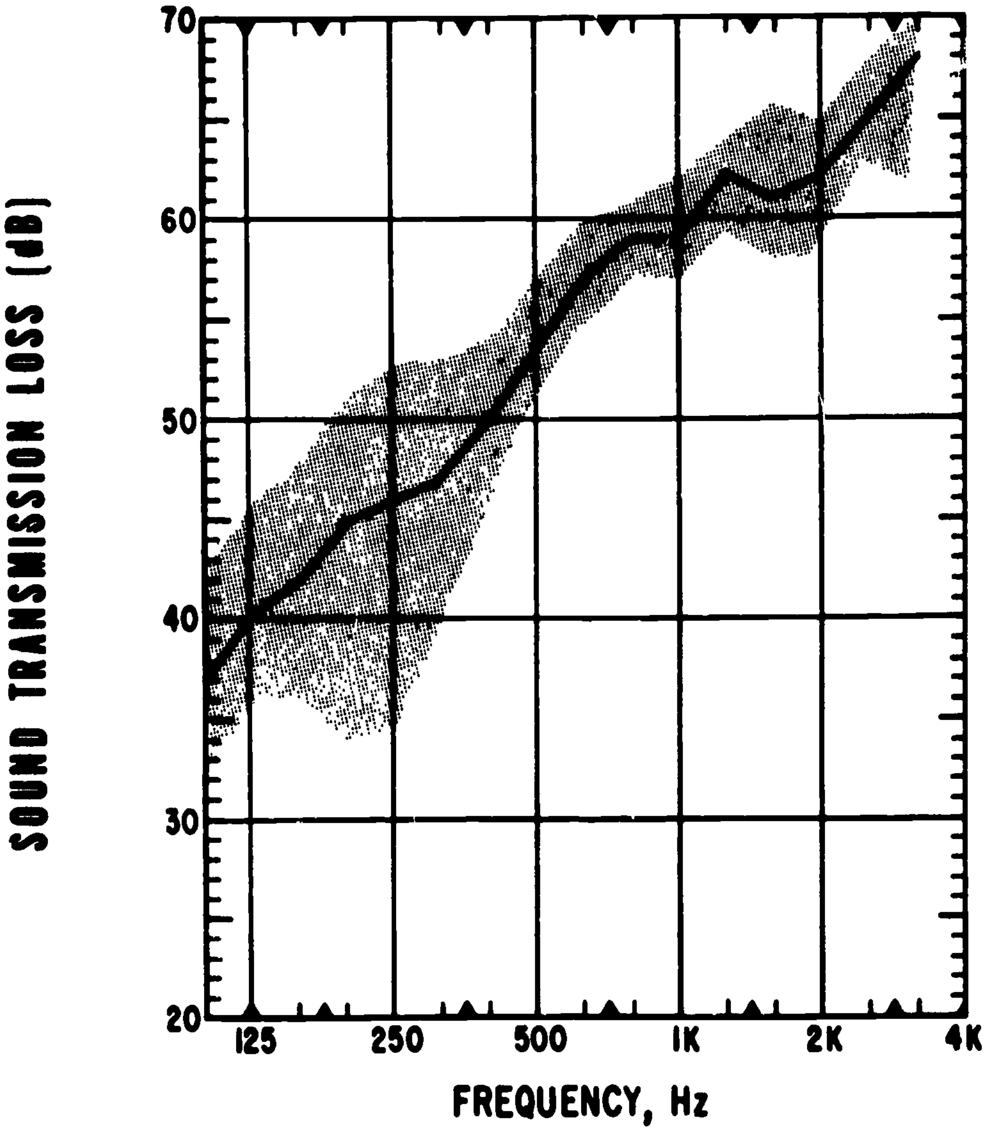
Total thickness: approximately 15 1/4 in.

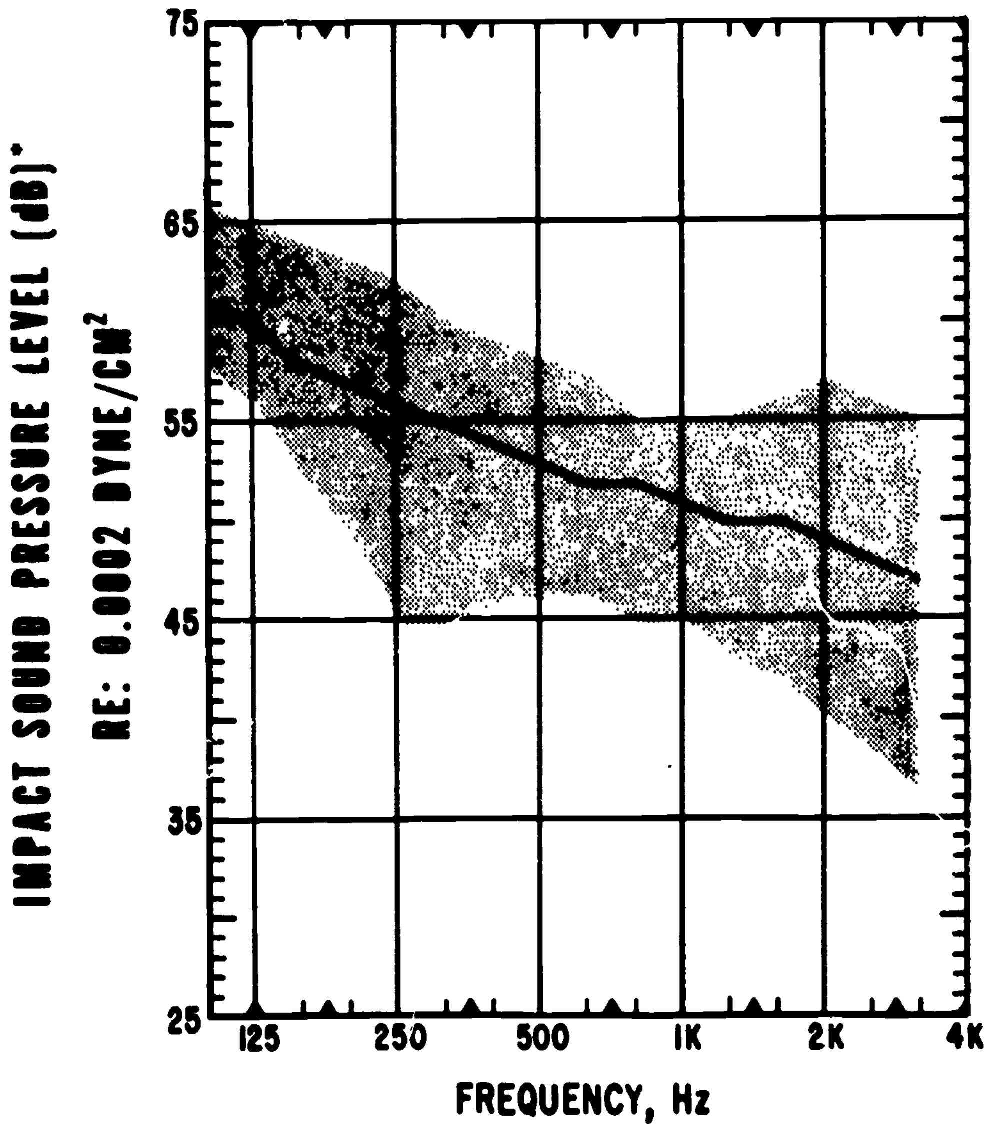
Area weight: 70 lb/ft^2



STC = 55; IIC = 53; Fire Rating: 2 hrs. (est.)

REMARKS: The plotted curves represent the average of field measurements of twelve nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to $T_0 = 0.5$ sec.

TYPE: HOLLOW TILE BEAM

TEST REF: (a) 11(b)-(Fig. 39b); (b) 11(b)-(Fig. 39f); (c) 11(b)-(Fig. 39g)

DESCRIPTION: (a) 5-in.-thick tile beams, 15 3/4 in. wide, held together with steel reinforcement and cement mortar. On the floor side, linoleum adhered to 3/4-in.-thick sand-cement screed. On the ceiling side, 3/8-in. layer of plaster.

(b) Similar to (a) except linoleum was replaced by coco matting.

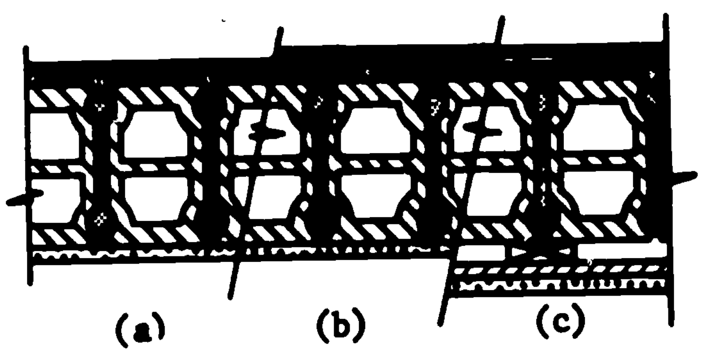
Total thickness: 6 3/4 in.

Area weight: approximately 41 lb/ft^2

(c) Similar to (a) except linoleum was replaced by parquet flooring, and on the ceiling side, 3/4- by 2 3/4-in. wooden battens, 19 in. on centers, held 1 3/8-in. layer of lath, reeds and plaster.

Total thickness: 9 1/4 in.

Area weight: approximately 43 lb/ft^2

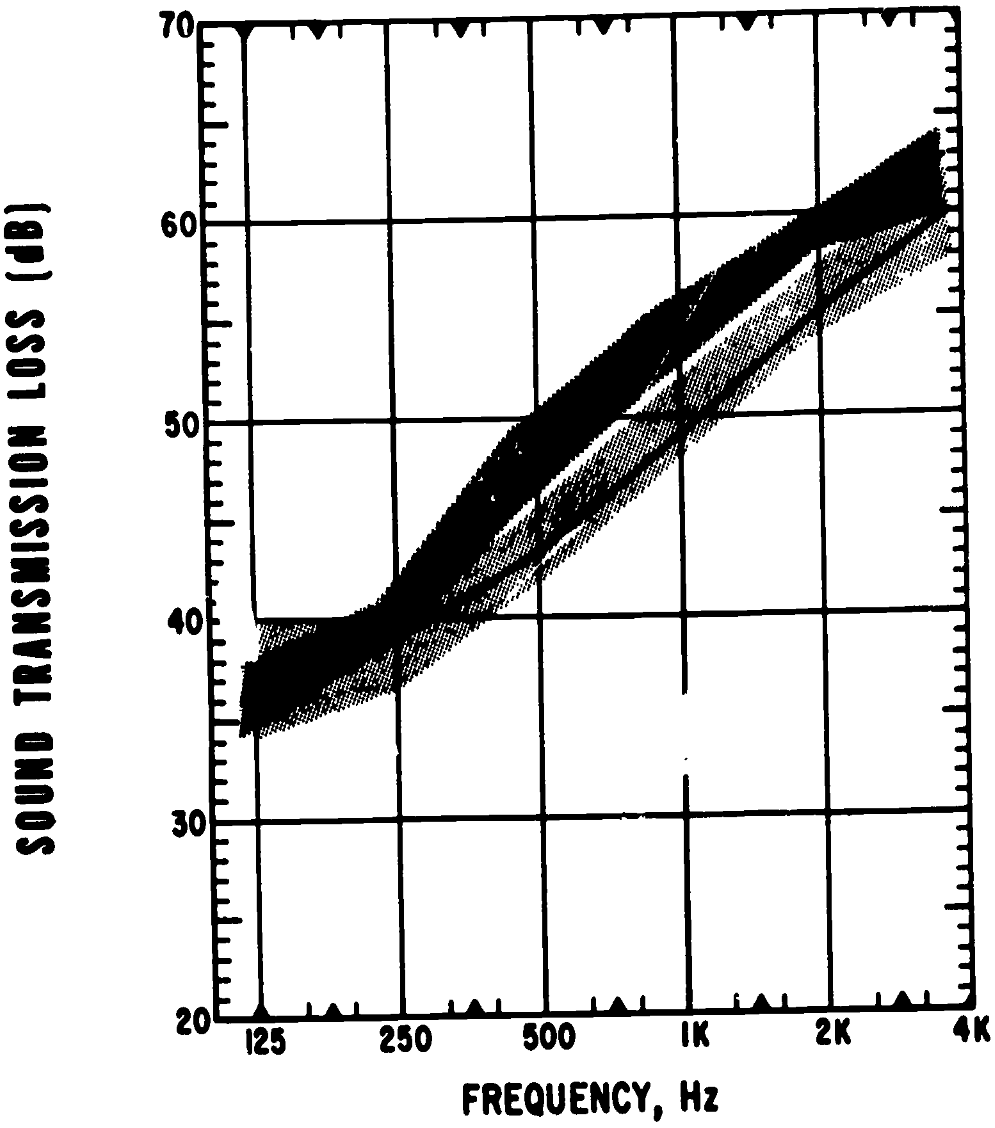


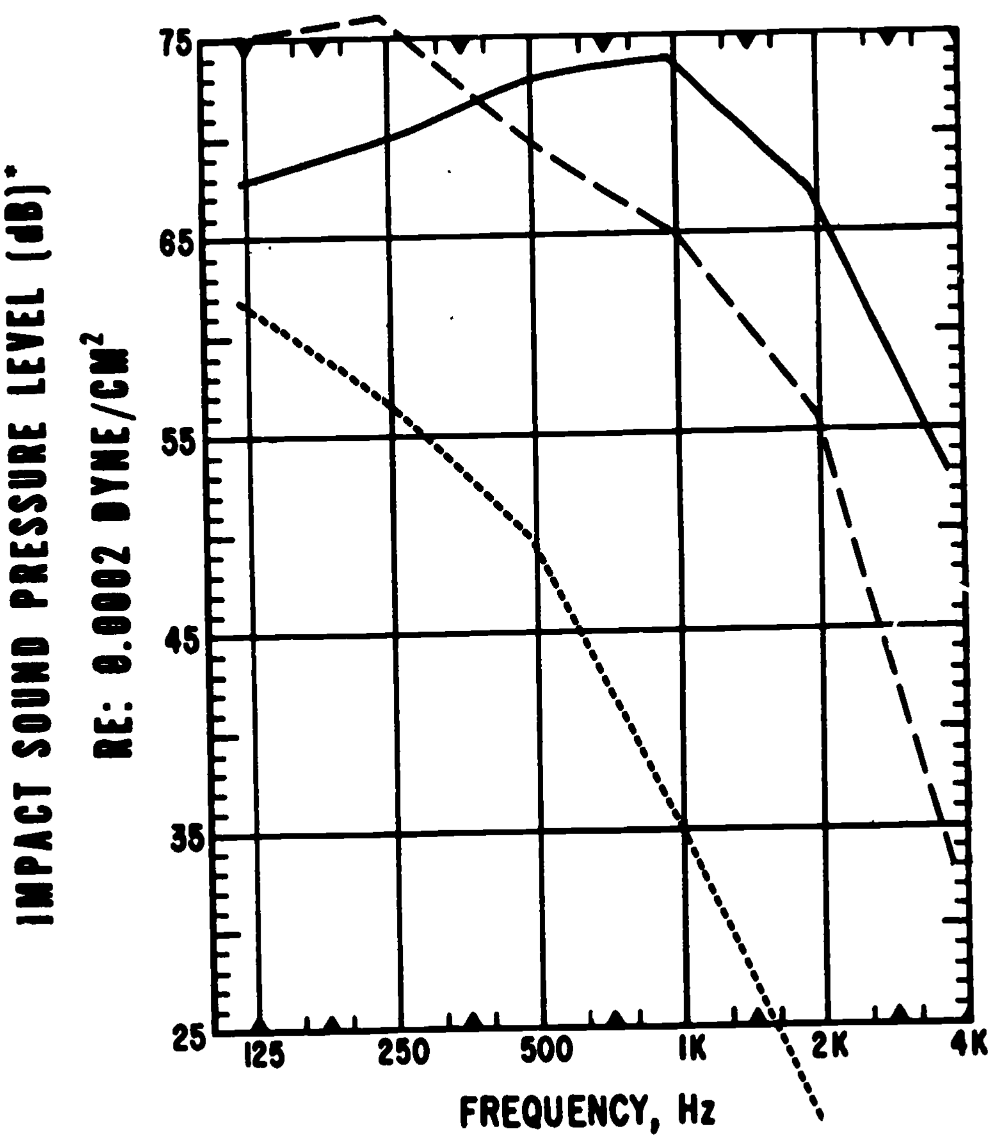
(a) STC = 47; IIC = 40; Fire Rating: 1 hr. (est.)

(b) STC = 47; IIC = 60; Fire Rating: 1 hr. (est.)

(c) STC = 50; IIC = 46; Fire Rating: 1 hr. (est.)

REMARKS: The airborne STL measurements were made without the floor coverings; however, these provide little additional airborne sound insulation, and the data are applicable to the above structures. The plotted STL curves represent the average of field measurements of nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

TYPE: PRECAST HOLLOW CONCRETE SLAB

TEST REF: (a) 17-(12a), 11(a)-(VI-A-36); (b) 17-(12b), 11(a)-(VI-A-37)

DESCRIPTION: (a) 6- by 20-in. precast pumice concrete slabs with cylindrical cavities. On the floor side, 3/8-in.-thick cement mortar and 3/4-in.-thick sand-cement finish; on the ceiling side, 3/8-in.-thick coat of plaster.

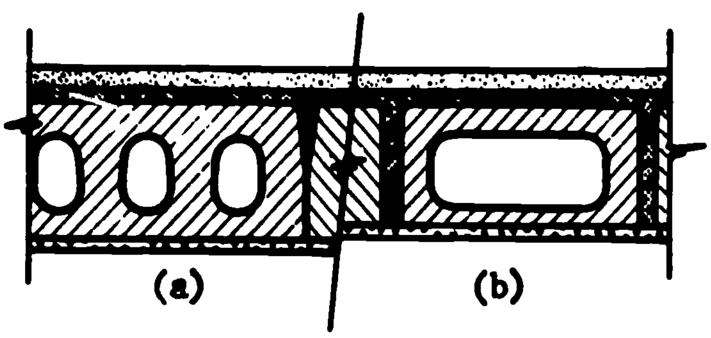
Total thickness: 7 1/2 in.

Area weight: 43 lb/ft^2

(b) Similar to (a) except 5- by 10 in. precast hollow concrete beams were used.

Total thickness: 6 3/4 in.

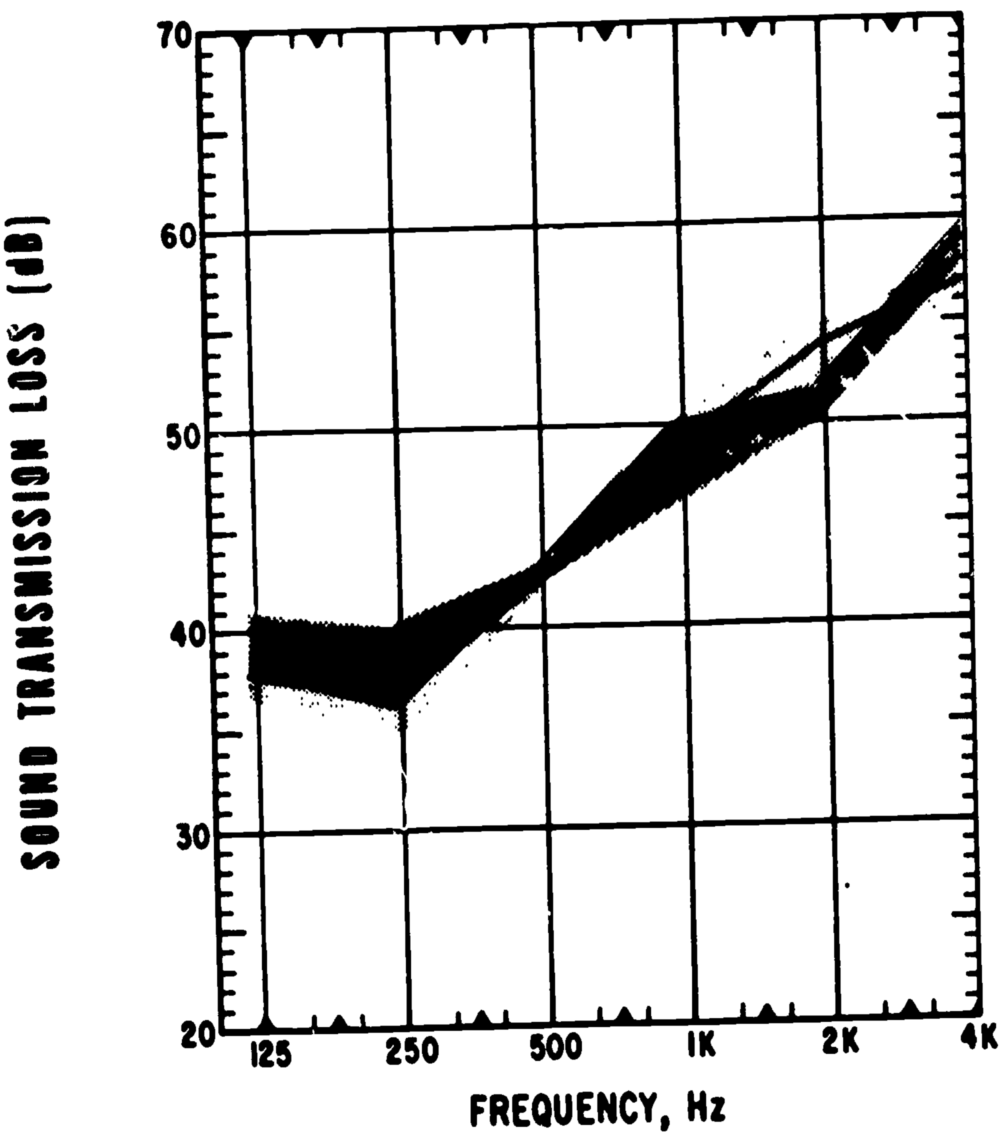
Area weight: 46 lb/ft^2

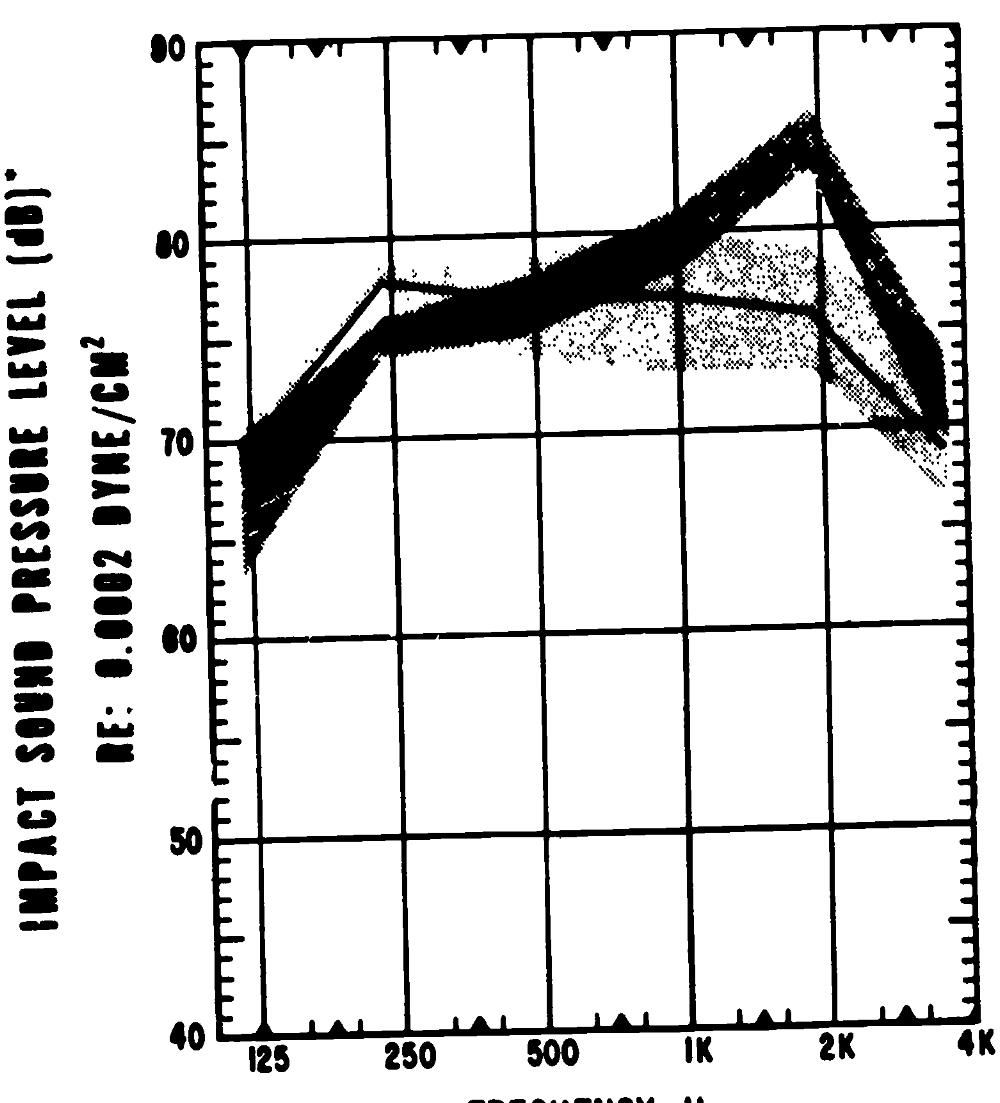


(a) STC = 46; IIC = 30; Fire Rating: 2 hrs. (est.)

(b) STC = 46; IIC = 24; Fire Rating: 1 hr. (est.)

REMARKS: The plotted curves are the average values of field measurements of three nominally identical structures of type (a) and (b). The shaded areas indicate the spreads of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

TYPE: CONCRETE CHANNEL SLAB

TEST REF: 11(a)-(VI-A-38), 17-(12c)

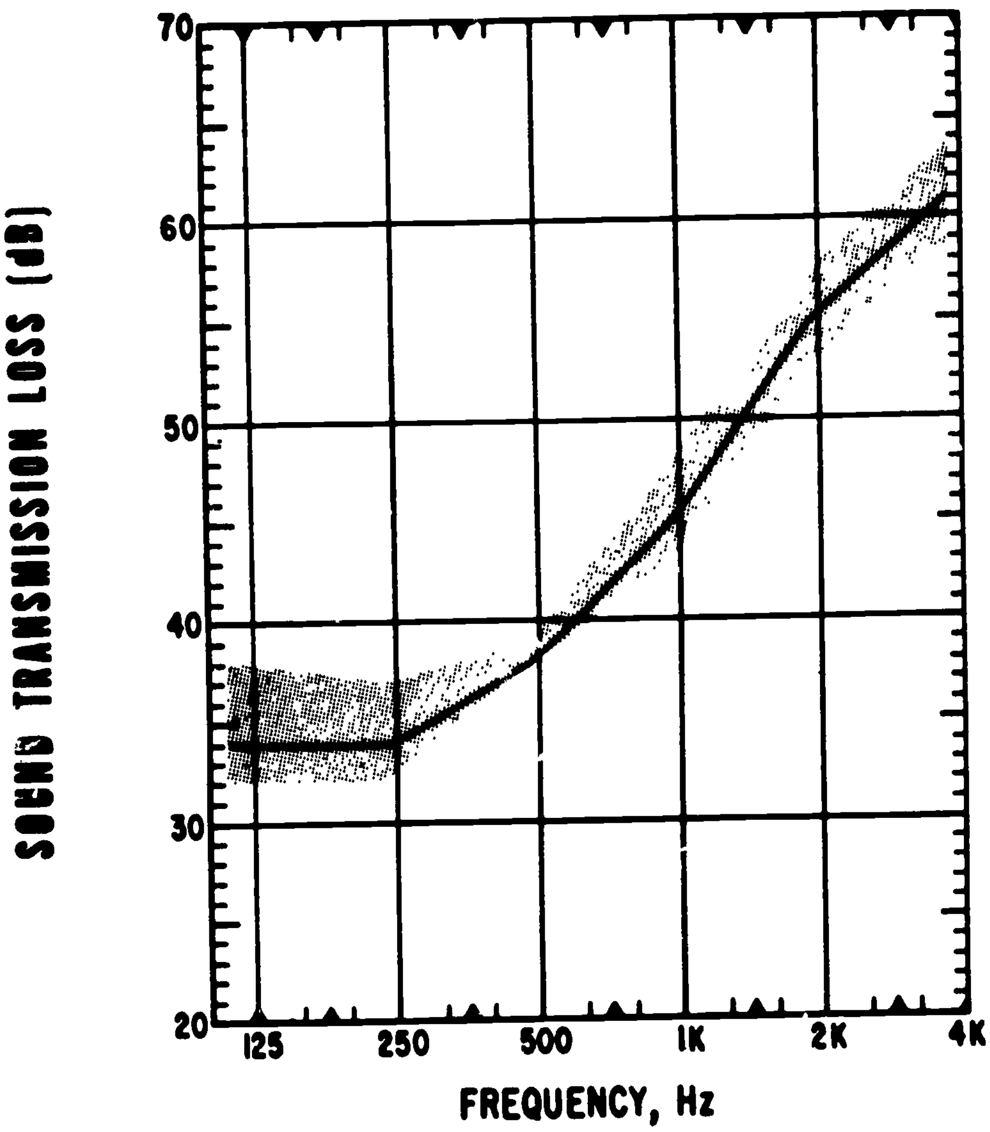
DESCRIPTION: Prefabricated concrete channel slabs mortared together 20 in. on centers. Each slab had a 3-in. deep trapezoidal channel with bases of 11 and 14 3/4 in. On the floor side, 3/4-in.-thick sand-cement finish.

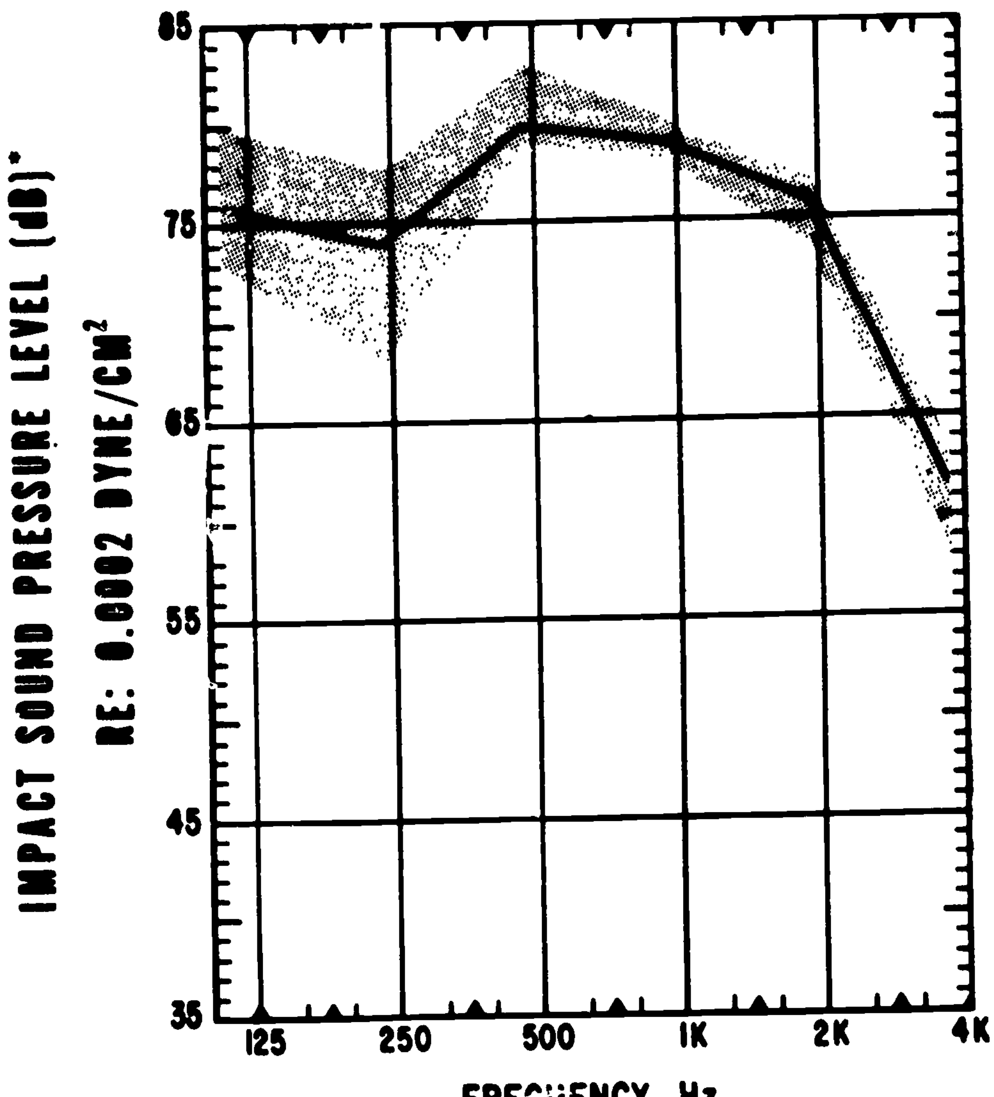
Total thickness: 6 1/4 in.

Area weight: 28 lb/ft^2

STC = 42; IIC = 32; Fire Rating: 45 min. (est.)

REMARKS: The plotted curves are the average values of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements due to the variance in structures and conditions of the tests.





*1/1-octave band data normalized to T_o = 0.5 sec.

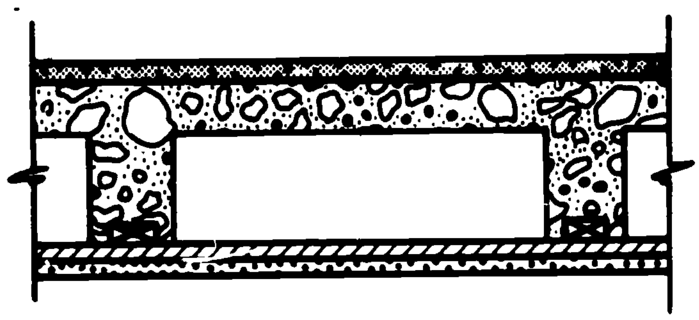
TYPE: RIBBED CONCRETE

TEST REF: 11(a)-(IV-A-21)

DESCRIPTION: 7 1/4-in. ribbed concrete floor. The ribs were 5 1/4- by 3 3/4-in., spaced 21 in. on centers, with 1- by 2-in. wooden nailing strips cast into ends. On the floor side, the slab was 2 in. thick with a 3/4-in.-thick sand-cement screed. On the ceiling side, 5/8-in.-thick wooden laths nailed to nailing strips, held 5/8-in.-thick reeds and plaster.

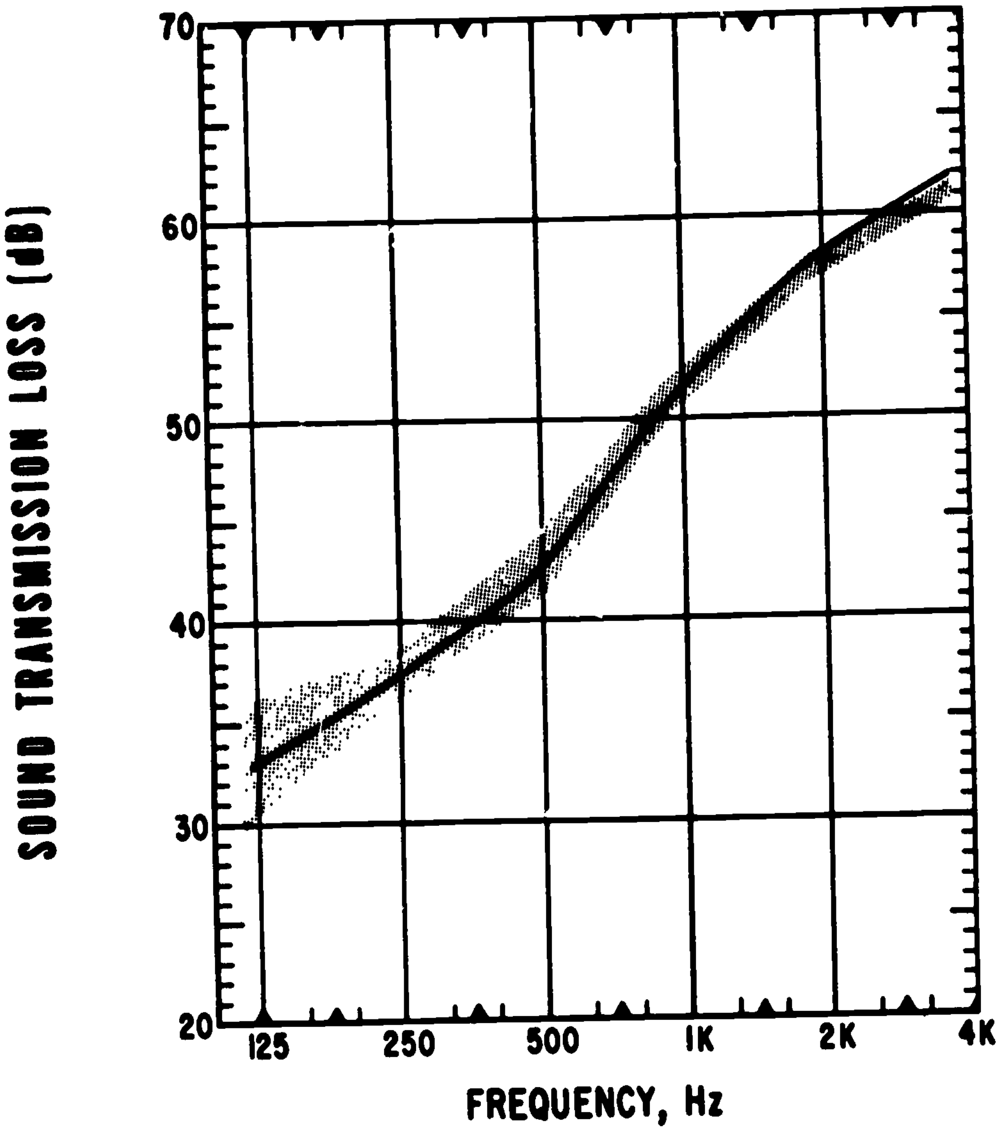
Total thickness: 9 1/2 in.

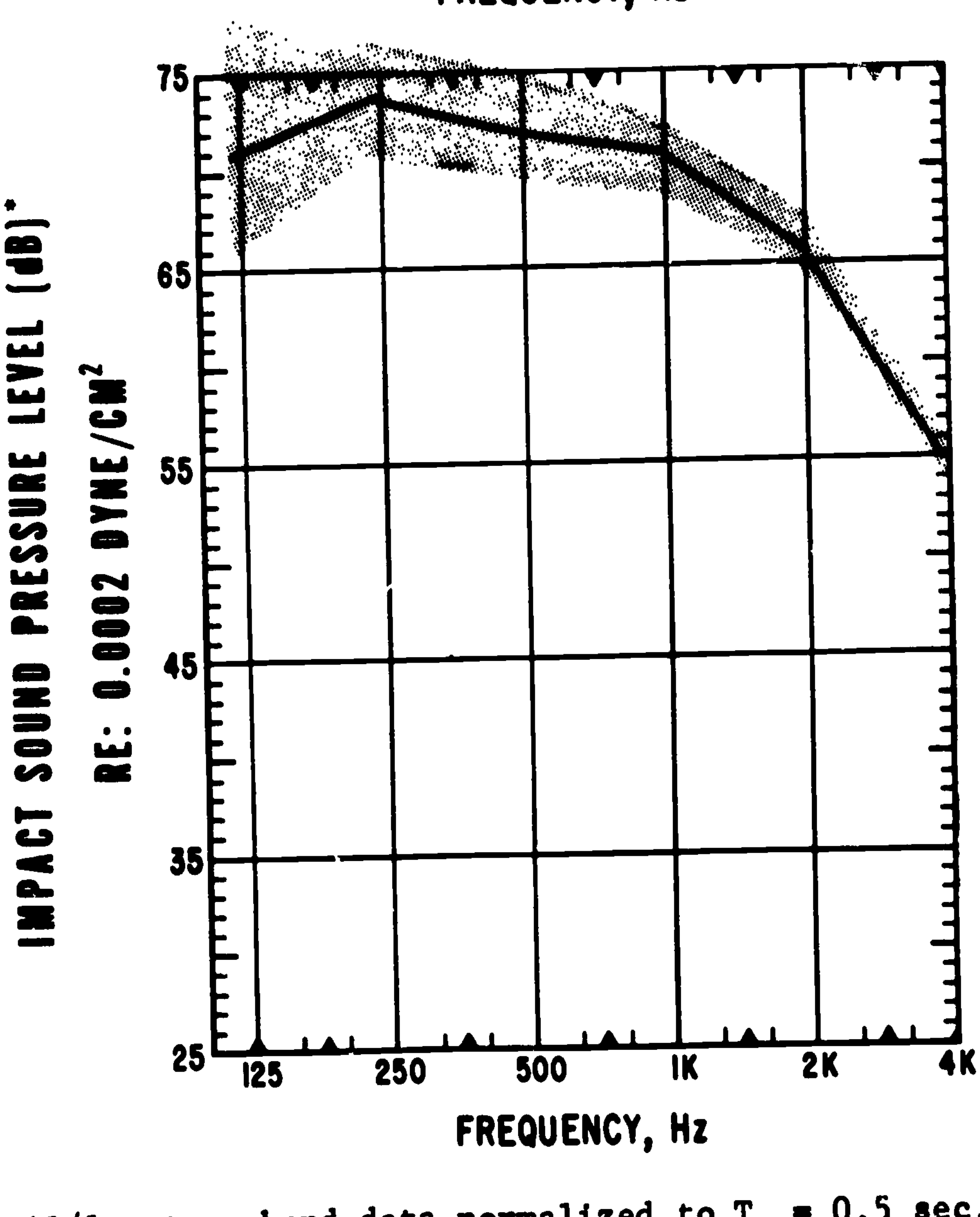
Area weight: approximately 45 lb/ft^2 (Not specified in reference.)



STC = 46; IIC = 42; Fire Rating: 45 min. (est.)

REMARKS: The plotted curves represent the average of field measurements of three nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/1-octave band data normalized to T_o = 0.5 sec.

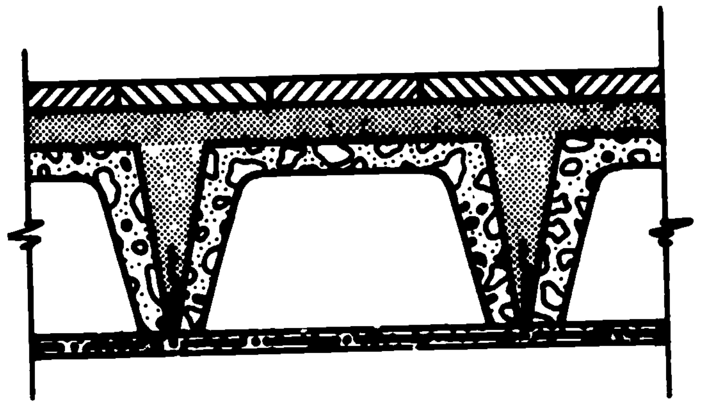
TYPE: CONCRETE CHANNEL BEAM

TEST REF: 1-(S117)

DESCRIPTION: 7-in. precast trapezoidal concrete channel beams, 14 in. on centers, with the spaces between the beams filled with a sand-cement mix. On the floor side, 1 1/2-in.-thick sand-cement screed with 1-in.-thick wood-block floor covering. On the ceiling side, approximately 3/4-in.-thick layer of plaster on expanded metal lath.

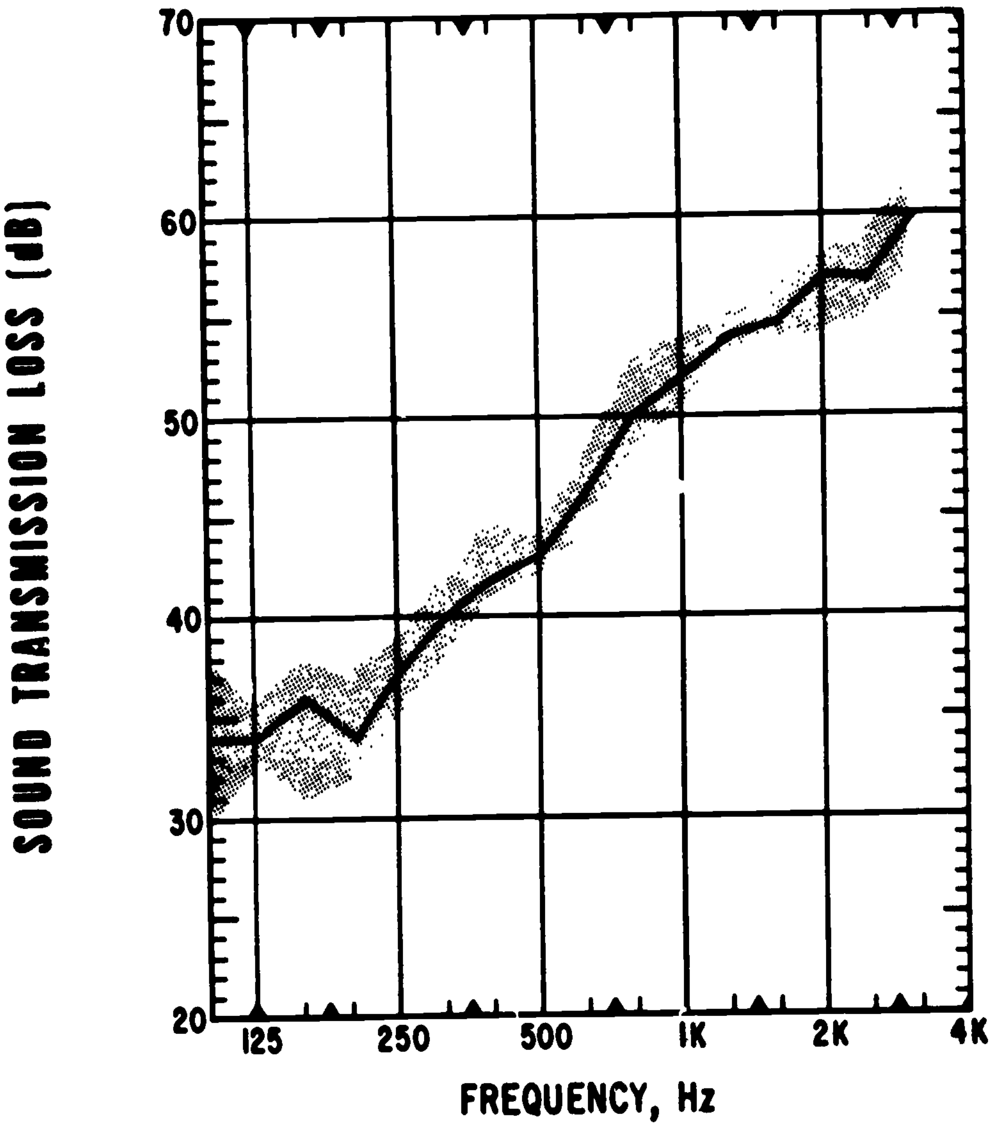
Total thickness: 10 1/4 in.

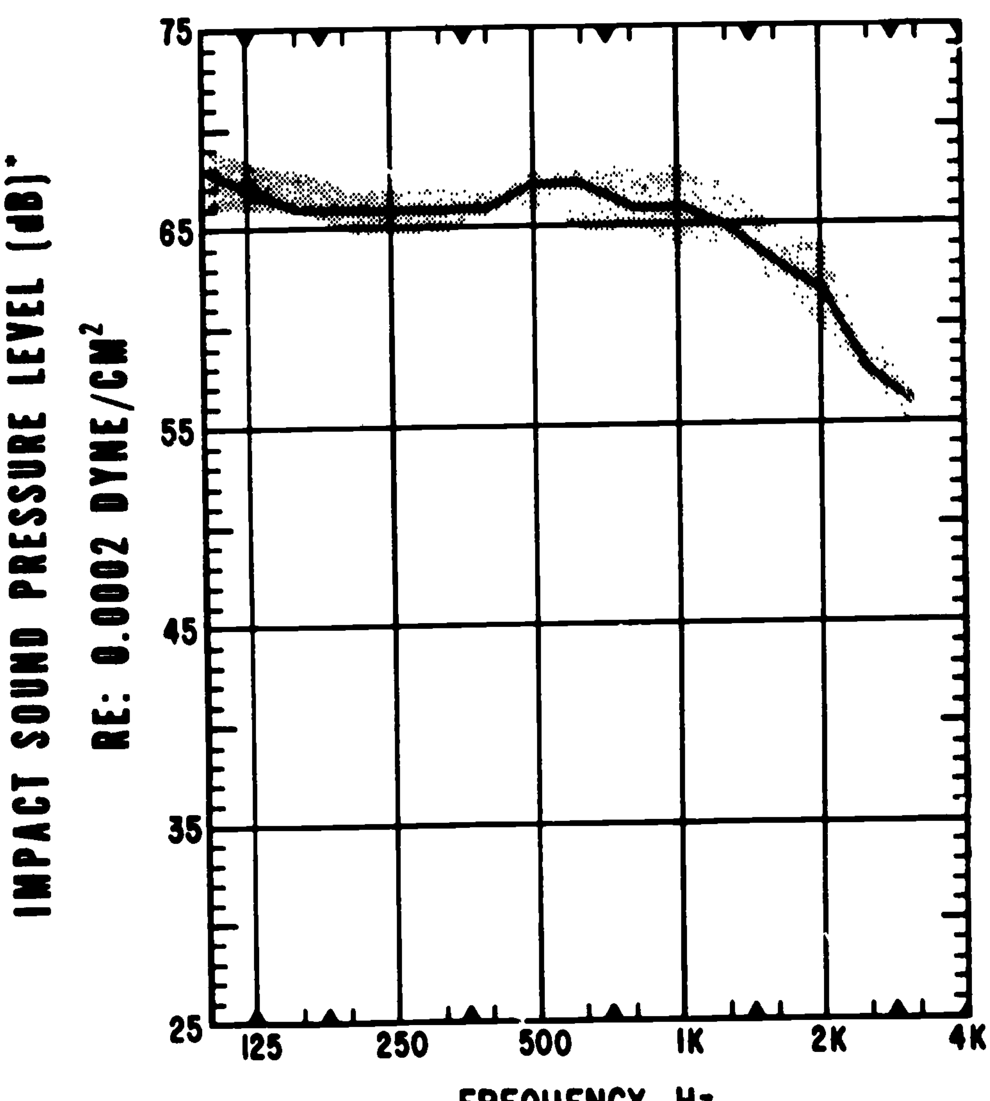
Area weight: 65 lb/ft^2



STC = 47; IIC = 42; Fire Rating: 45 min. (est.)

REMARKS: The plotted curves are the average values of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to $T_o = 0.5$ sec.

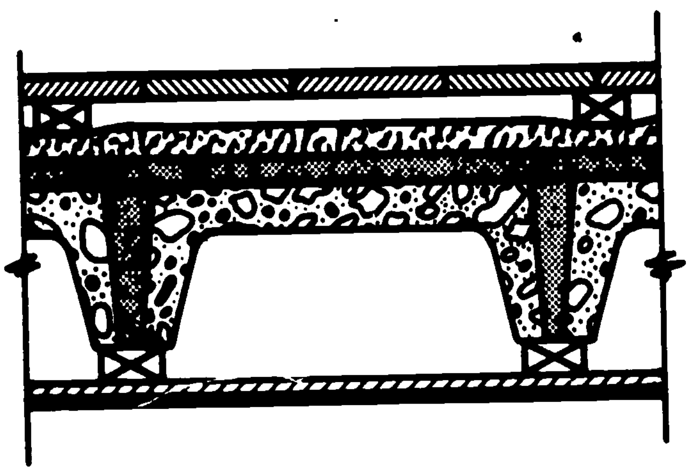
TYPE: PRECAST CONCRETE BEAM, FLOATING FLOOR

TEST REF: 1-(S116)

DESCRIPTION: 5-in. precast concrete channel beams, 14 1/2 in. on centers, with the spaces between beams filled with a sand-cement mix. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring nailed to 1- by 2-in. wooden battens, 20 in. on centers, on approximately 1-in.-thick glass-wool quilt on 3/4-in.-thick sand-cement screed. On the ceiling side, 1/8-in. layer of plaster on 3/8-in. gypsum wallboard nailed to 1- by 2-in. wooden battens spaced 14 1/2 in. on centers.

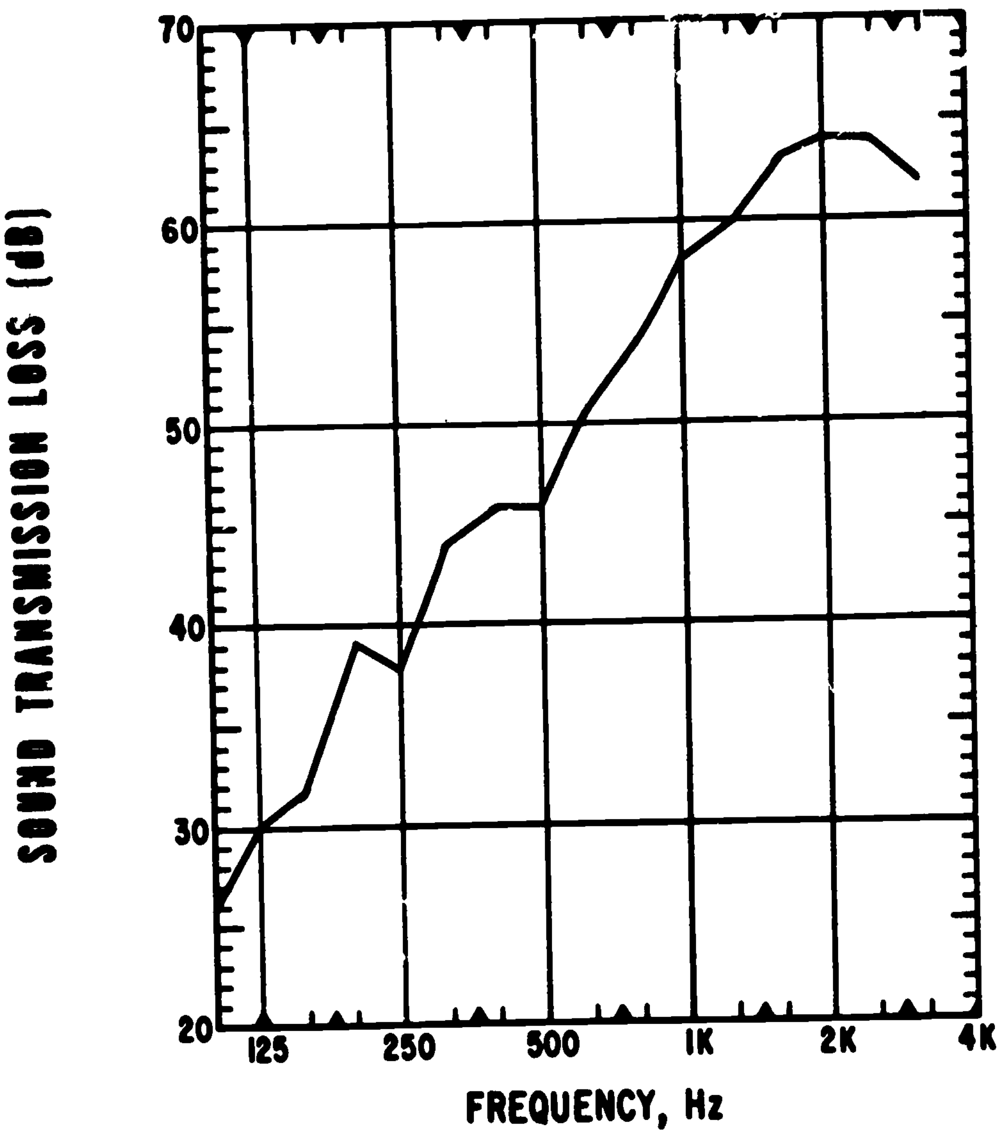
Total thickness: approximately 10 in.

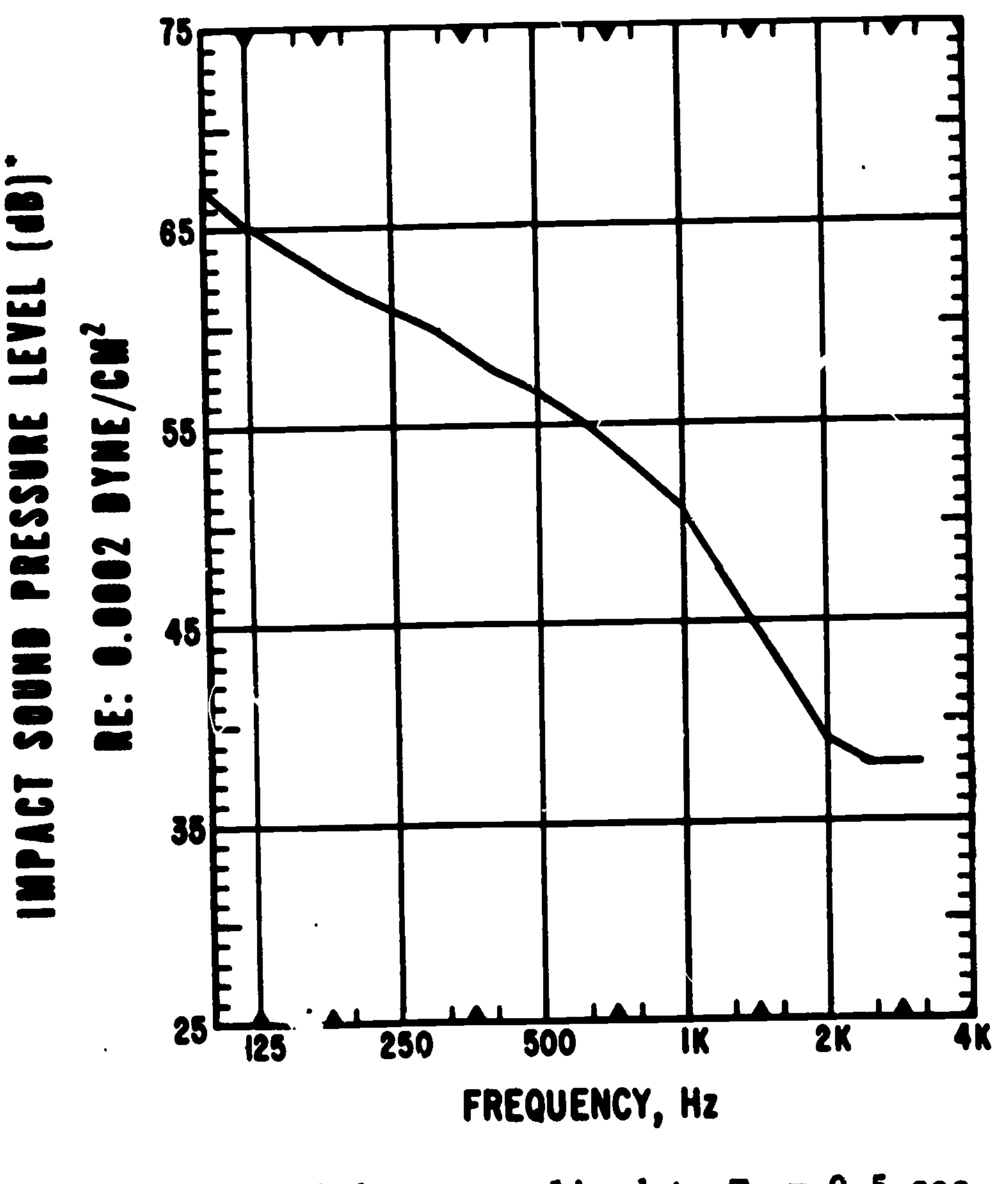
Area weight: 45 lb/ft^2



STC = 50; IIC = 53; Fire Rating: 45 min. (est.)

REMARKS: The plotted STL curve represents the average of field measurements of two nominally identical structures, and the plotted ISPL curve represents the measurements of one structure.





*1/3-octave band data normalized to T_o = 0.5 sec.

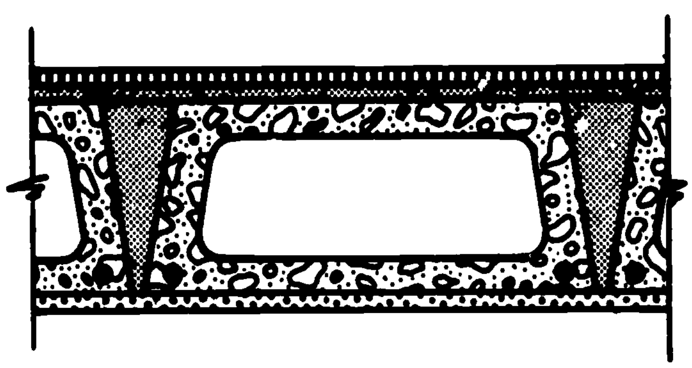
TYPE: PRECAST HOLLOW CONCRETE BEAM

TEST REF: 1-(S58)

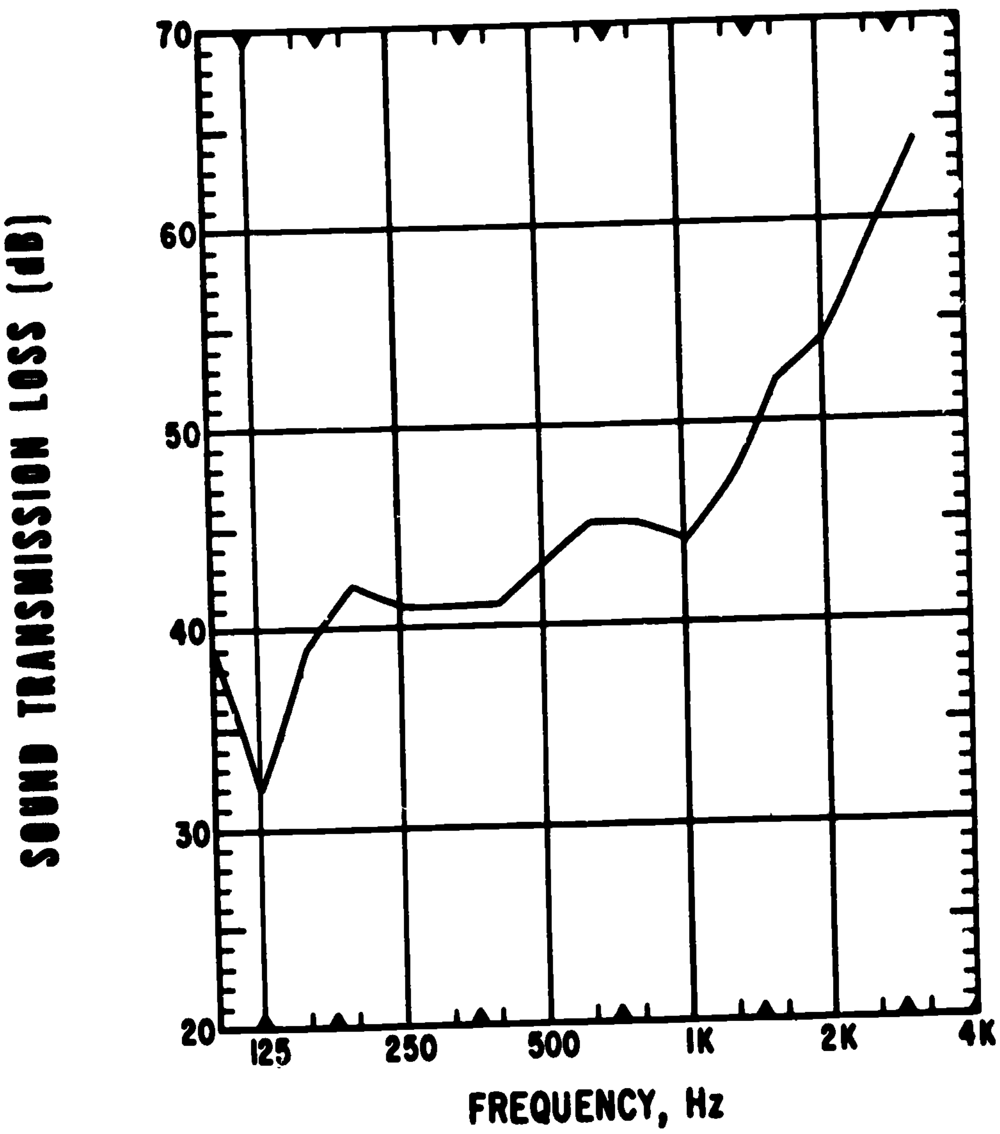
DESCRIPTION: 6-in. precast hollow trapezoidal concrete beams 14 1/2 in. on centers, with bases of 14 in. and 12 in. The spaces between the beams filled with concrete. On the floor side, 1/2-in.-thick sand-cement screed with 1/2-in.-thick pitch-mastic finish floor. On ceiling side, approximately 1/2-in. layer of plaster.

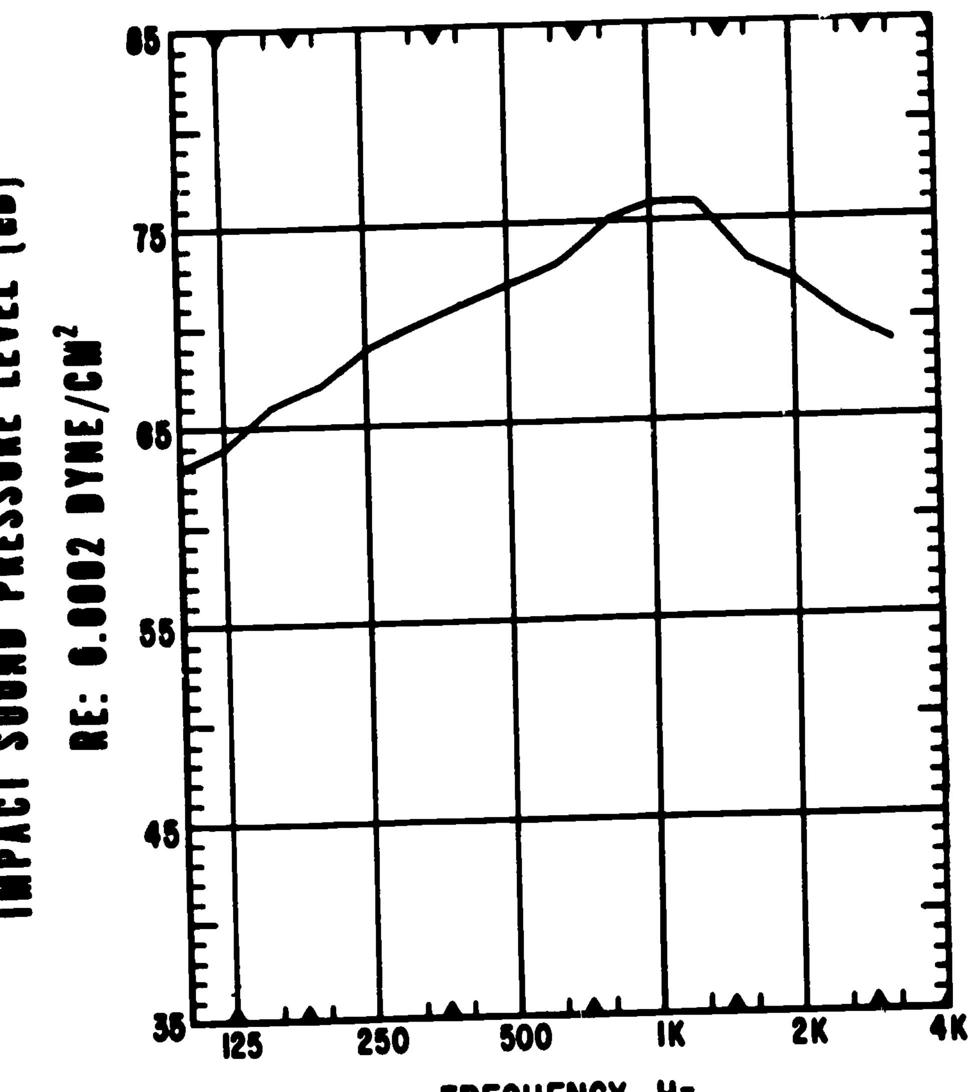
Total thickness: 7 1/2 in.

Area weight: 55 lb/ft^2



STC = 45; IIC = 31; Fire Rating: 45 min. (est.)





*1/3-octave band data normalized to T_o = 0.5 sec.

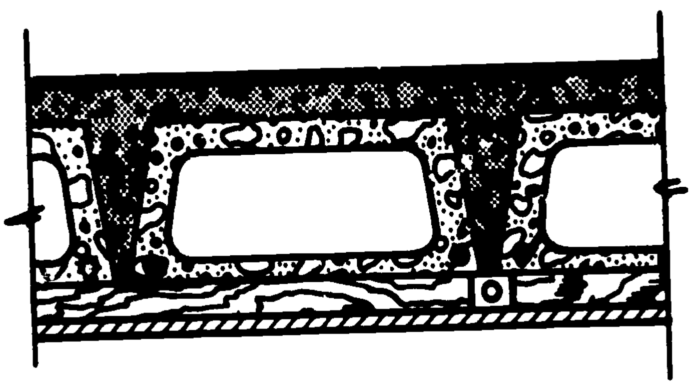
TYPE: HOLLOW CONCRETE BEAM, SUSPENDED CEILING

TEST REF: 1-(S115)

DESCRIPTION: 5-in. precast trapezoidal hollow concrete beams, 14 1/2 in. on centers, with bases of 14 in. and 12 1/2 in. The spaces between beams filled with a sand-cement mix. On the floor side, 1-in.-thick sand-cement screed with 3/16-in. cork tile floor covering. On the ceiling side, 3/8-in.-thick gypsum wallboard attached to 1- by 2-in. wooden battens held by metal clips.

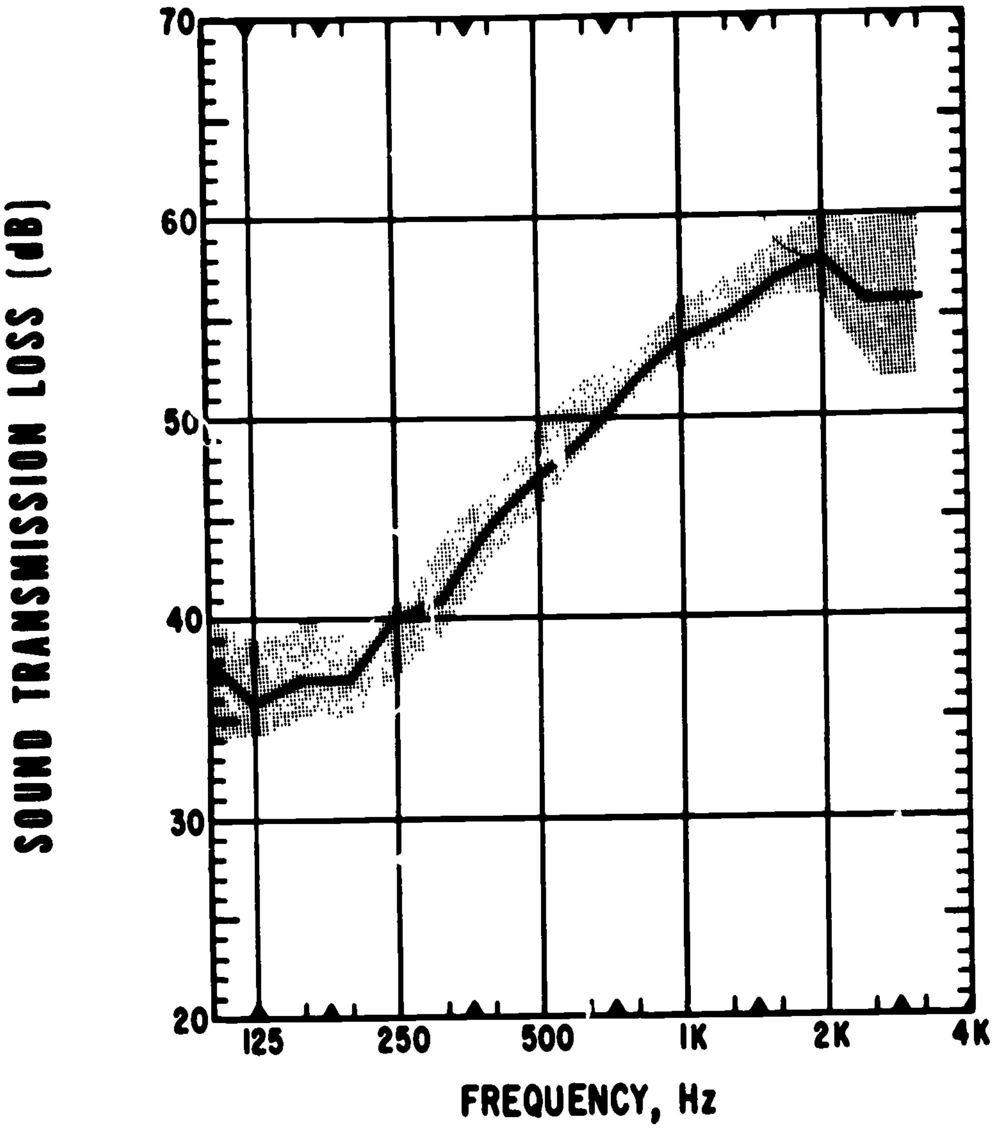
Total thickness: 7 5/8 in.

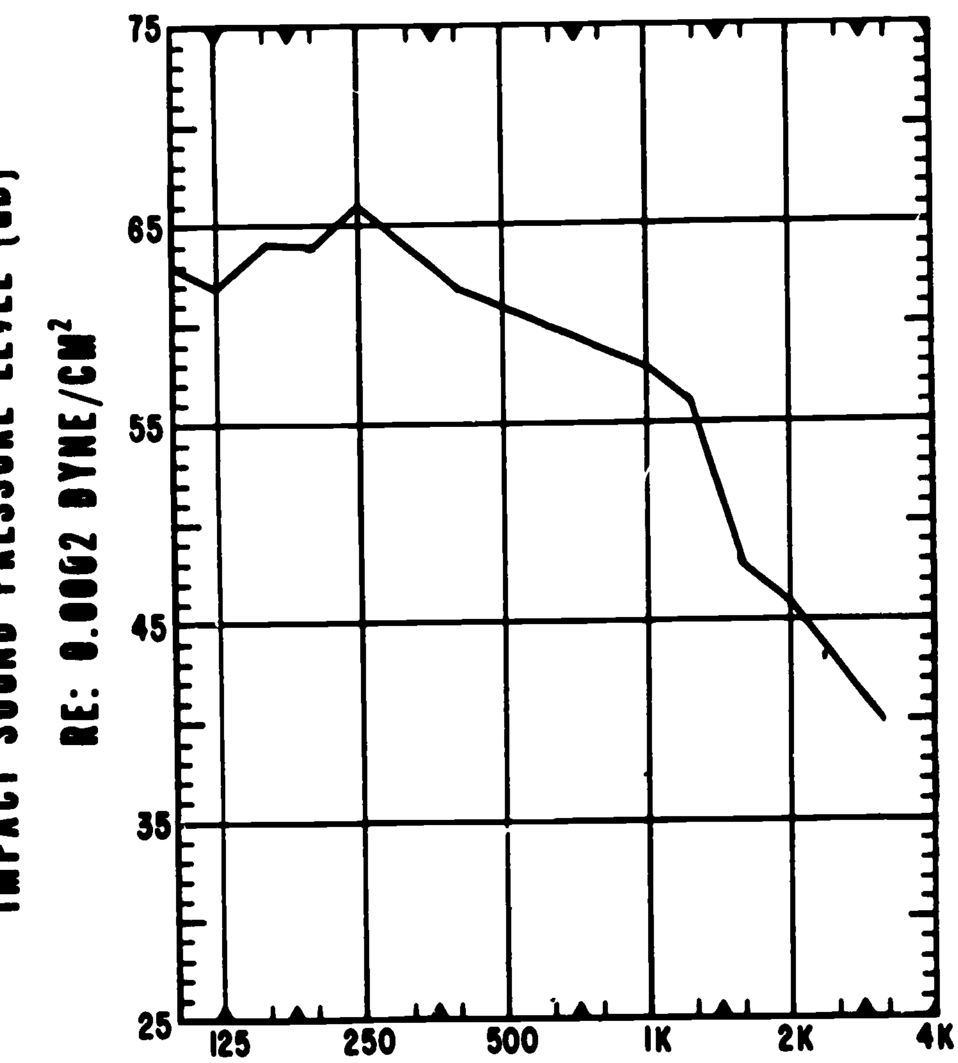
Area weight: 50 lb/ft^2



STC = 50; IIC = 51; Fire Rating: 45 min. (est.)

REMARKS: The plotted STL curve represents the average of field measurements of four nominally identical structures, and the plotted ISPL curve is the average of two structures. The shaded area indicates the spread of the measurements.





*1/3-octave band data normalized to T_0 = 0.5 sec.

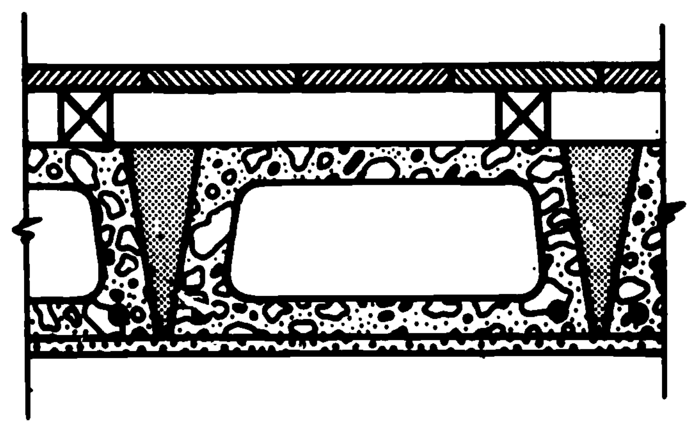
TYPE: HOLLOW CONCRETE BEAM, WOOD RAFT FLOOR

TEST REF: 1-(S64)

DESCRIPTION: 7-in.-thick precast trapezoidal hollow concrete beams, 14 1/2 in. on centers, with bases of 14 in. and 12 in. The spaces between beams were filled with concrete. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring nailed to 2- by 2-in. wooden battens, 18 in. on centers; linoleum floor covering. On the ceiling side, 3/4-in. layer of plaster.

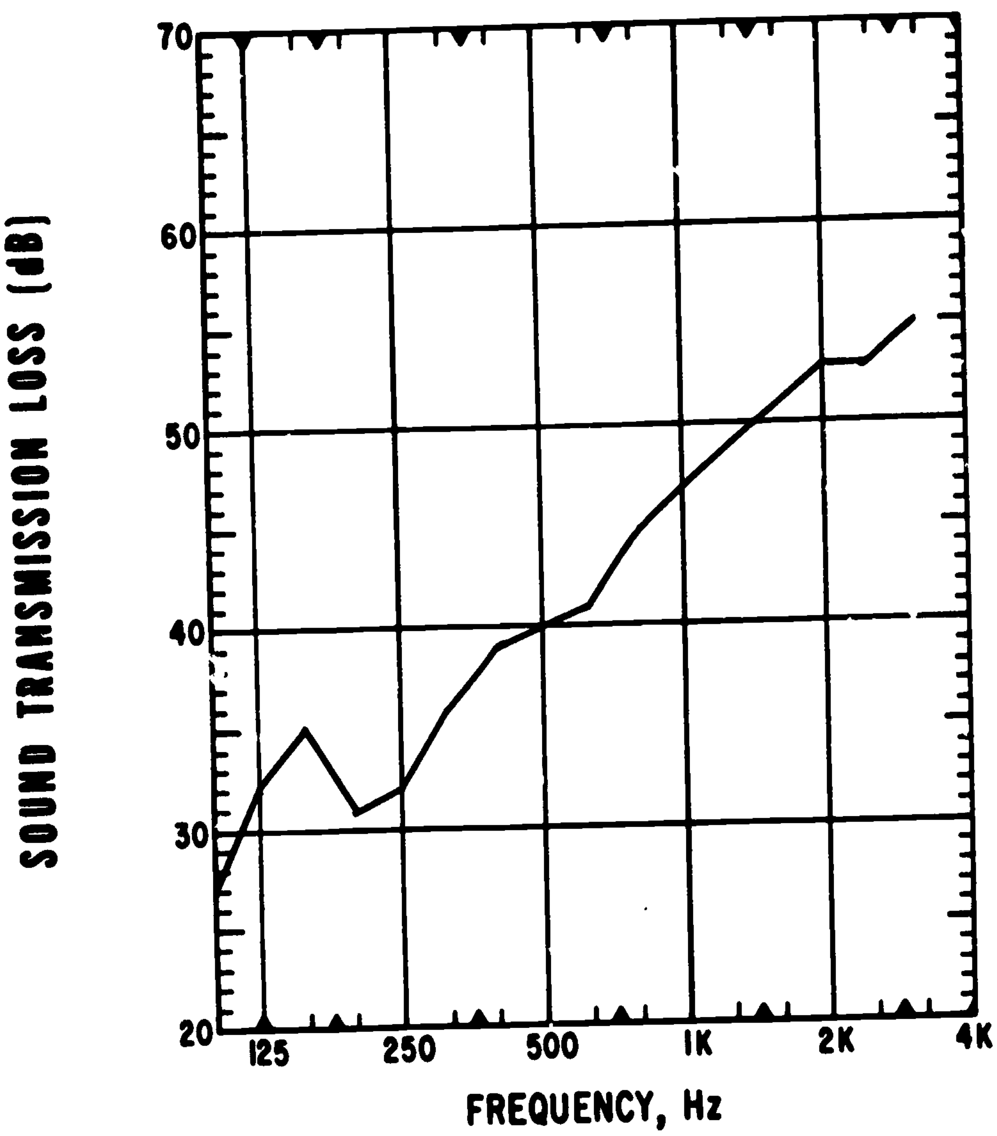
Total thickness: 10 5/8 in.

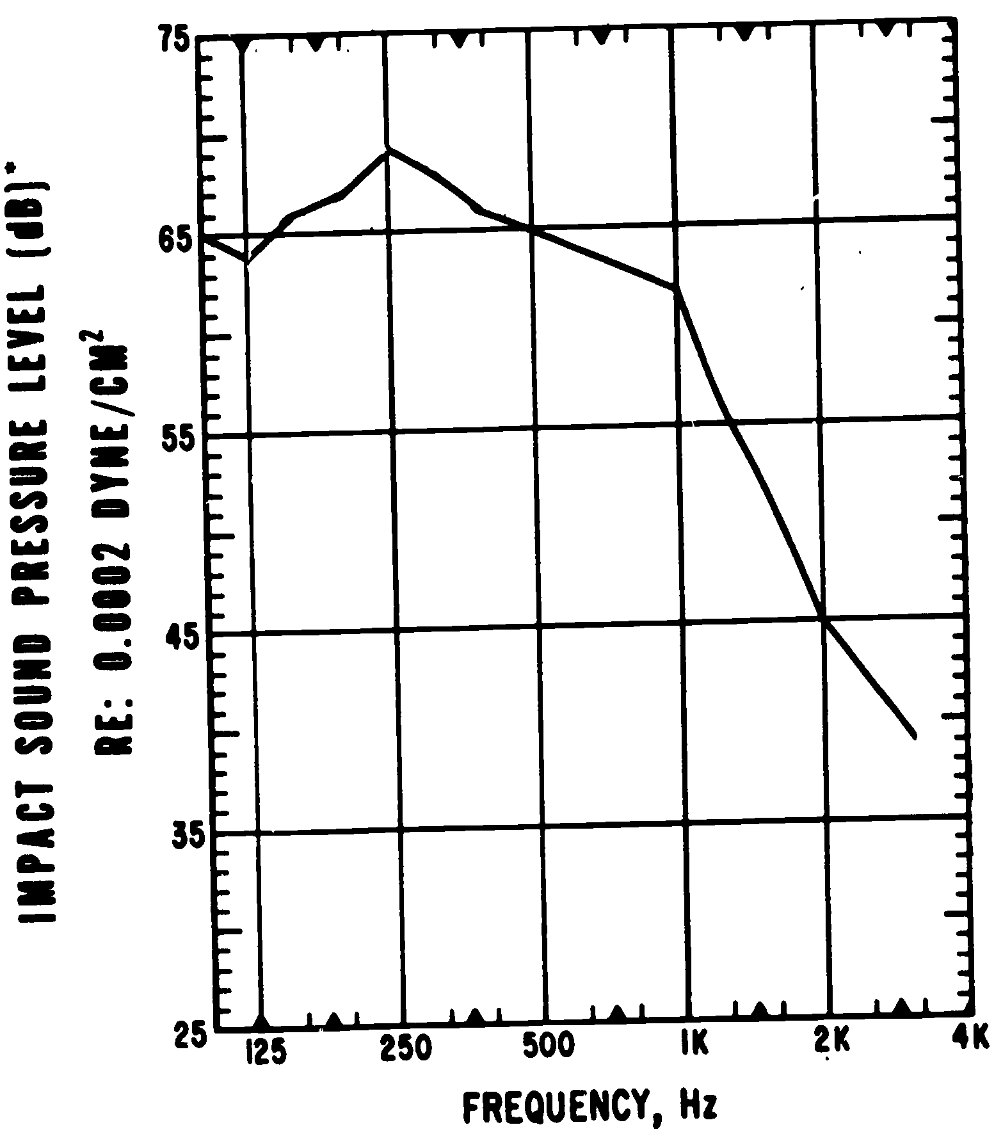
Area weight: 45 lb/ft^2



STC = 44; IIC = 48; Fire Rating: 1/2 hr. (est.)

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

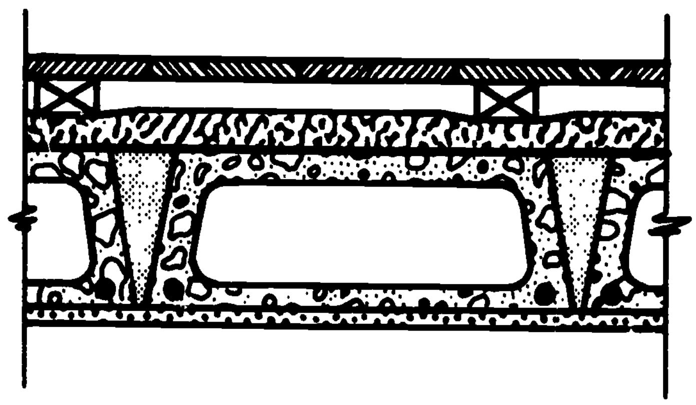
TYPE: HOLLOW CONCRETE BEAM, FLOATING FLOOR

TEST REF: 1-(S78-2)

DESCRIPTION: 5-in.-thick precast trapezoidal hollow concrete beams, 14 1/2 in. on centers, with bases of 14 in. and 12 1/2 in. The spaces between the beams were filled with a sand-cement mix. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring nailed to 1 1/2- by 2-in. wooden battens, 20 in. on centers, floating on a glass-wool quilt, approximately 1 in. thick; linoleum floor covering. On the ceiling side, 5/8-in. layer of plaster.

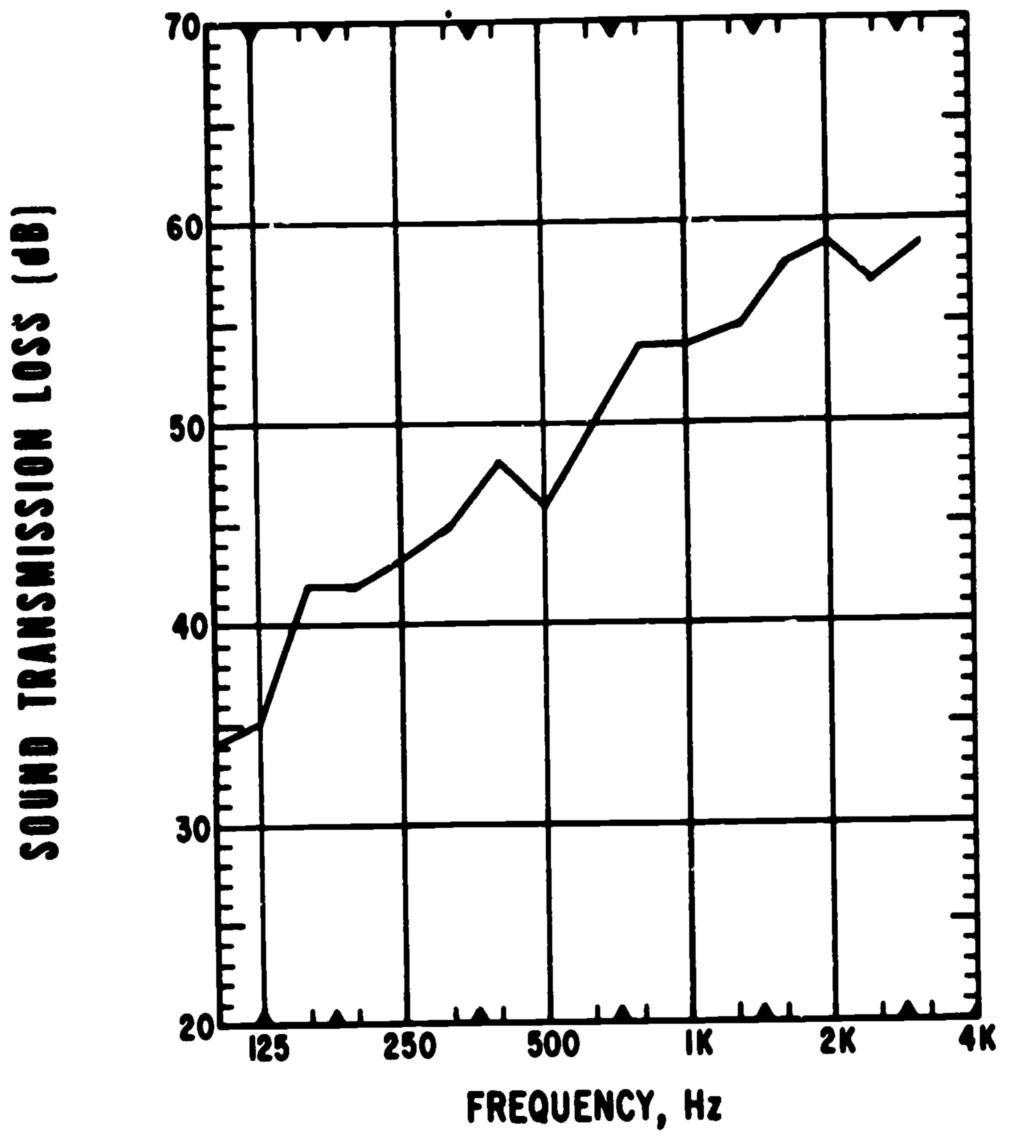
Total thickness: approximately 8 3/4 in.

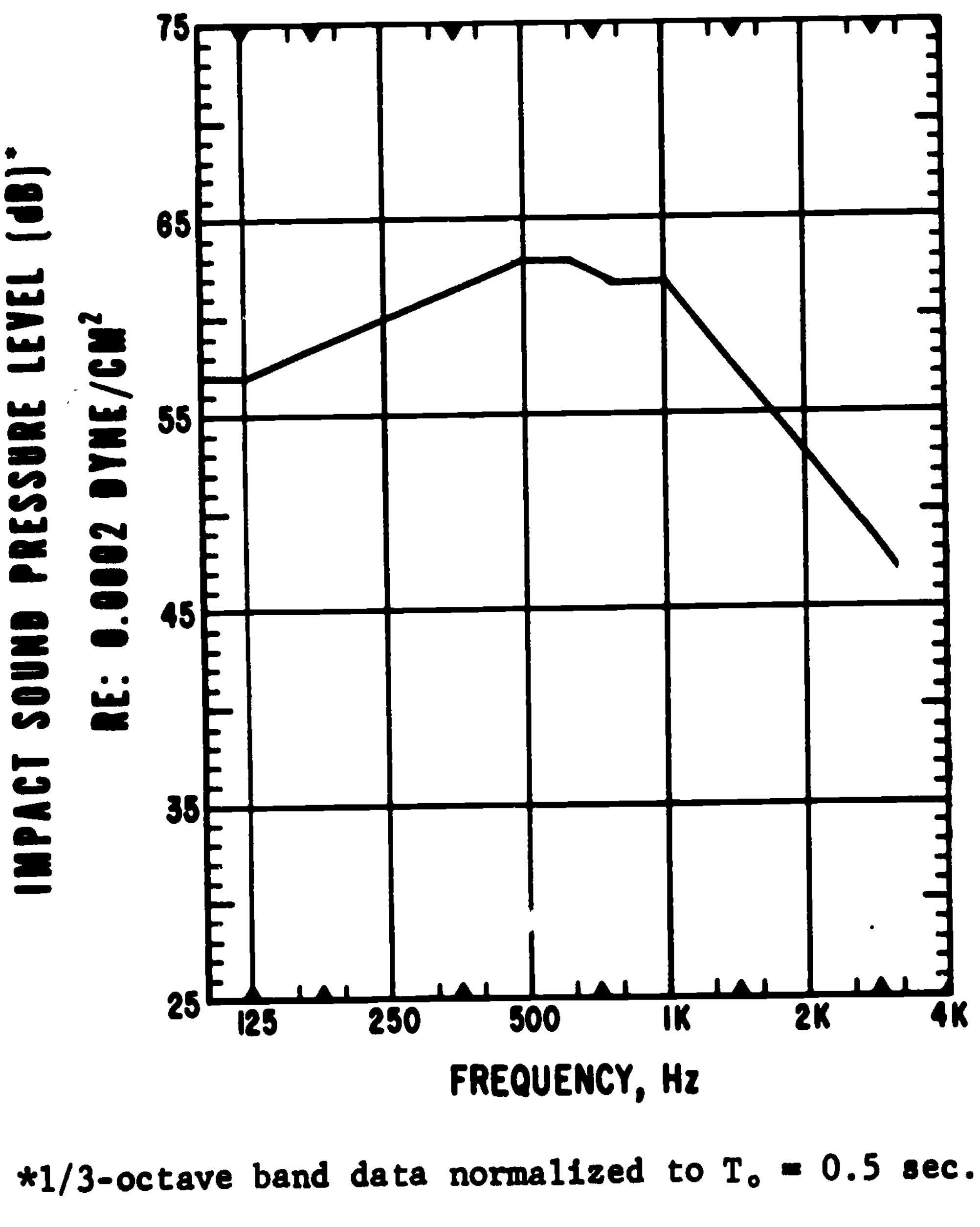
Area weight: 42 lb/ft^2



STC = 50; IIC = 49; Fire Rating: Not available

REMARKS: These measurements were conducted in the field.





*1/3-octave band data normalized to T_o = 0.5 sec.

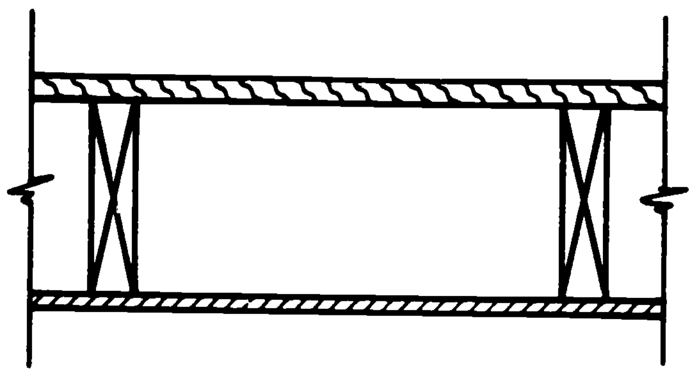
TYPE: WOODEN JOIST

TEST REF: 1-(S288-1, 2; S289-1, 2)

DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 7/8-in. tongue-and-groove flooring nailed to joists; on ceiling side, 3/8-in. gypsum wallboard nailed to joists with the joints sealed.

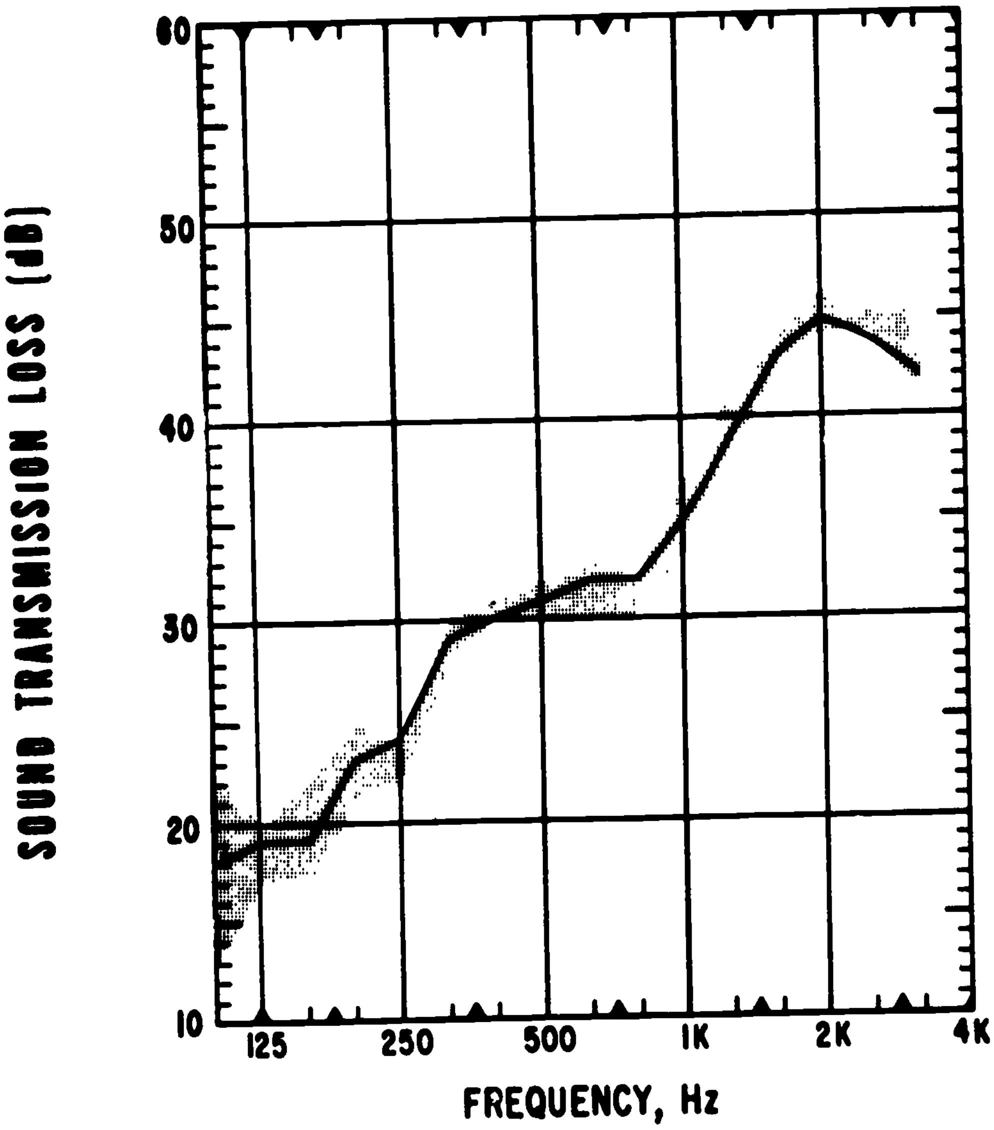
Total thickness: 9 1/2 in.

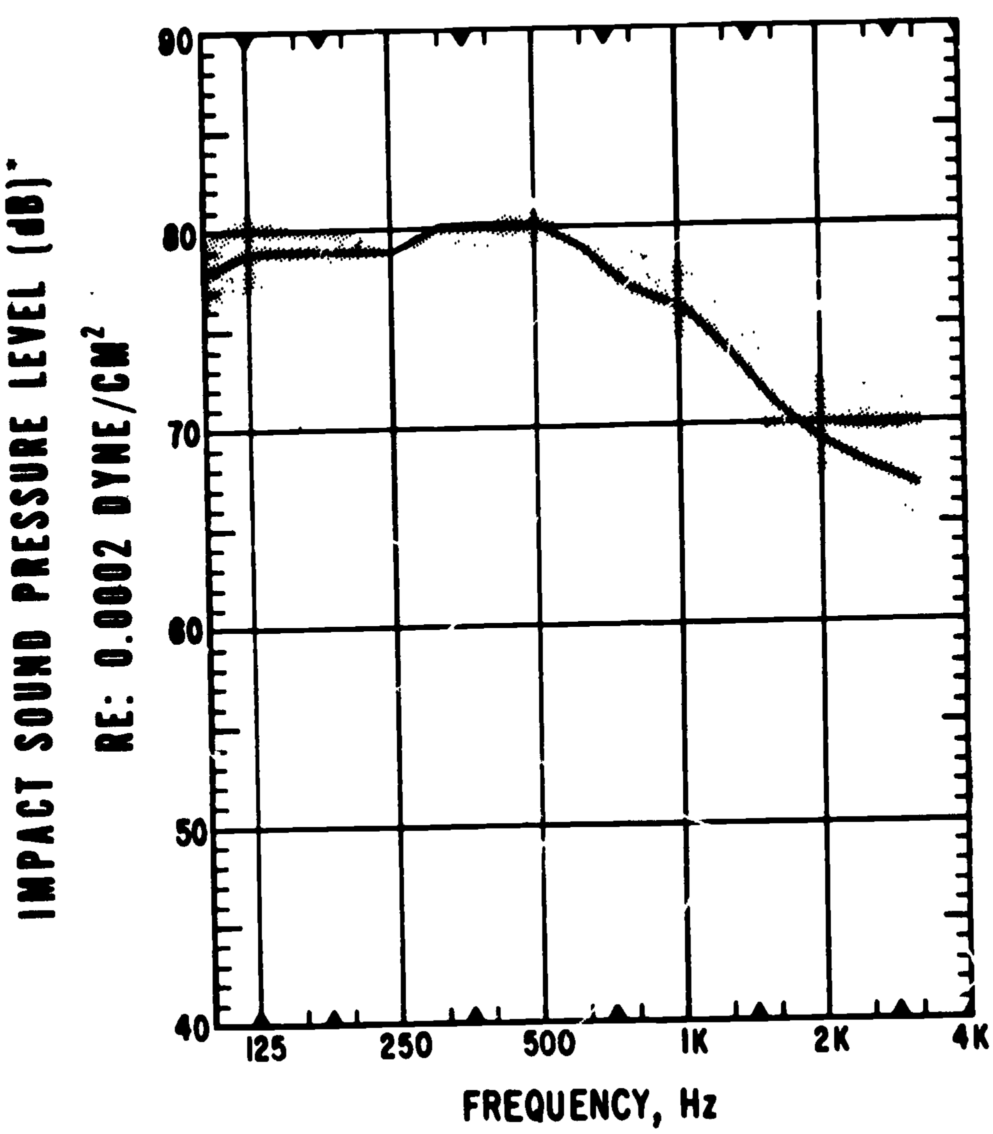
Area weight: 7 lb/ft^2



STC = 34; IIC = 32; Fire Rating: 15 min. (est.) - combustible

REMARKS: The plotted curves represent the average of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to T_o = 0.5 sec.

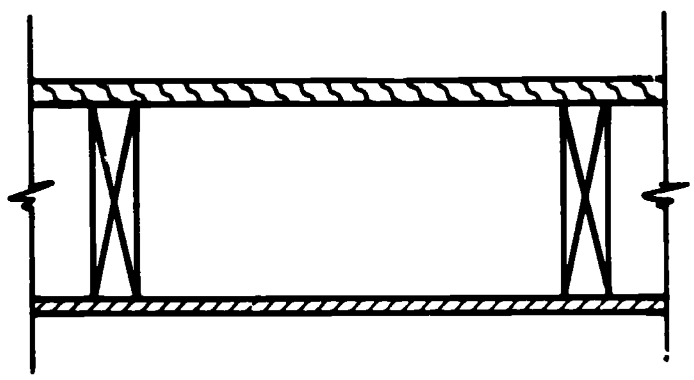
TYPE: WOODEN JOIST

TEST REF: 1-(S290)

DESCRIPTION: 2- by 7-in. wooden joists 16 in. on centers. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring nailed to joists. On the ceiling side, 3/8-in.-thick gypsum wallboard nailed to joists, approximately 3/16-in. skim-coat of plaster applied to gypsum board.

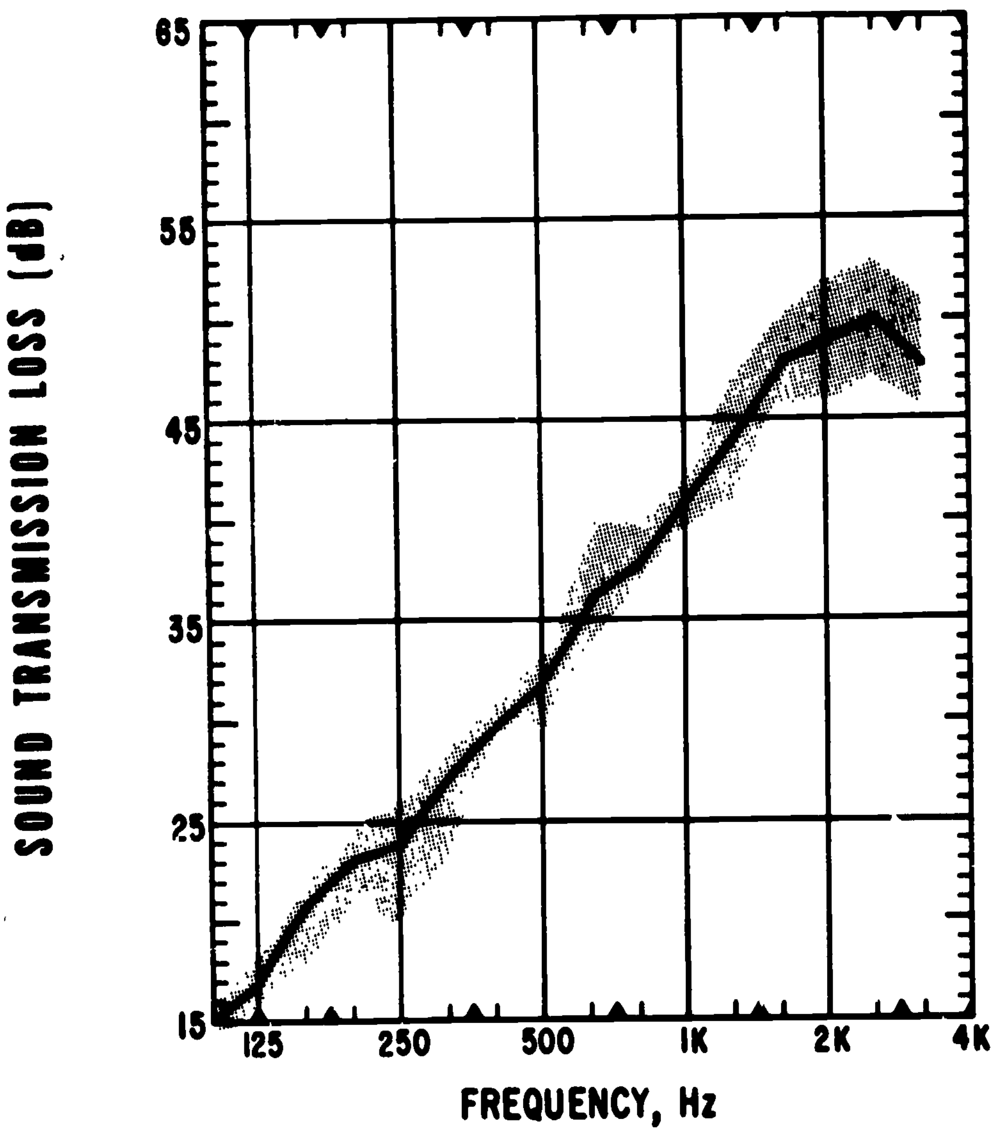
Total thickness: approximately 8 1/2 in.

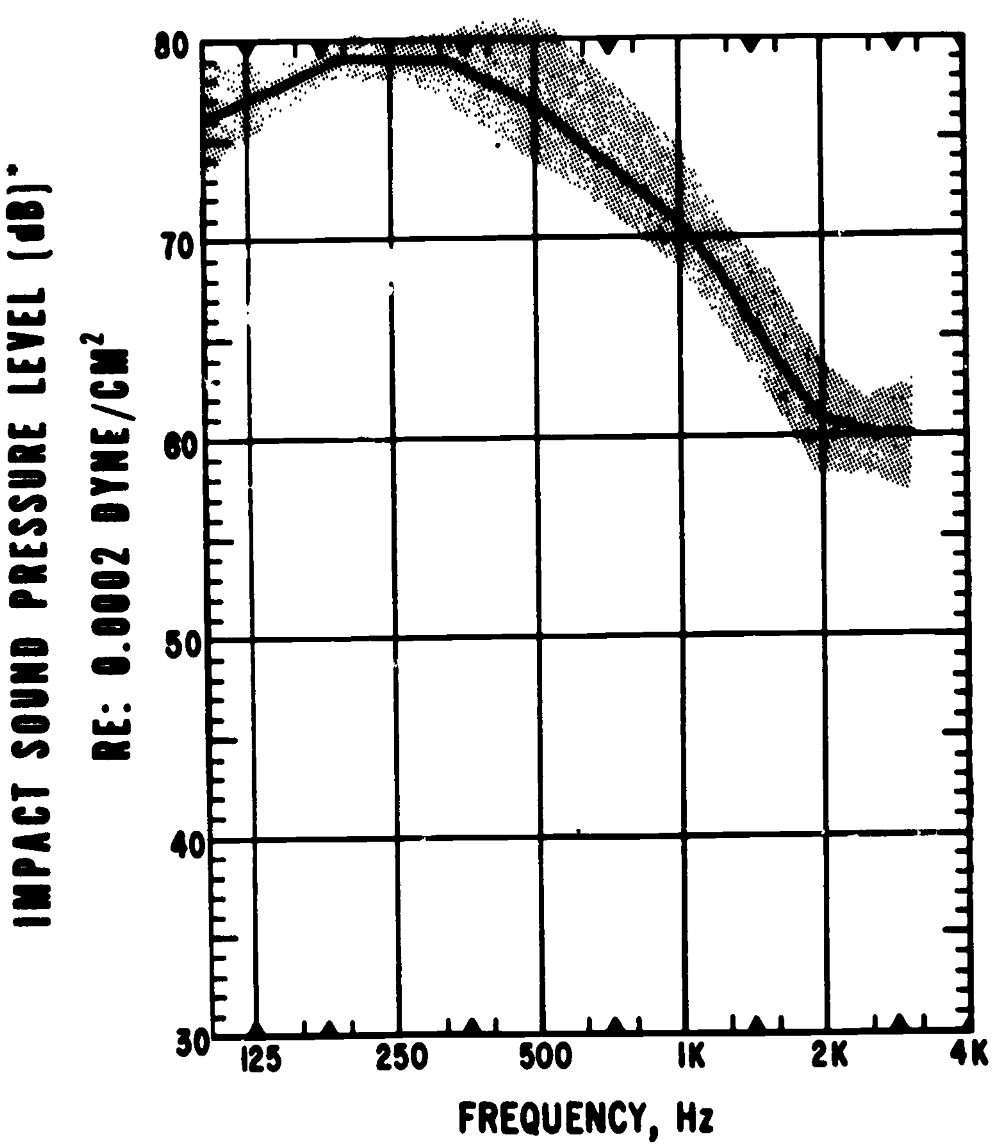
Area weight: 8 lb/ft^2



STC = 35; IIC = 36; Fire Rating: 15 min. (est.) - combustible

REMARKS: The plotted curves represent the average of field measurements of three nominally identical structures. The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to T_0 = 0.5 sec.

TYPE: WOODEN JOIST

TEST REF: (a) 1-(S293, S294); (b) 1-(S292-2)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring screwed to joists; 1- by 2-in. wooden battens nailed to the underside of the wood flooring midway between joists. On the ceiling side, 1/2-in. layer of plaster on expanded metal lath nailed to joists.

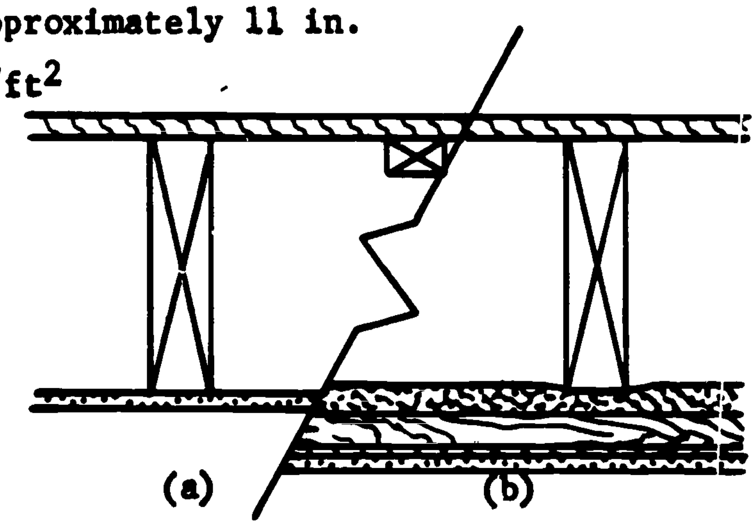
Total thickness: 9 1/2 in.

Area weight: 13 lb/ft^2

(b) 2- by 8-in. wooden joists 18 in. on centers. On the floor side, 7/8-in. tongue-and-groove wood flooring nailed to joists. On the ceiling side, 1-in. battens nailed through glass-wool quilt, approximately 1 in. thick; 1/2-in. layer plaster on 1/4-in.-thick wood lath.

Total thickness: approximately 11 in.

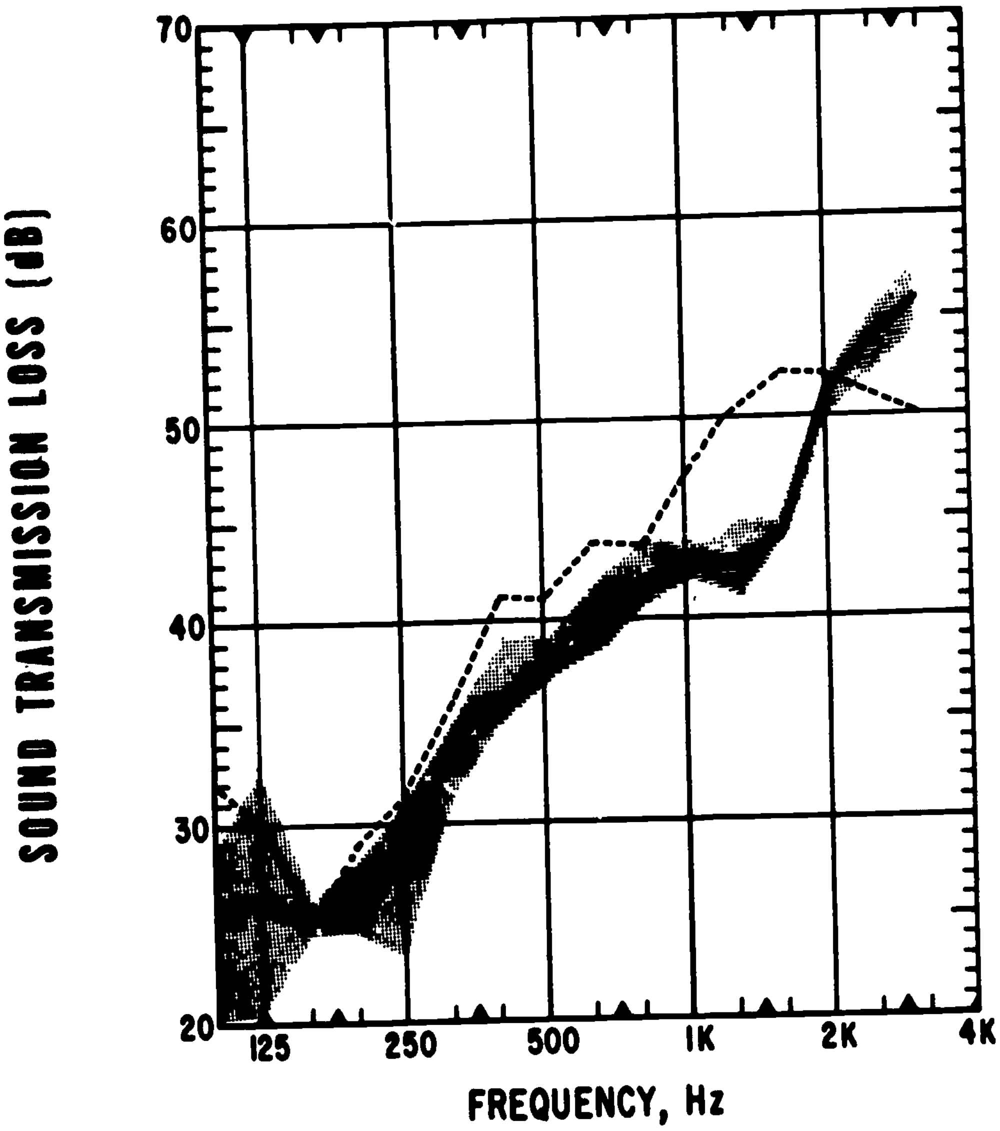
Area weight: 12 lb/ft^2

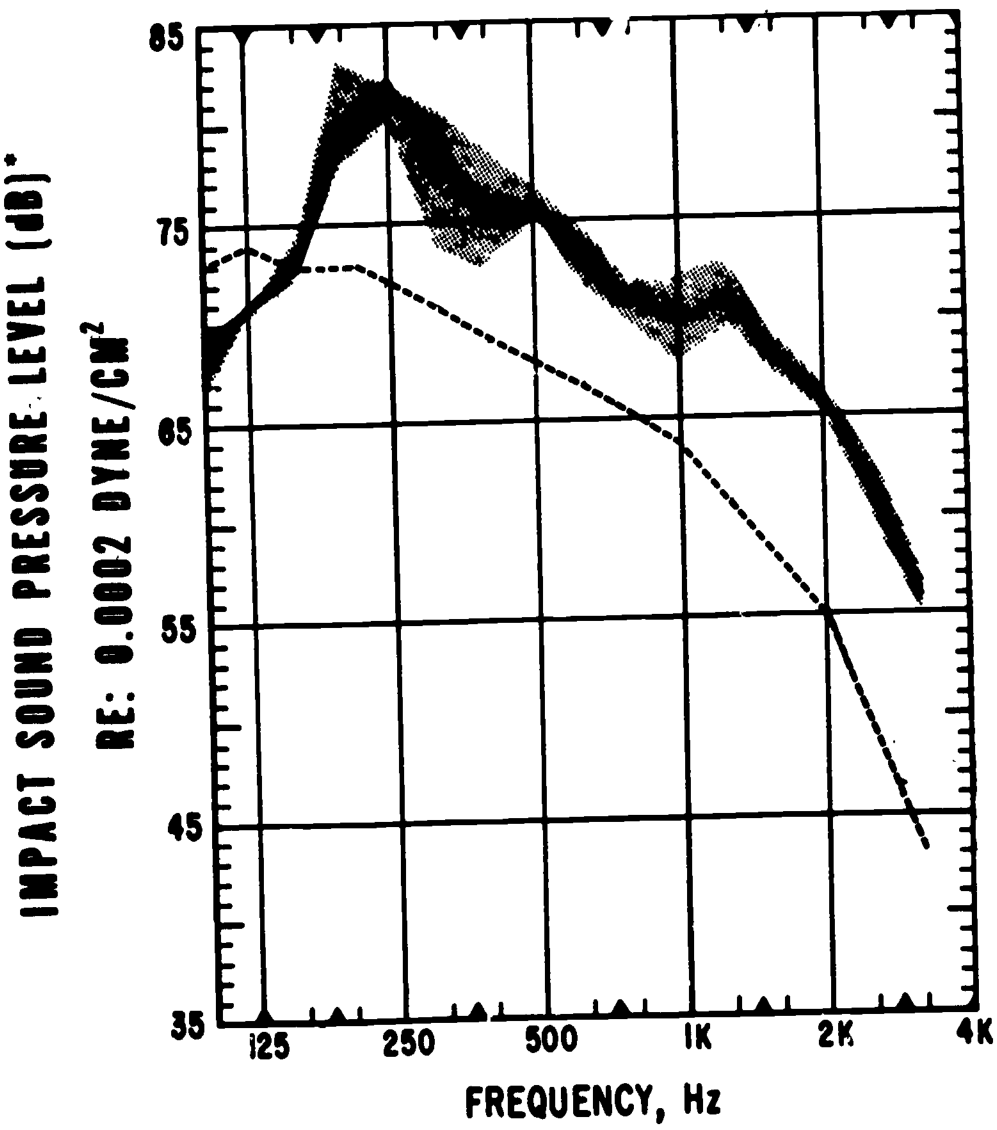


(a) ▬▬▬ STC = 41; IIC = 36; Fire Rating: 30 min. (est.) - combustible

(b) ··········· STC = 43; IIC = 43; Fire Rating: 45 min. (est.) - combustible

REMARKS: The plotted curves, for structure (a), represent the average of field measurements of four nominally identical structures. The shaded areas indicate the spreads of the measurements. The curves, for structure (b), are the results of measurements of one structure.





*1/3-octave band data normalized to T_o = 0.5 sec.

TYPE: WOODEN JOIST

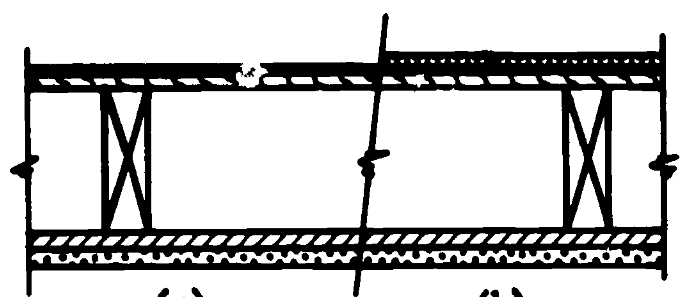
TEST REF: (a) 11(b)-(34b); (b) 11(b)-(34f); 17-(9a)

DESCRIPTION: (a) 3- by 7-in. wooden joists, 24 in. on centers. On the floor side, 1-in.-thick wood flooring nailed to joists, linoleum floor covering. On the ceiling side, 1 3/8-in. layer of lath, reeds and plaster.

(b) Similar to (a) except coco matting replaced linoleum.

Total thickness: 9 1/2 in.

Area weight: approximately 12 lb/ft^2

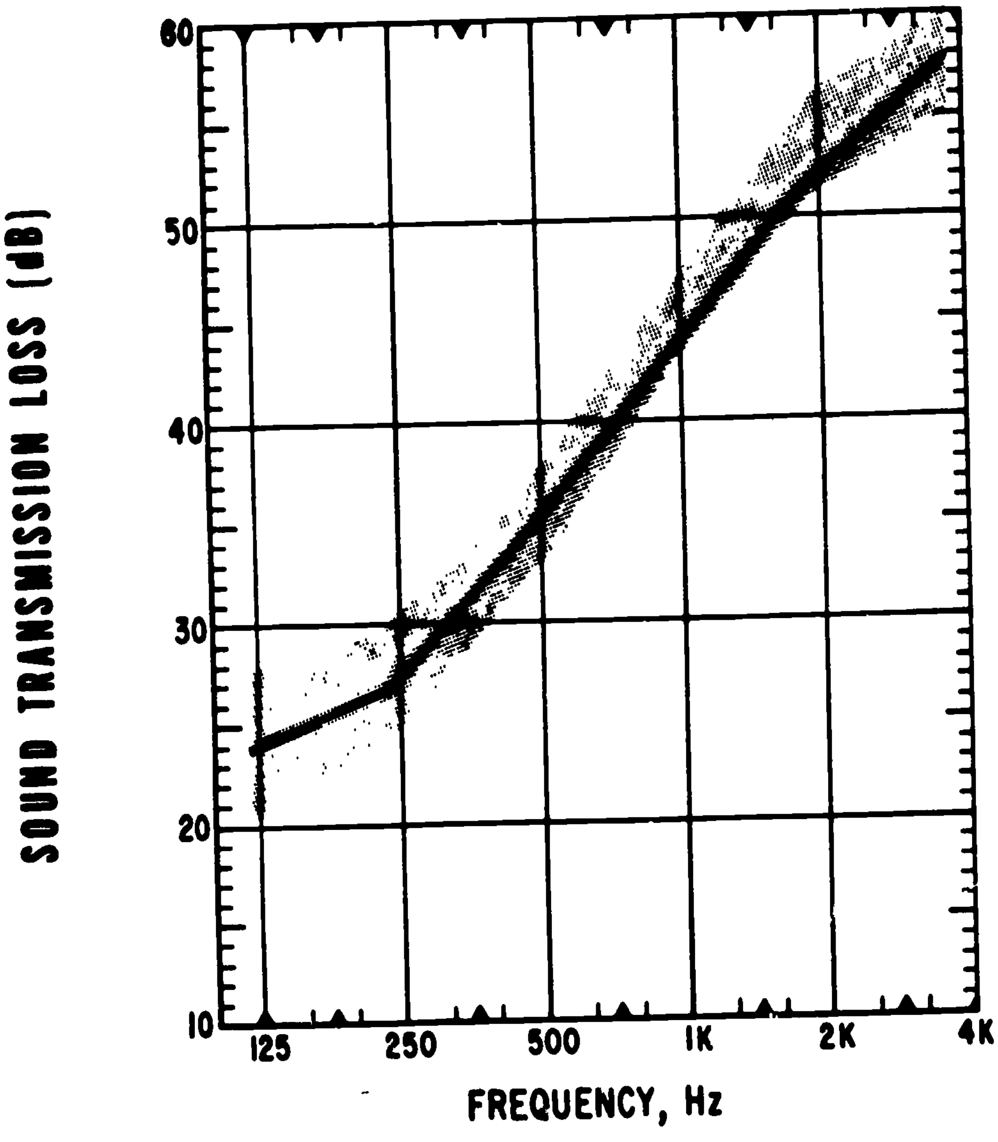


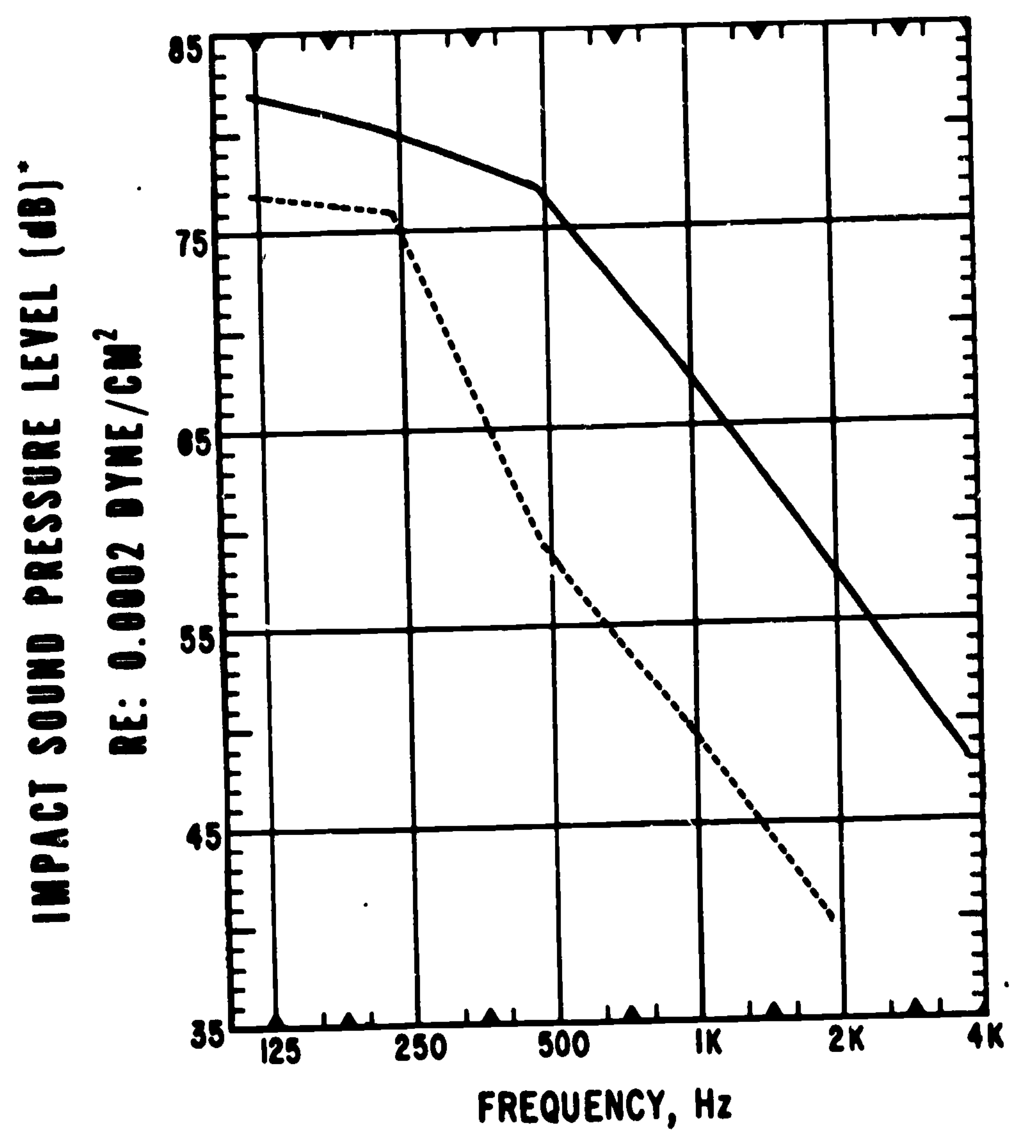
(a) (b)

(a) ———— STC = 39; IIC = 40; Fire Rating: 20 min. (est.) - combustible

(b) ········ STC = 39; IIC = 45; Fire Rating: 20 min. (est.) - combustible

REMARKS: The airborne STL measurements were made without floor coverings; however, these provide little additional airborne sound insulation, and the data are applicable to the above structures. The plotted curve represents the average of field measurements of seven nominally identical structures. The shaded area indicates the spread of the measurements. Each plotted ISPL curve represents the results of field measurements of one structure.





*1/1-octave band data normalized to T_o = 0.5 sec.

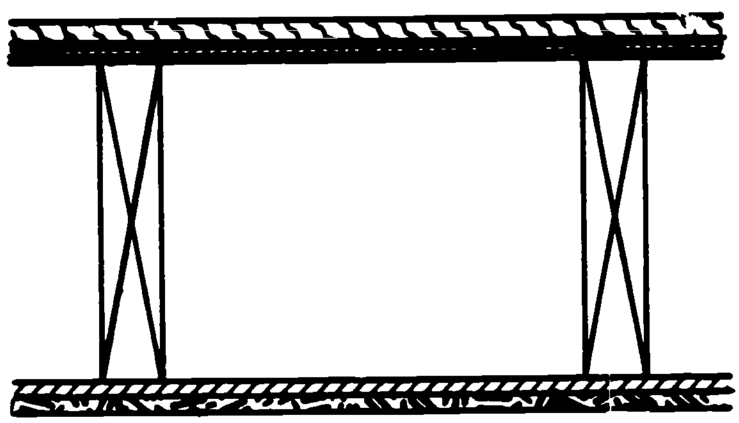
TYPE: WOODEN JOIST

TEST REF: 6-(FIT 2)

DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 1/2-in.-thick C-D plywood nailed 8 in. on centers to joists, 25/32-in.-thick hard wood flooring on plywood. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 6 in. on centers to joists; all joints taped and finished; ceiling tile adhered to gypsum board.

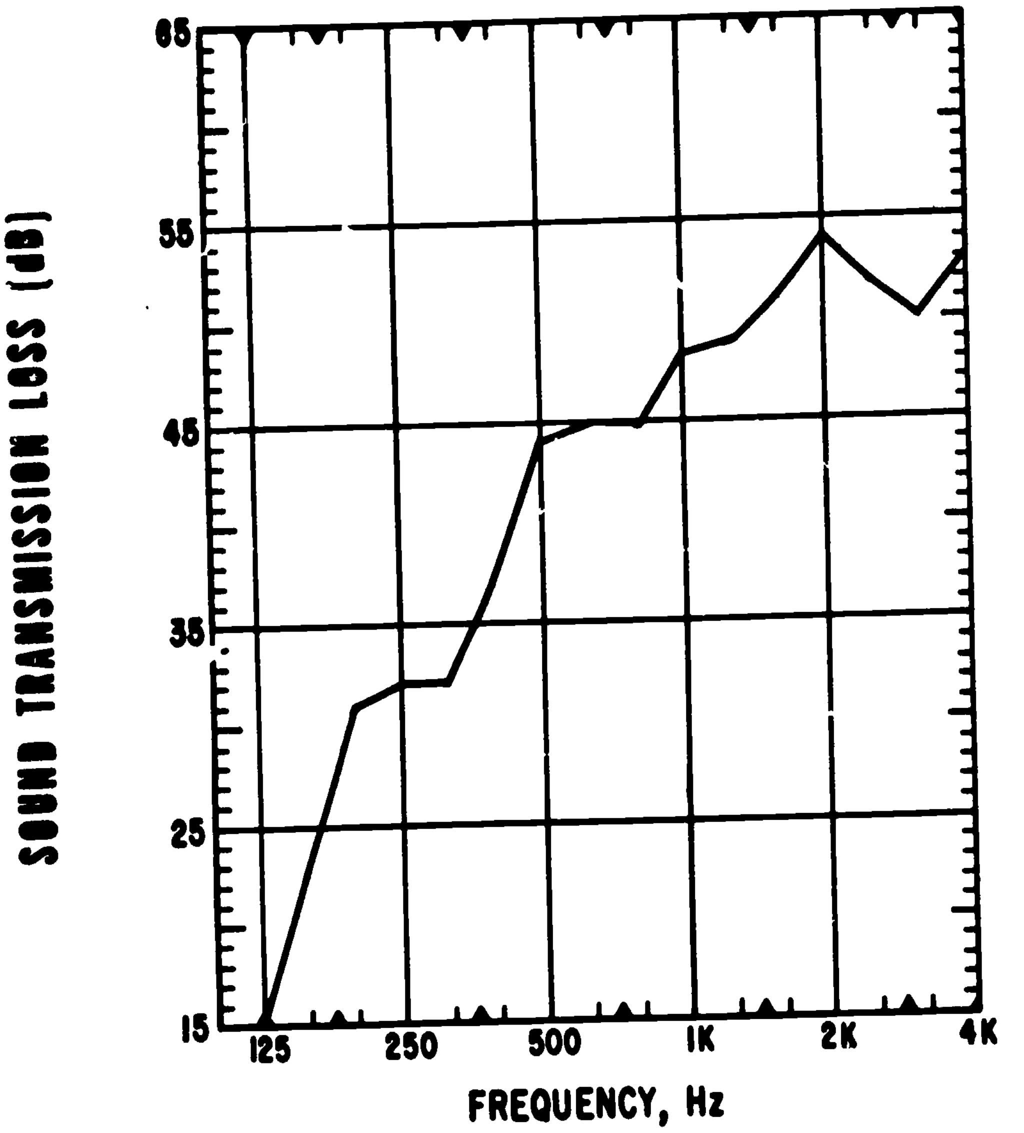
Total thickness: 10 1/4 in.

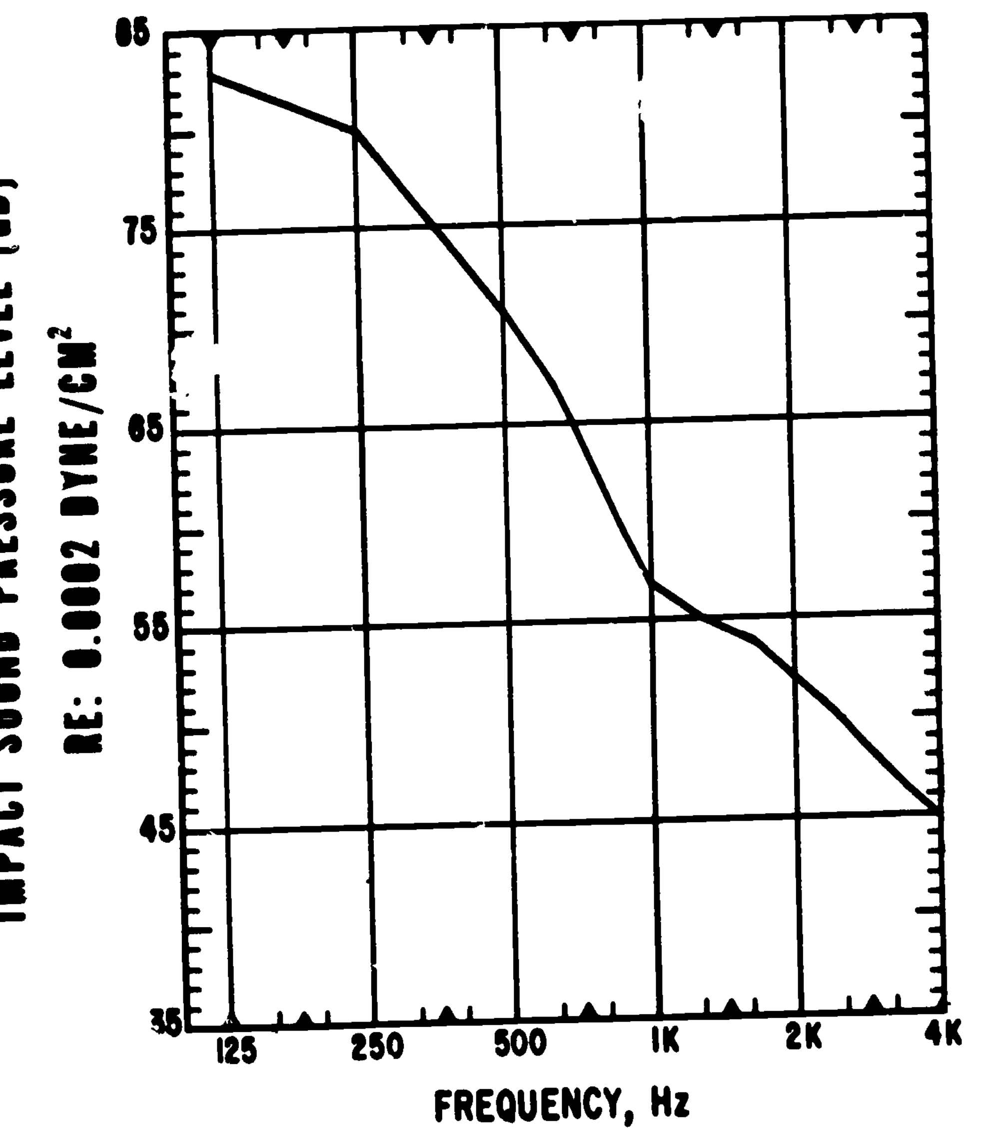
Area weight: 9.9 lb/ft^2



STC = 39; IIC = 37; Fire Rating: 1 hr. - combustible

REMARKS: The airborne sound insulation measurements were made without the ceiling tile. The above measurements were conducted in the field.





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST

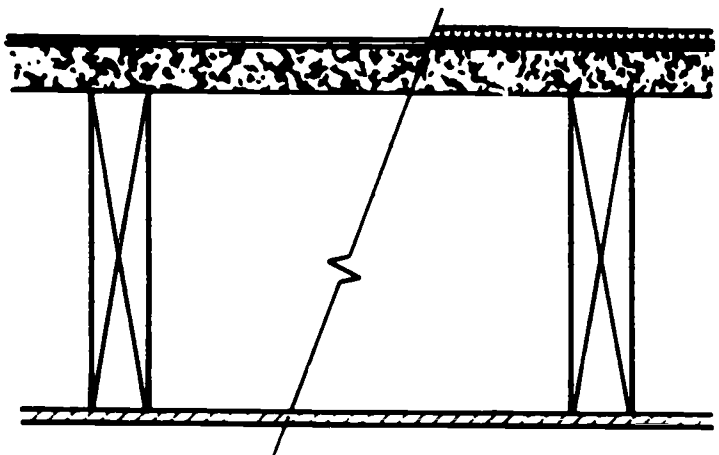
TEST REF: (a) 6-(FIT 8); (b) 6-(FIT 8)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 1 1/2-in.-thick tongue-and-groove wood fiber board nailed to joists, vinyl tile floor covering. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 6 in. on centers to joists. All joints taped and finished.

(b) Similar to (a) except fiber board was covered with carpet and pad.

Total thickness: 10 in.

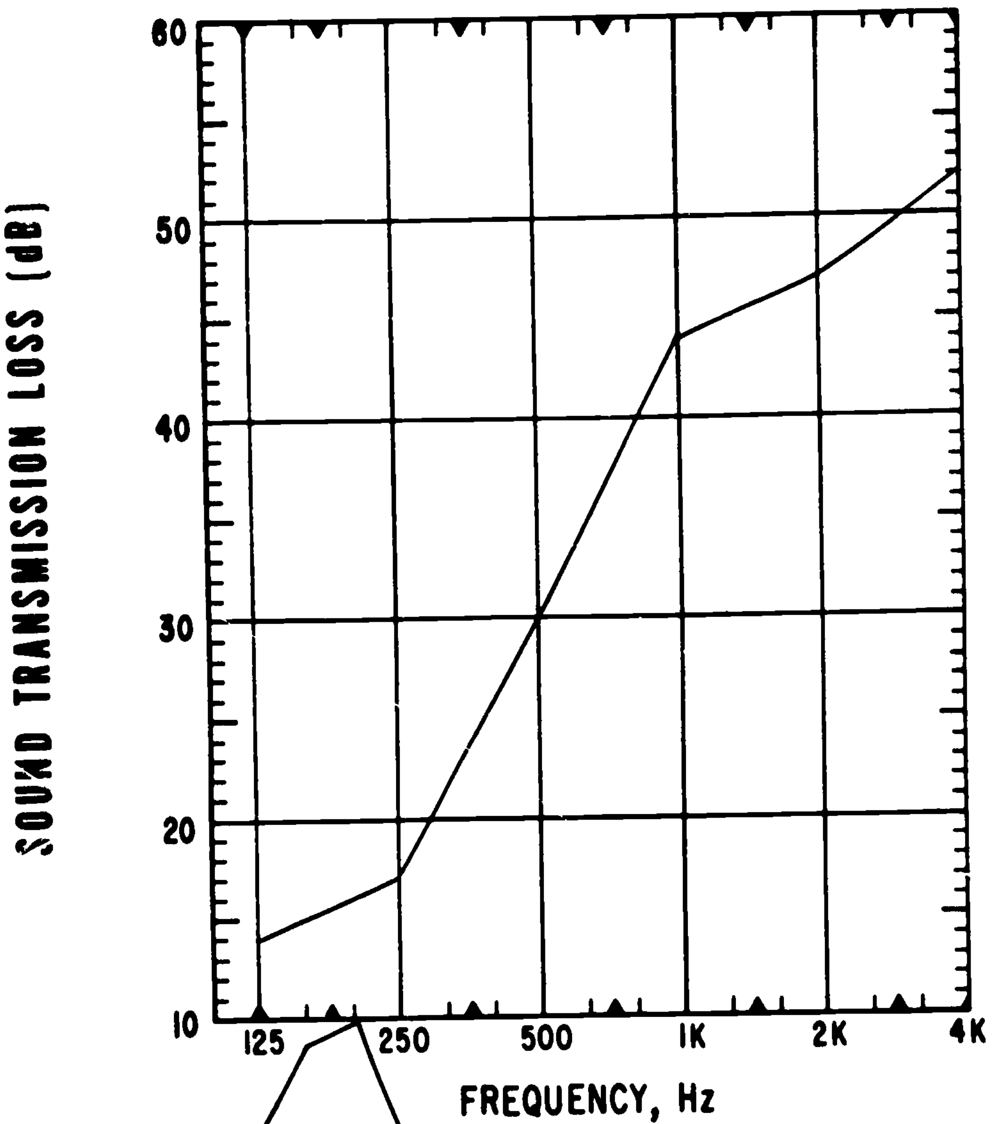
Area weight: 9.2 lb/ft^2

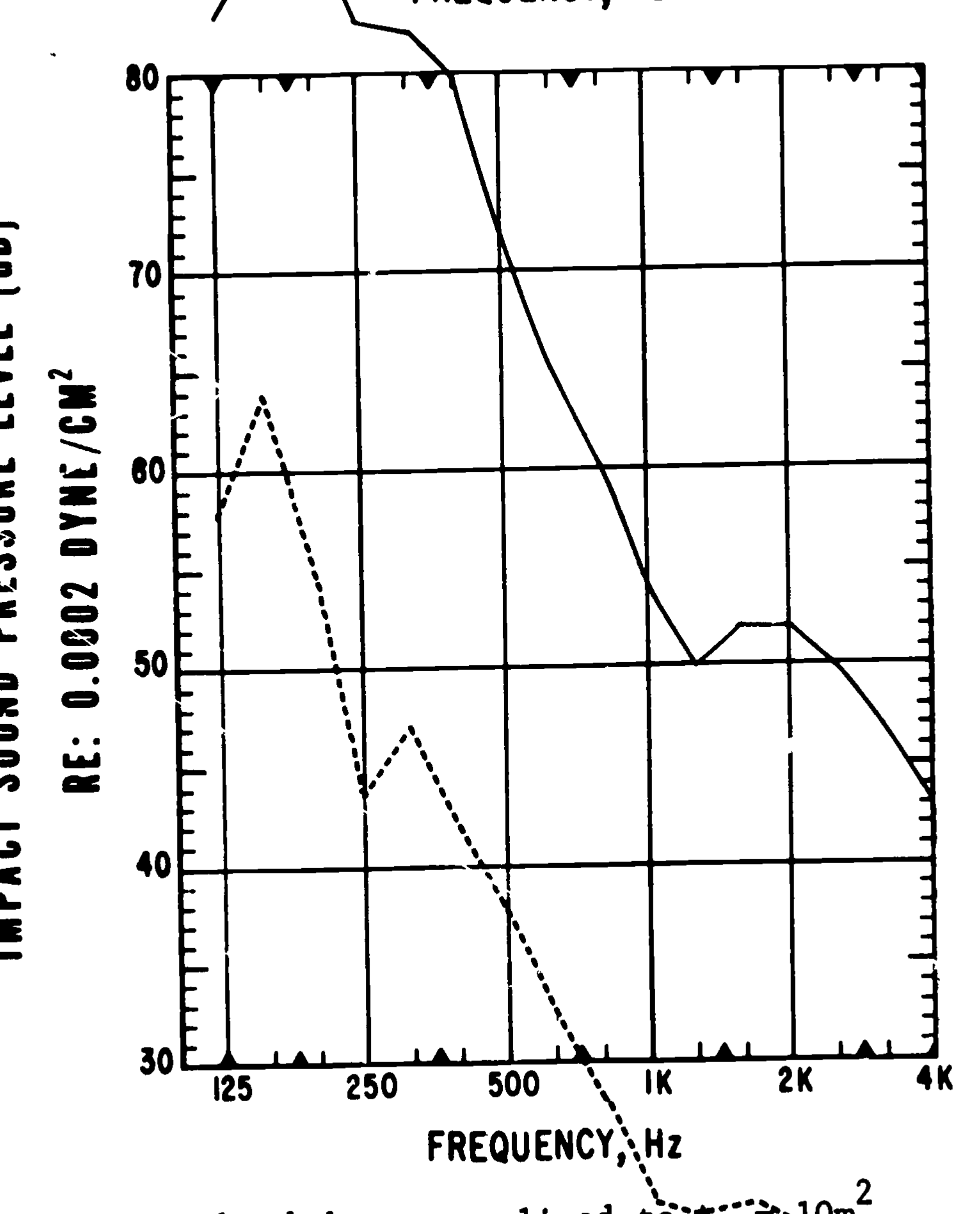


(a)———————STC = 29; IIC = 32; Fire Rating: Not available

(b)---------------- IIC = 56

REMARKS: The airborne sound insulation measurements (in 1/1-octave bands) were made without floor coverings; however, these provide little additional airborne sound insulation, and these data are applicable to the above structures. The plotted curves are the results of field measurements.





*1/3-octave band data normalized to A_o = 10m^2

TYPE: WOODEN JOIST

TEST REF: (a) 3-(723-A); (b) 3-(724-A)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers. On the floor side, 1 11/32- by 23 1/4-in. compressed homogeneous paper pulp building board (approximate density 26.1 lb/ft^3) nailed 8 in. on centers perpendicular to the joists, 1/8-in.-thick hardboard glued to building board, a single layer of 15 lb felt building paper glued to hardboard, and 1/8- by 9- by 9-in. vinyl asbestos tile glued to felt paper. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 12 in. on centers, with all joints taped and finished.

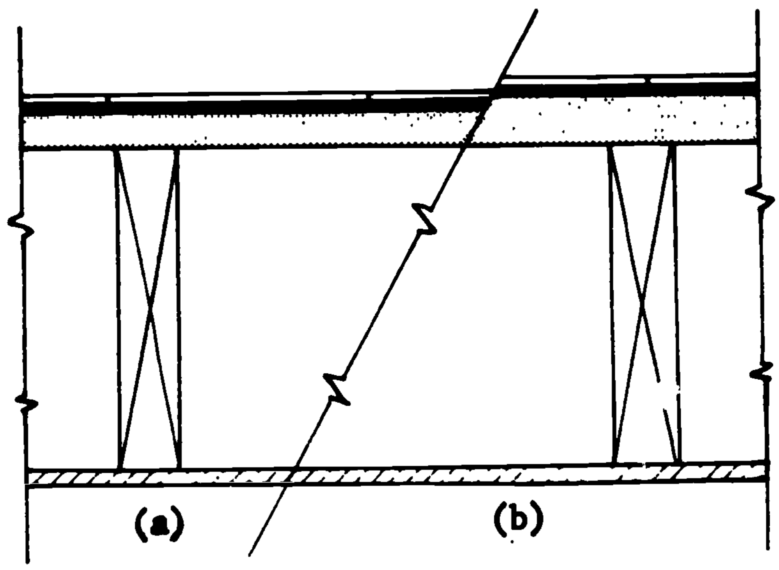
Total thickness: 12 1/4 in.

Area weight: 8.4 lb/ft^2

(b) Similar to (a) except the wooden joists were 24 in. on centers and the building board was 1 27/32 in. thick.

Total thickness: 12 3/4 in.

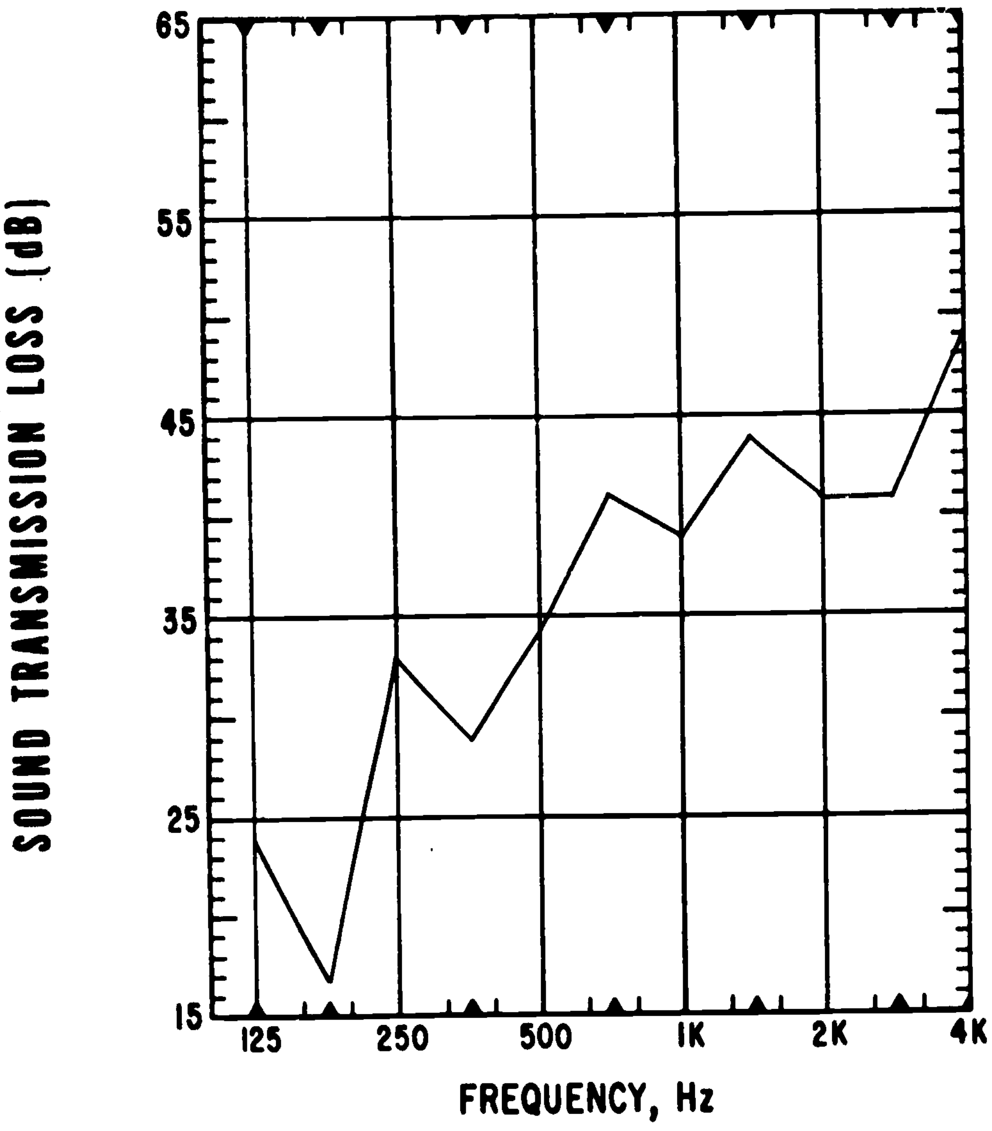
Area weight: approximately 9 lb/ft^2 (Not specified in reference.)

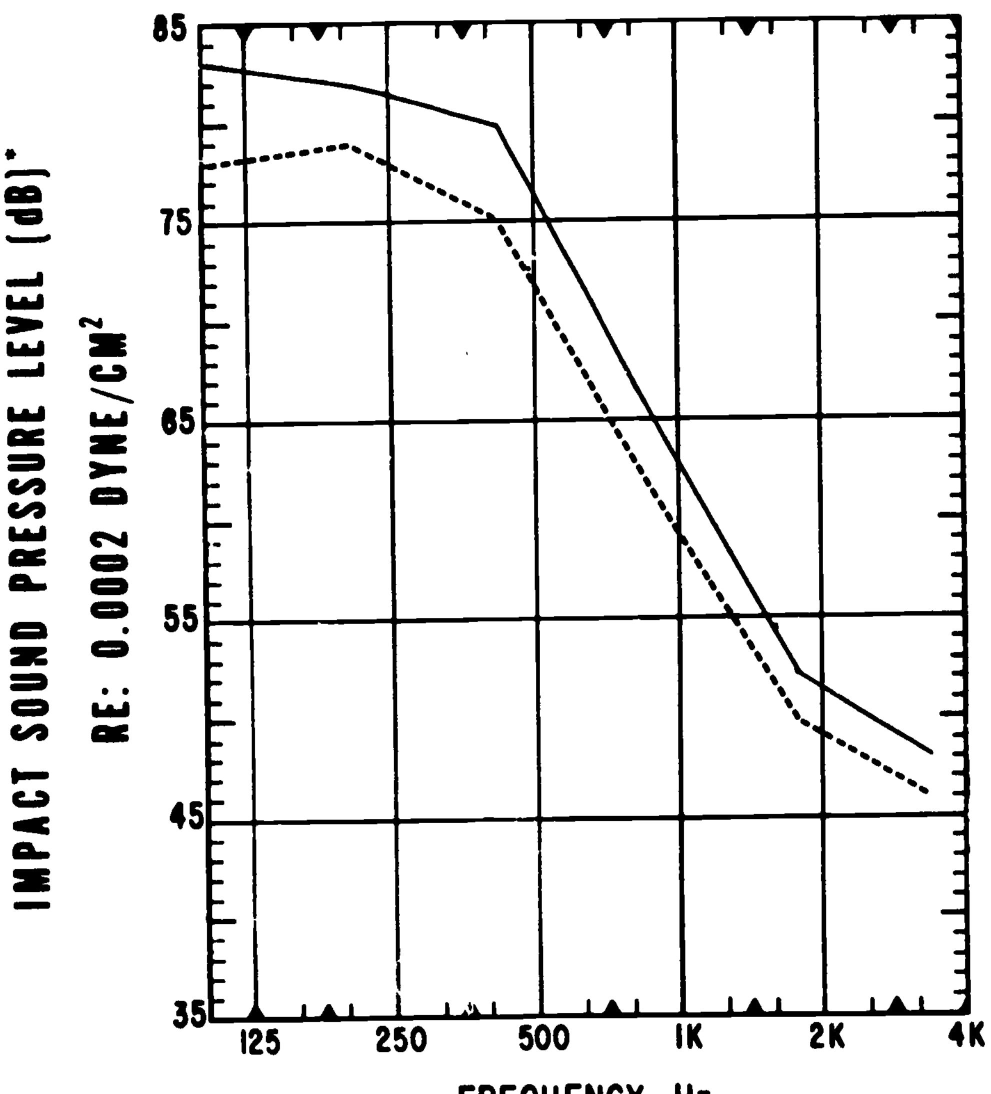


(a) ———— STC = 35; IIC = 39; Fire Rating: 1/2 hr. (est.) - combustible

(b) ············ IIC = 43

REMARKS: The STL measurements were made without the hardboard, felt paper and tile. See F-37 for variation in floor covering.





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST, CARPET AND PAD

TEST REF: (a) 3-(723-B); (b) 3-(724-B)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers. On the floor side, 1 11/32- by 23 1/4-in. compressed homogeneous paper pulp building board (approximate density 26.1 lb/ft^3) nailed 8 in. on centers perpendicular to the joists; building board covered with a foam rubber carpet pad and nylon carpet. The carpet pad had an uncompressed thickness of 1/4 in., backed with a woven jute fiber cloth. The nylon carpet had 1/8-in.-thick woven backing and 1/4-in.-thick looped pile spaced 7 loops per inch with a total thickness of 3/8 in. On the ceiling side, 1/2-in. gypsum wallboard nailed 12 in. on centers.

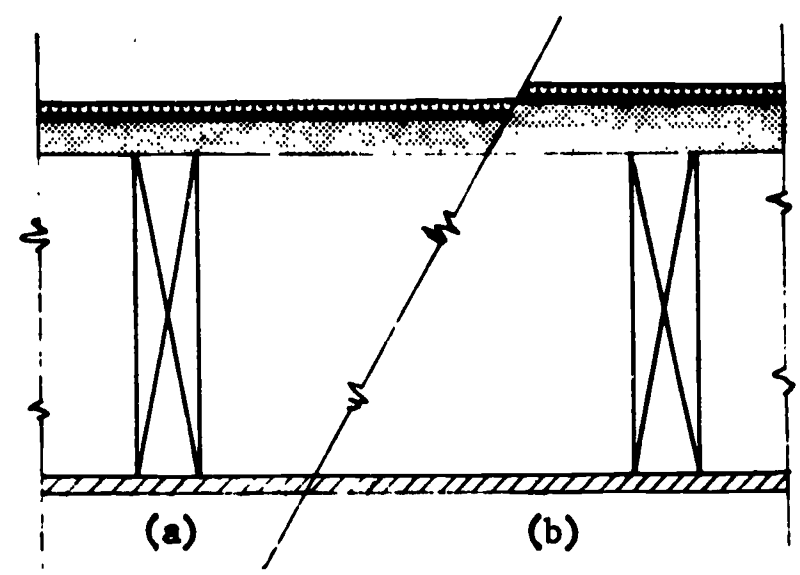
Total thickness: 12 1/2 in.

Area weight: 9.2 lb/ft^2

(b) Similar to (a) except the wood joists were 24 in. on centers and the building board was 1 27/32 in. thick.

Total thickness: 13 in.

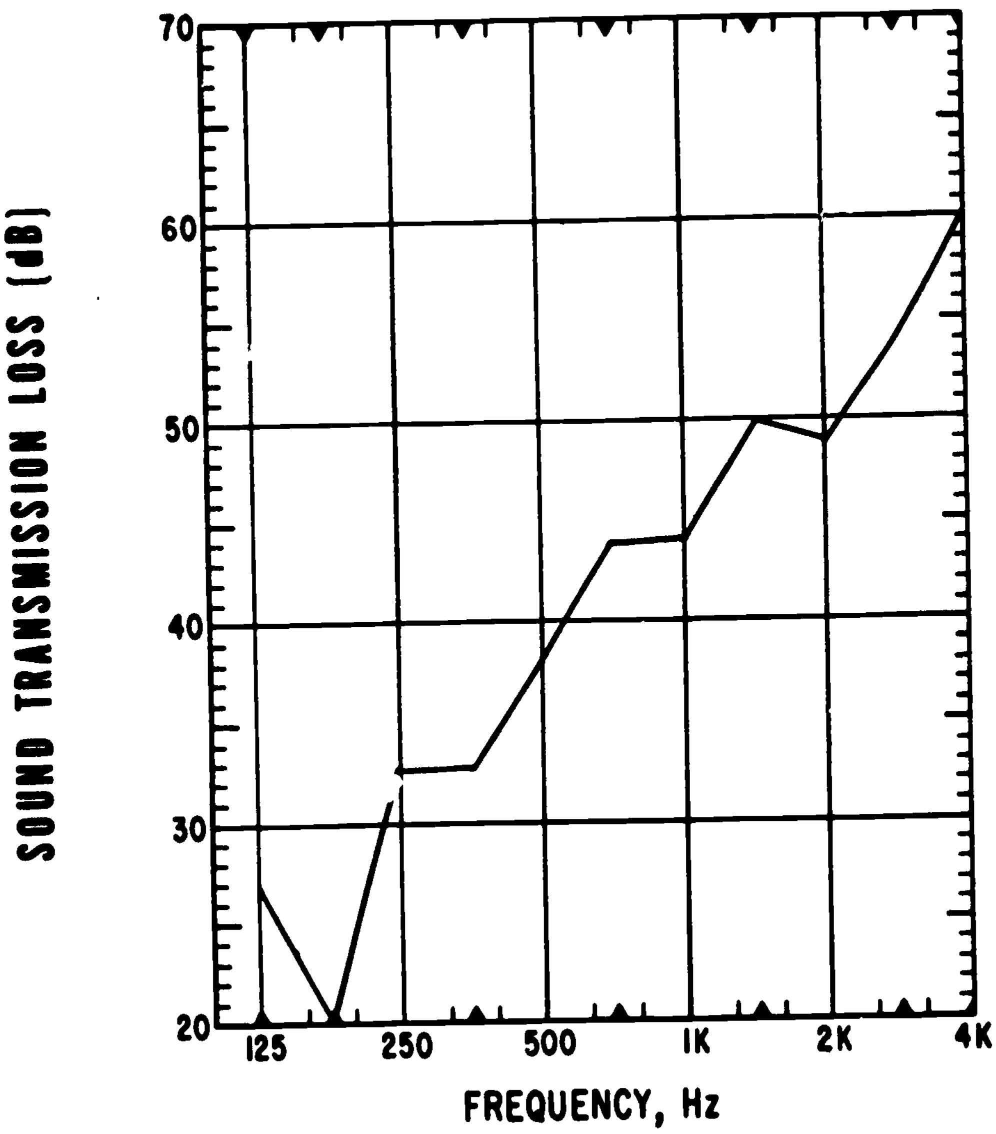
Area weight: approximately 10 lb/ft^2 (Not specified in reference.)

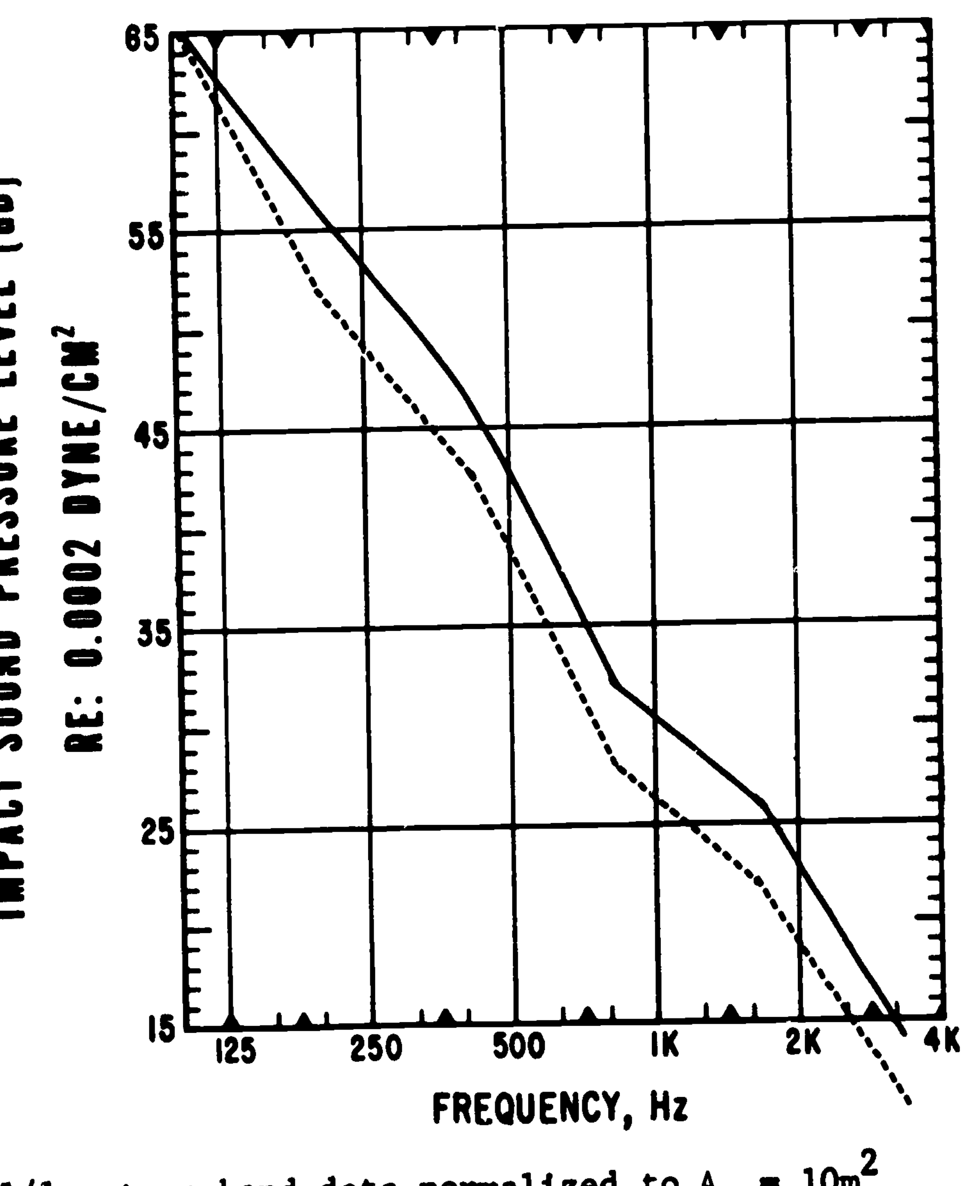


(a)———————STC = 38; IIC = 57; Fire Rating: 1/2 hr. (est.) - combustible

(b)---------------- IIC = 57

REMARKS: See F-36 for variation in floor covering.





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST

TEST REF: (a) 3-(728-A); (b) 3-(728-B)

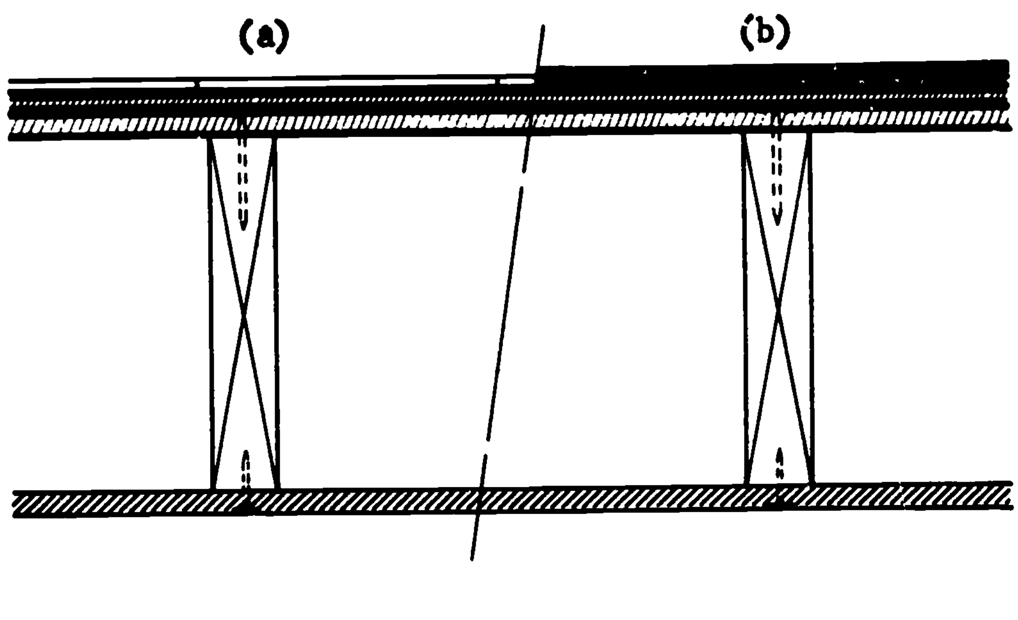
DESCRIPTION: (a) 2- by 10-in. wooden floor joists spaced 16 in. on centers. 5/8-in. fir plywood subfloor nailed to joists 8 in. on centers; 1/2-in. plywood underlayment nailed to subfloor with joints staggered to miss joints of the subfloor; 1/8- by 9- by 9-in. vinyl asbestos tile glued to underlayment. On the ceiling side, 1/2-in. gypsum wallboard nailed 12 in. on centers with all joints and nailheads taped and finished.

Total thickness: 11 3/4 in.

Area weight: 9.0 lb/ft^2

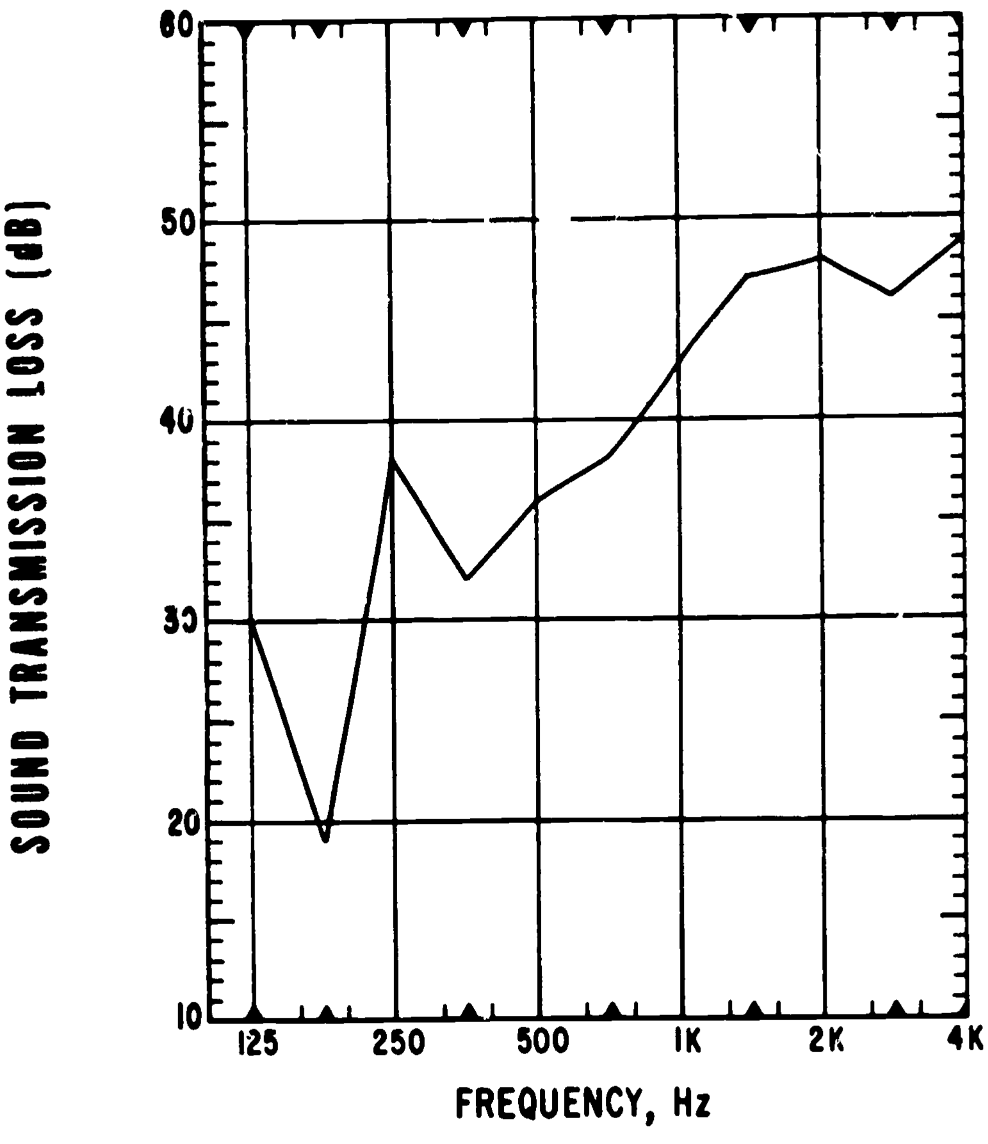
(b) Similar to (a), except a 1/4-in.-thick foam rubber pad and 3/8-in.-thick nylon loop carpet replaced vinyl asbestos tile. The rubber pad was backed with a woven jute fiber cloth and was perforated to approximately half its depth with holes 1/8 in. in diameter and spaced 3/4 in. on centers. The carpet had 1/8-in. woven backing and 1/4-in. looped pile spaced 7 loops per inch.

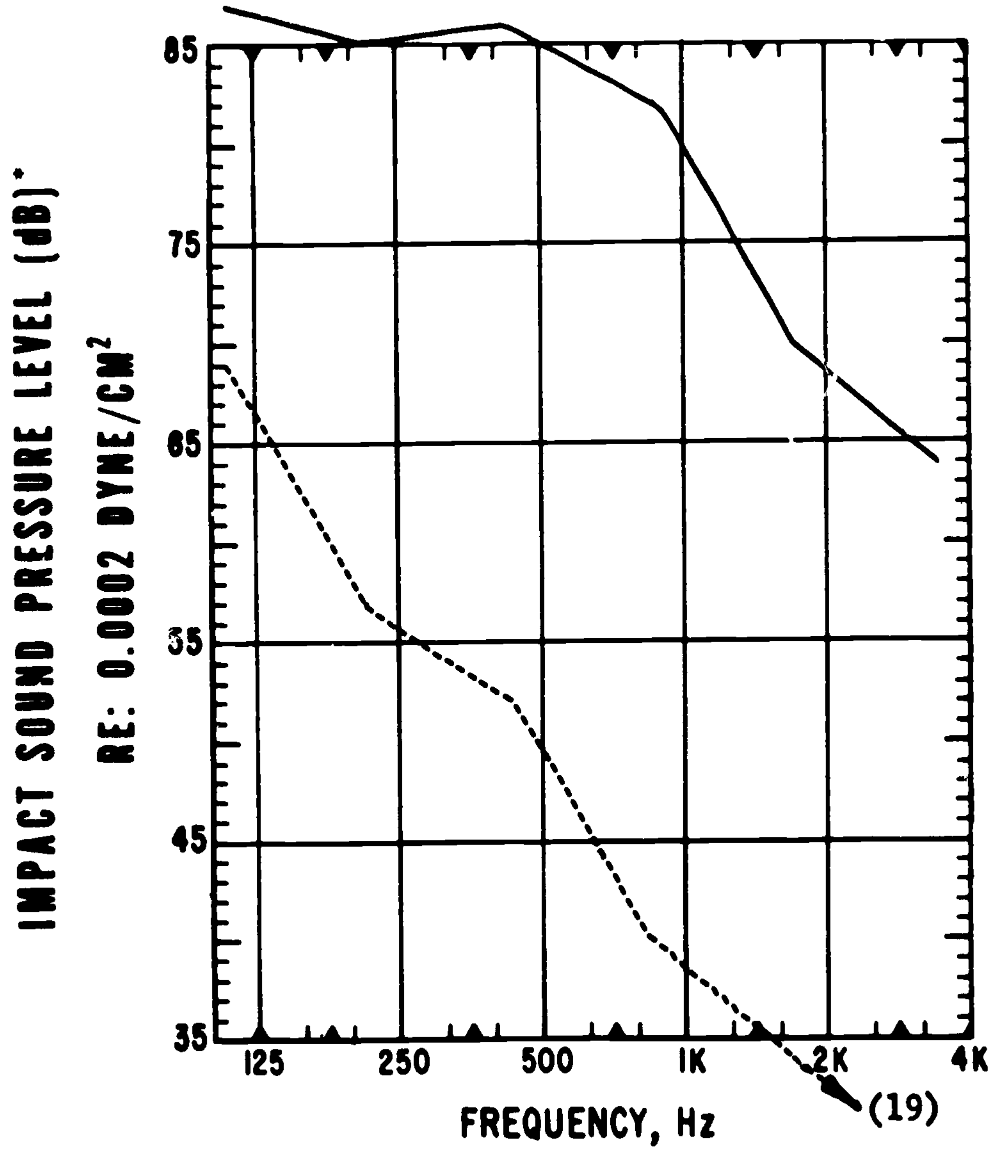
Total thickness: 12 1/4 in.



(a) ——— STC = 37; IIC = 33; Fire Rating: 1/2 hr. (est.) - combustible

(b) ——— IIC = 53





*1/1 octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST

TEST REF: (a) 13-(6412-7); (b) 13-(6412-10)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers. On the floor side, 1/2-in.-thick plywood subfloor nailed 6 in. on centers along edges and 10 in. on centers in field, building paper underlayment, 25/32- by 2 1/4-in. oak wood flooring nailed at each joist intersection and midway between joists. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed 6 in. on centers to joists; all joints taped and finished.

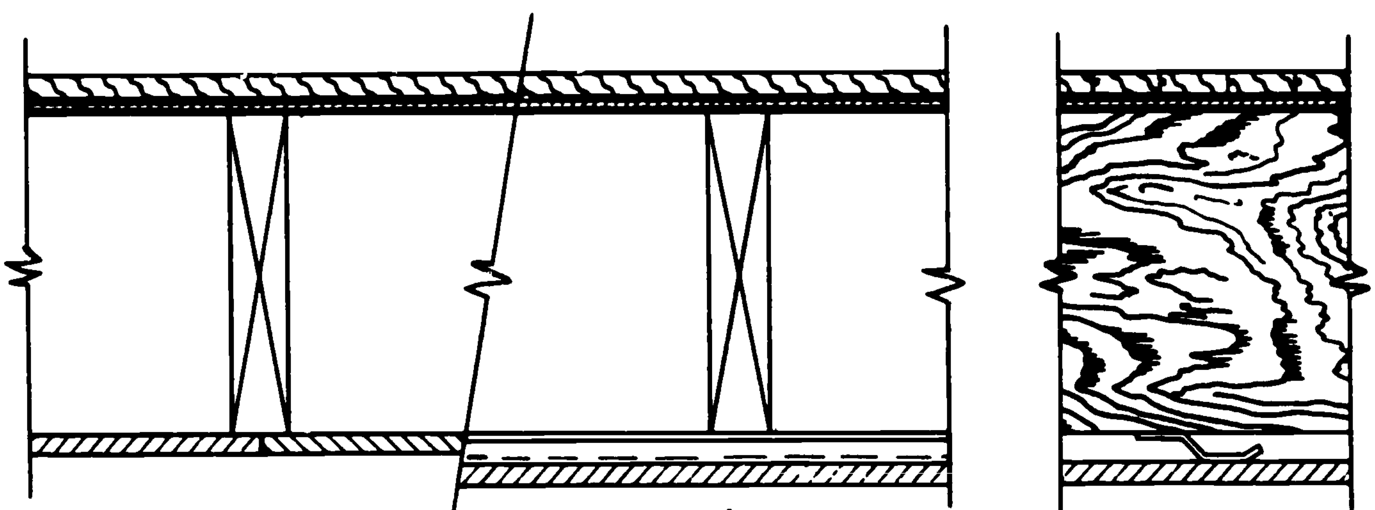
Total thickness: 11 7/8 in.

Area weight: approximately 9.5 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except the gypsum wallboard was screwed 12 in. on centers to resilient channels spaced 24 in. on centers perpendicular to joists.

Total thickness: approximately 12 3/8 in.

Area weight: approximately 9.6 lb/ft^2 (Not specified in reference.)

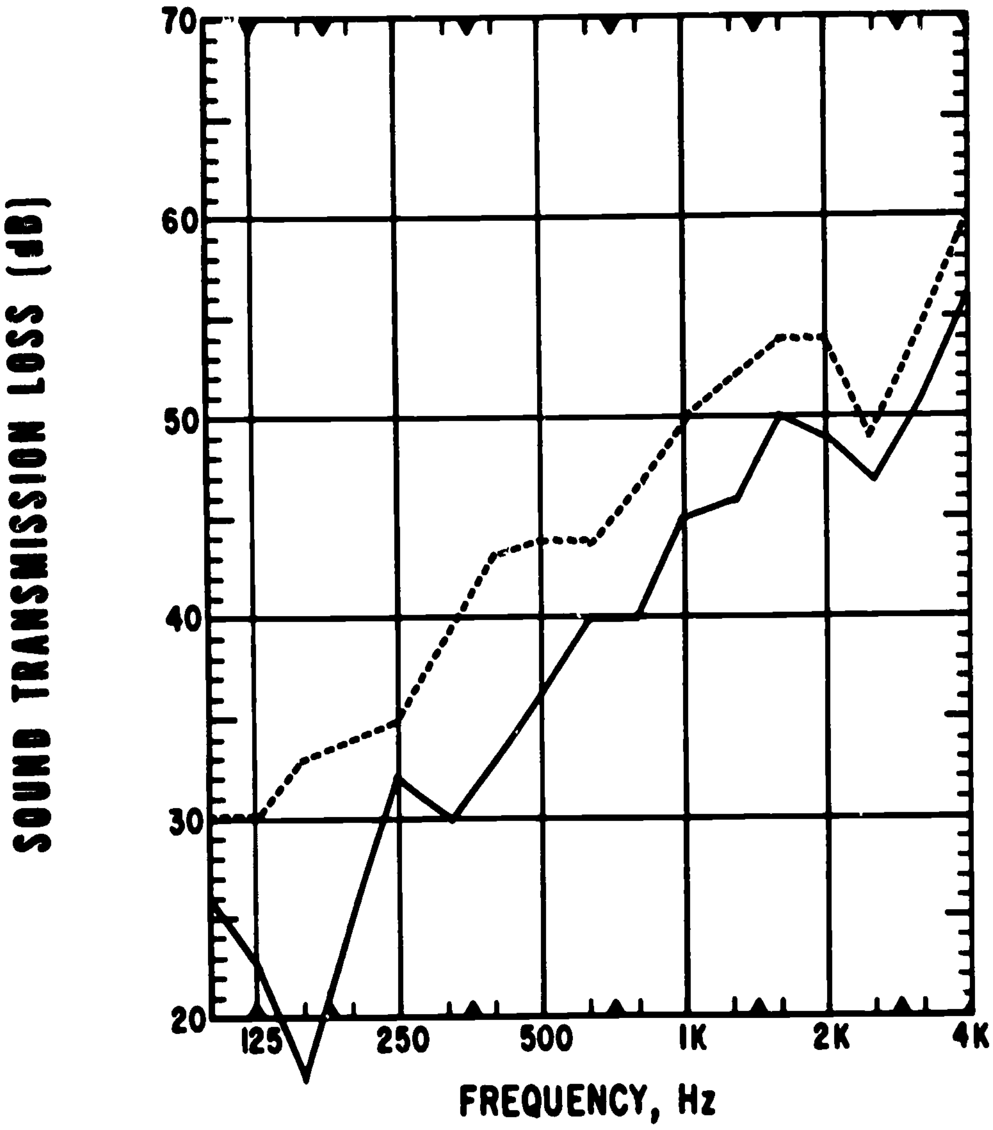


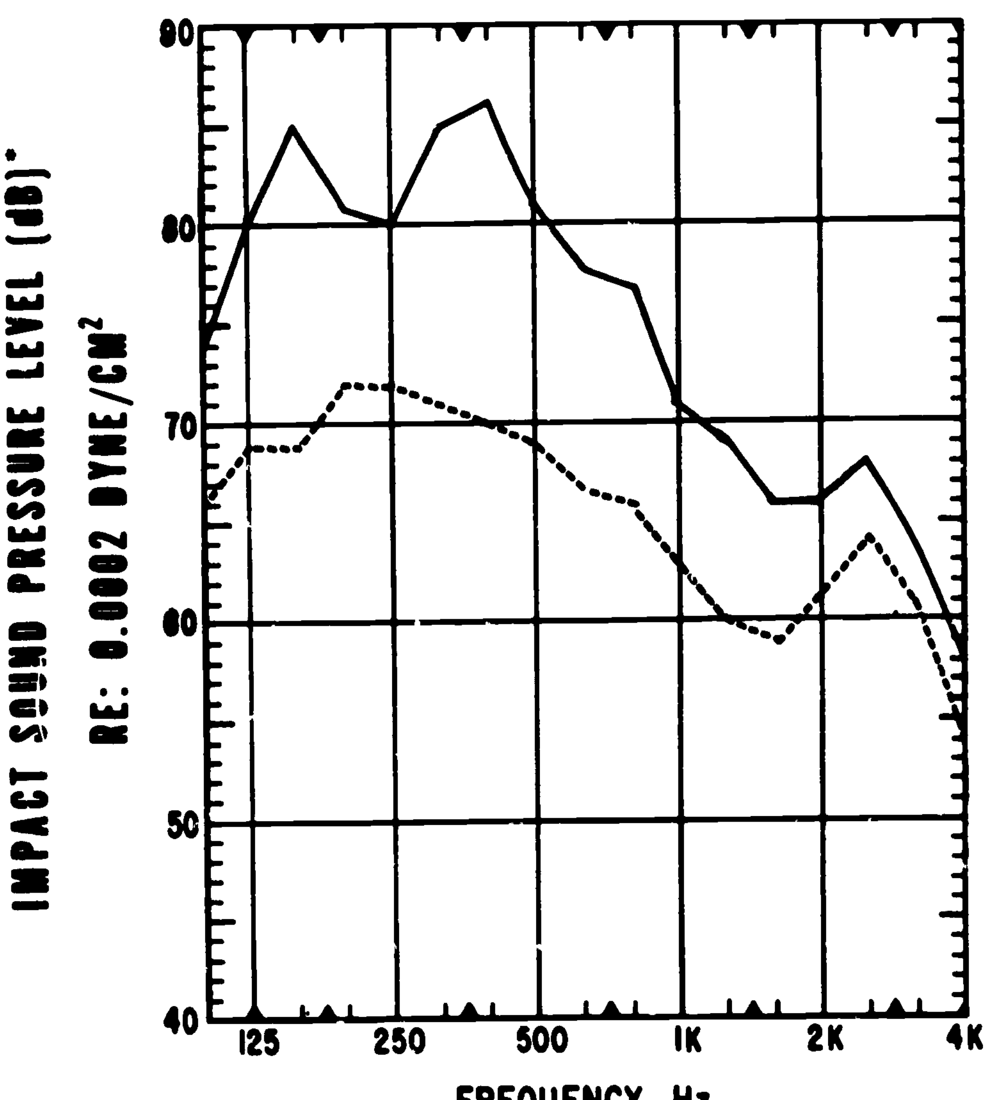
(a) (b)

(a)———————STC = 37; IIC = 32; Fire Rating: 1 hr. (est.) - combustible

(b)··············STC = 47; IIC = 39; Fire Rating: 1 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_0 = 10m^2$

TYPE: WOODEN JOIST WITH INSULATION

TEST REF: (a) 13-(6412-6); (b) 13-(6412-3)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers with 3-in.-thick mineral fiber batts stapled between joists. On the floor side, 1/2-in.-thick plywood subfloor nailed 6 in. on centers along edges and 10 in. on centers in field, building paper underlayment, 25/32- by 2 1/4-in. oak wood flooring nailed at each joist intersection and midway between joists. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed 6 in. on centers to joists; all joints taped and finished.

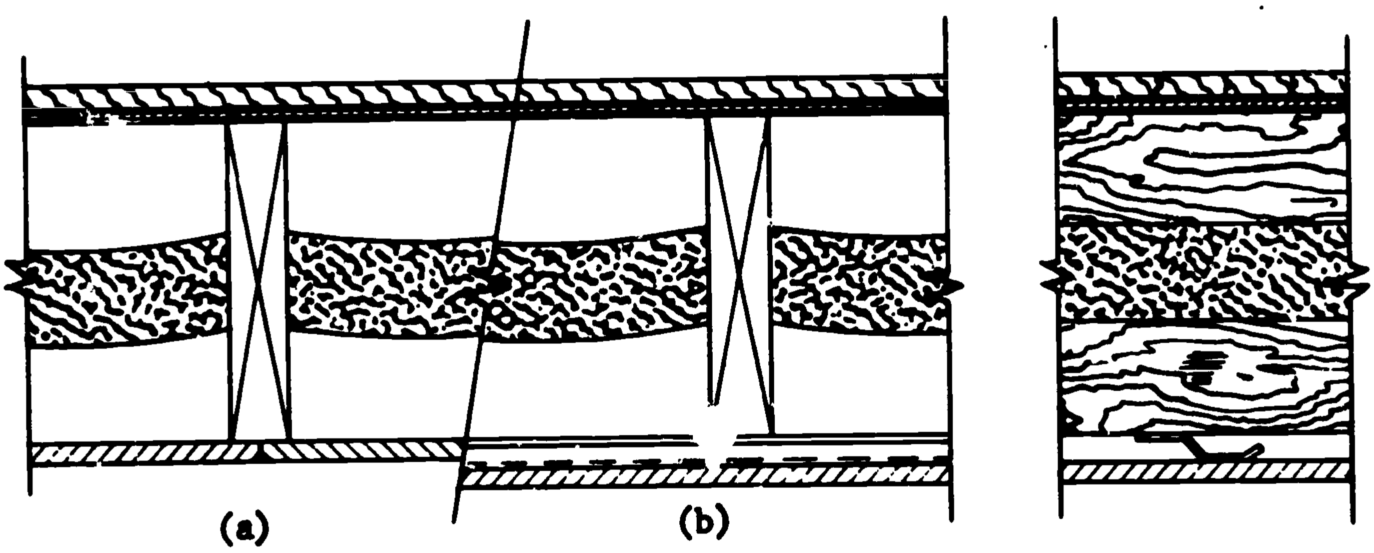
Total thickness: 11 7/8 in.

Area weight: approximately 10.0 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except the gypsum wallboard was screwed 12 in. on centers to resilient channels spaced 24 in. on centers perpendicular to joists.

Total thickness: approximately 12 3/8 in.

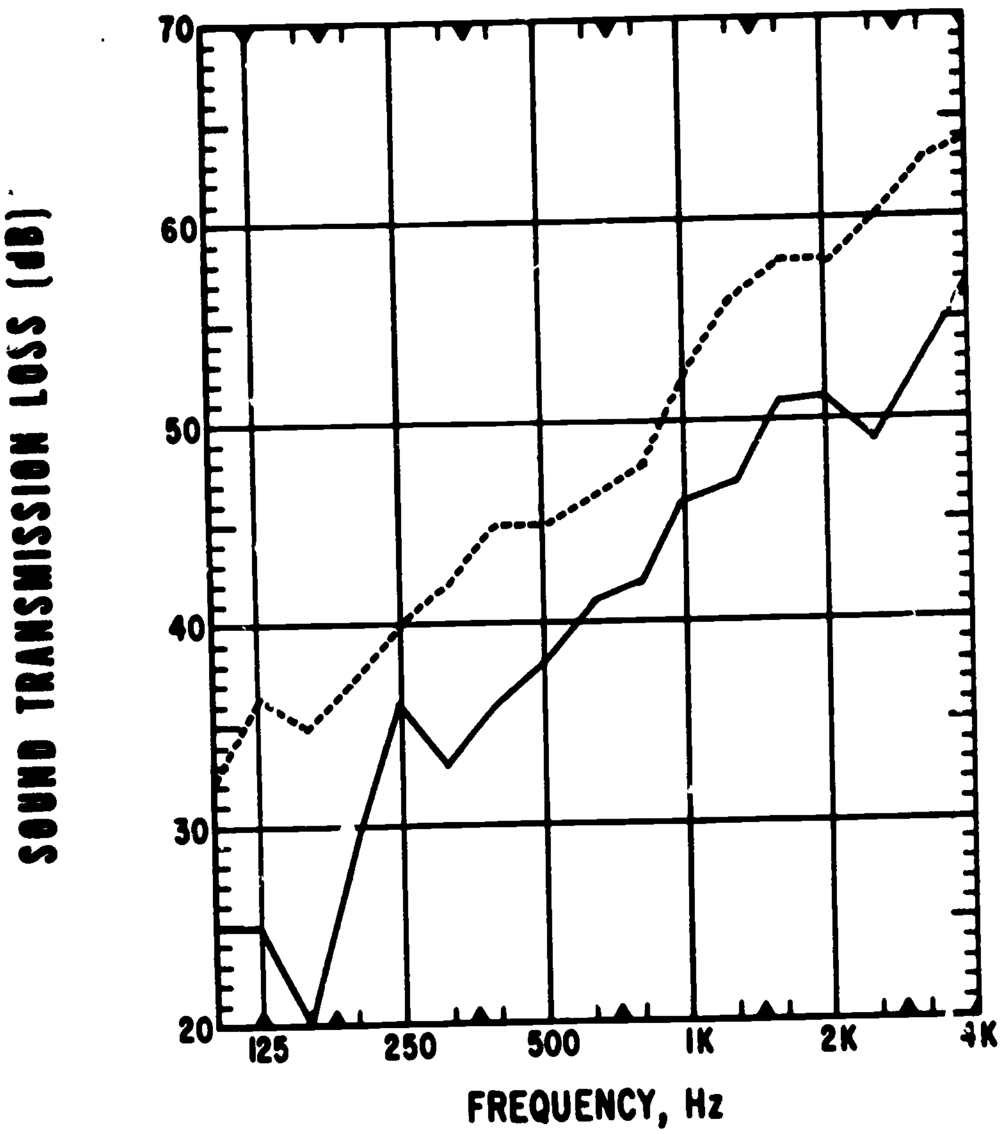
Area weight: approximately 10.1 lb/ft^2 (Not specified in reference.)

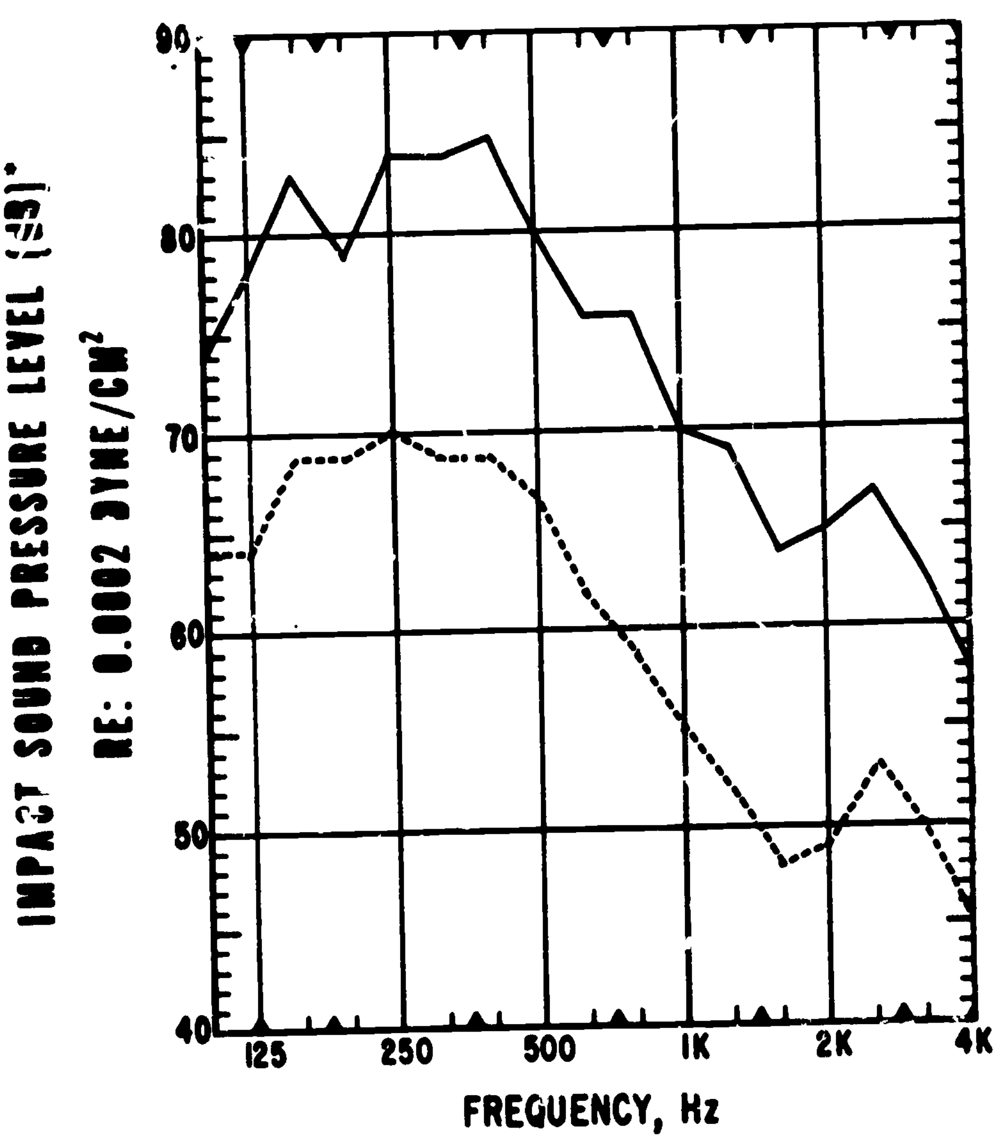


(a)———————STC = 40; IIC = 32; Fire Rating: 1 hr. (est.) - combustible

(b)··················STC = 49; IIC = 46; Fire Rating: 1 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST, CARPET AND PAD

TEST REF: (a) 13-(6412-8); (b) 13-(6412-9)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers. On the floor side, 1/2-in.-thick plywood subfloor nailed 6 in. on centers along edges and 10 in. on centers in field, building paper underlayment, 25/32- by 2 1/4-in. oak wood flooring nailed at each joist intersection and midway between joists; carpet, 44 oz/yd^2, with hair felt pad, 40 oz/yd^2, placed on wood flooring. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed 6 in. on centers to joists; all joints taped and finished.

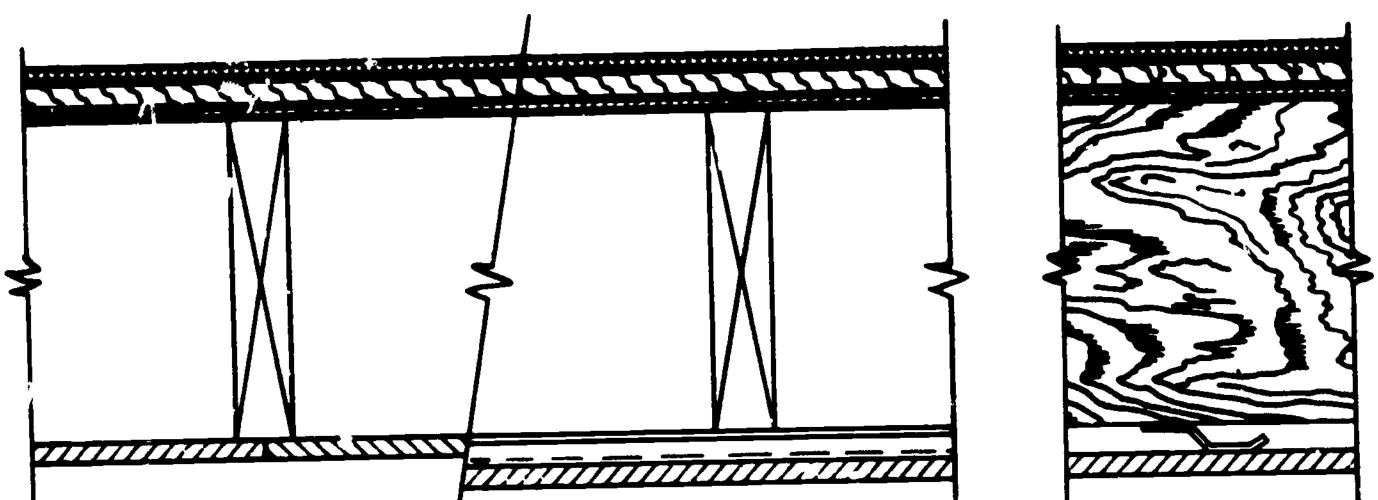
Total thickness: approximately 12 1/2 in.

Area weight: approximately 10.0 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except the gypsum wallboard was screwed 12 in. on centers to resilient channels spaced 24 in. on centers perpendicular to joists.

Total thickness: approximately 13 in.

Area weight: approximately 10.1 lb/ft^2 (Not specified in reference.)

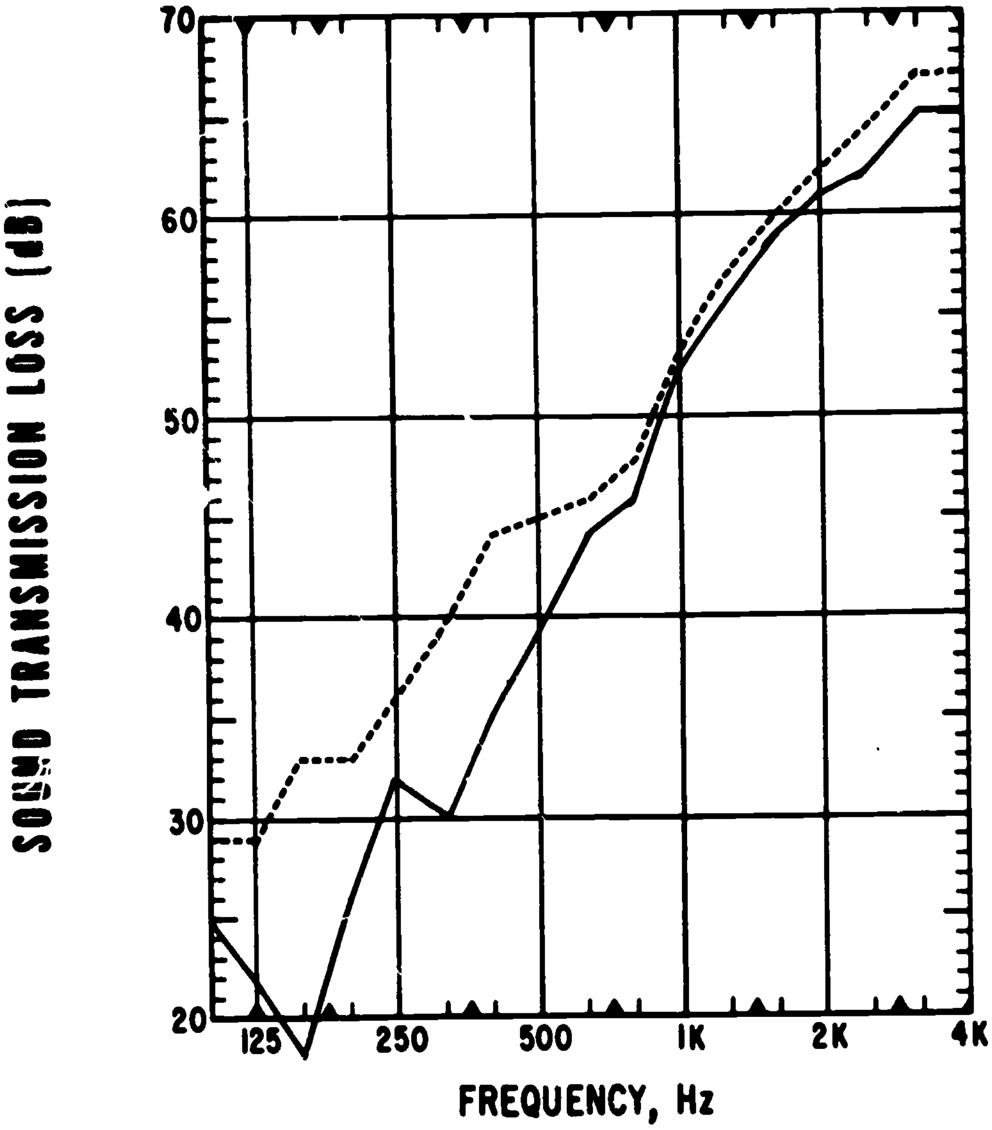


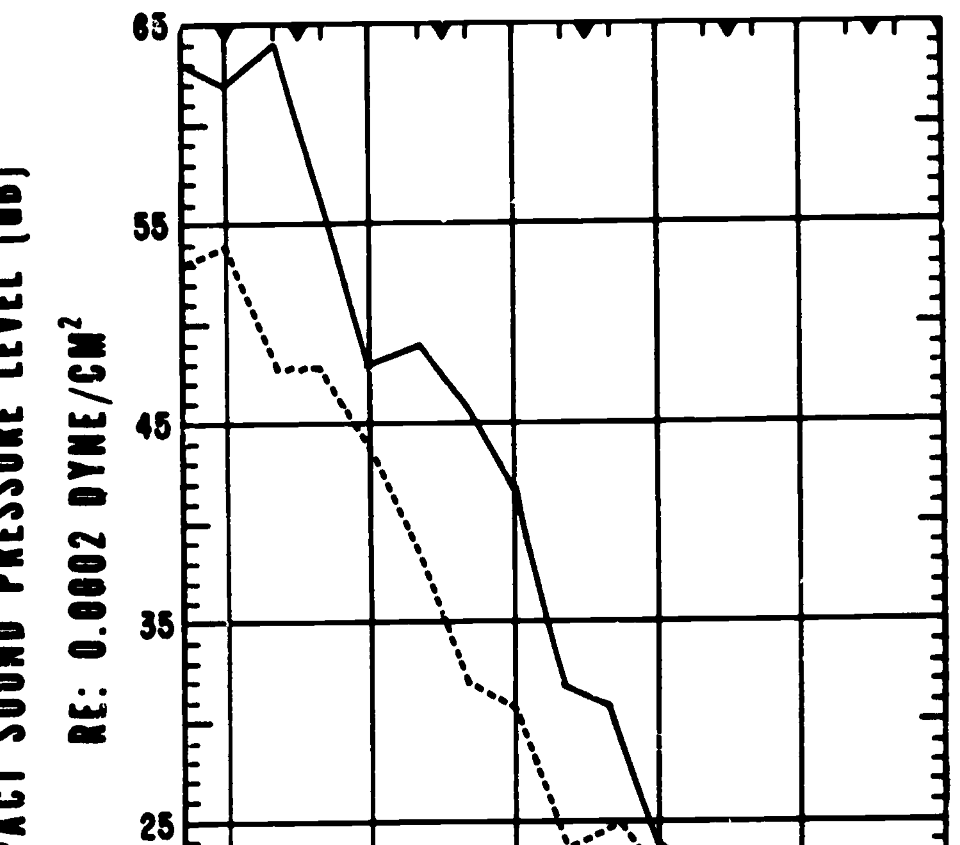
(a) (b)

(a)———————STC = 38; IIC = 56; Fire Rating: 1 hr. (est.) - combustible

(b)-----------------STC = 47; IIC = 66; Fire Rating: 1 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to A_o = $10m^2$

TYPE: WOODEN JOIST WITH INSULATION, CARPET AND PAD

TEST REF: (a) 13-(6412-5); (b) 13-(6412-4)

DESCRIPTION: (a) 2- by 10-in. wooden joists 16 in. on centers with 3-in.-thick mineral fiber batts stapled between joists. On the floor side, 1/2-in.-thick plywood subfloor nailed 6 in. on centers along edges and 10 in. on centers in field, building paper underlayment, 25/32- by 2 1/4-in. oak wood flooring nailed at each joist intersection and midway between joists; carpet, 44 oz/yd^2, with hair felt pad, 40 oz/yd^2, placed on flooring. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed 6 in. on centers to joists; all joints taped and finished.

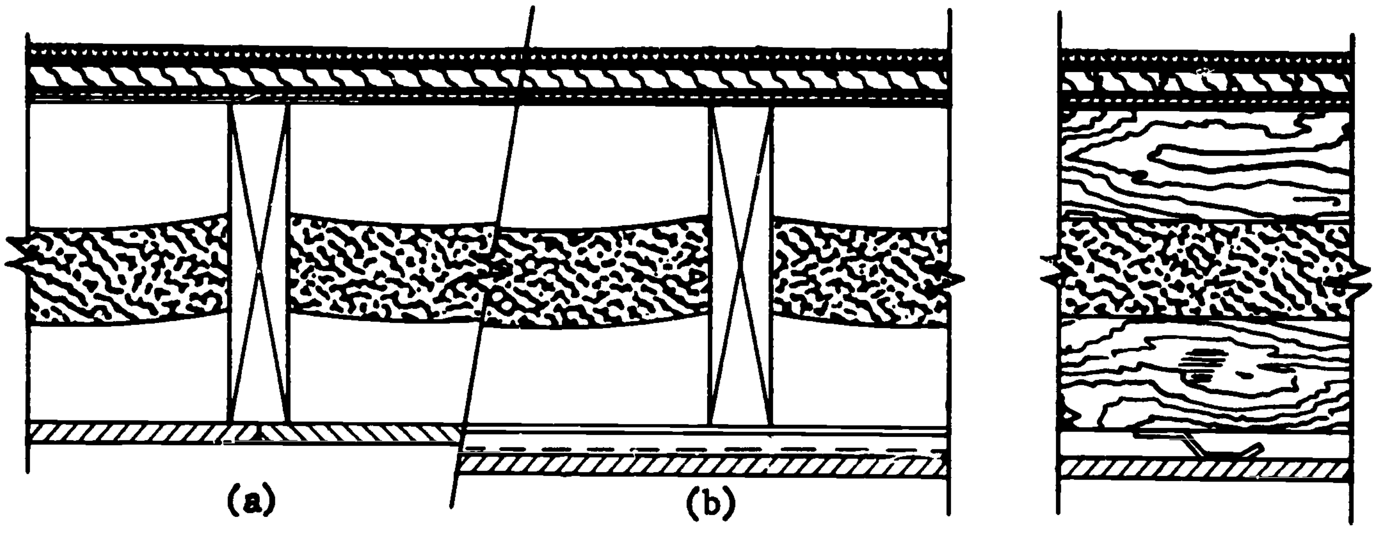
Total thickness: 12 1/2 in.

Area weight: approximately 10.5 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except gypsum wallboard was screwed 12 in. on centers to resilient channels spaced 24 in. on centers perpendicular to joists.

Total thickness: approximately 13 in.

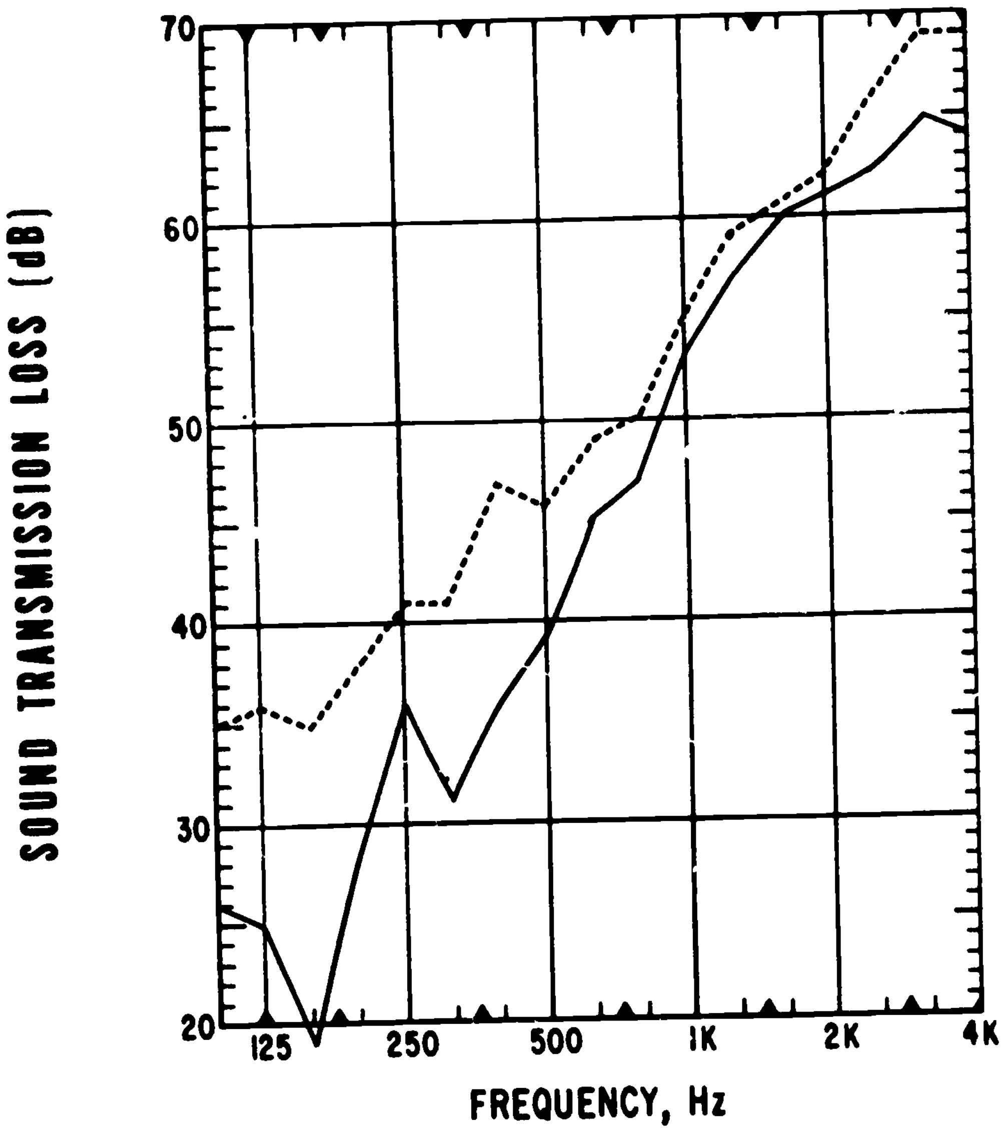
Area weight: approximately 10.6 lb/ft^2 (Not specified in reference.)

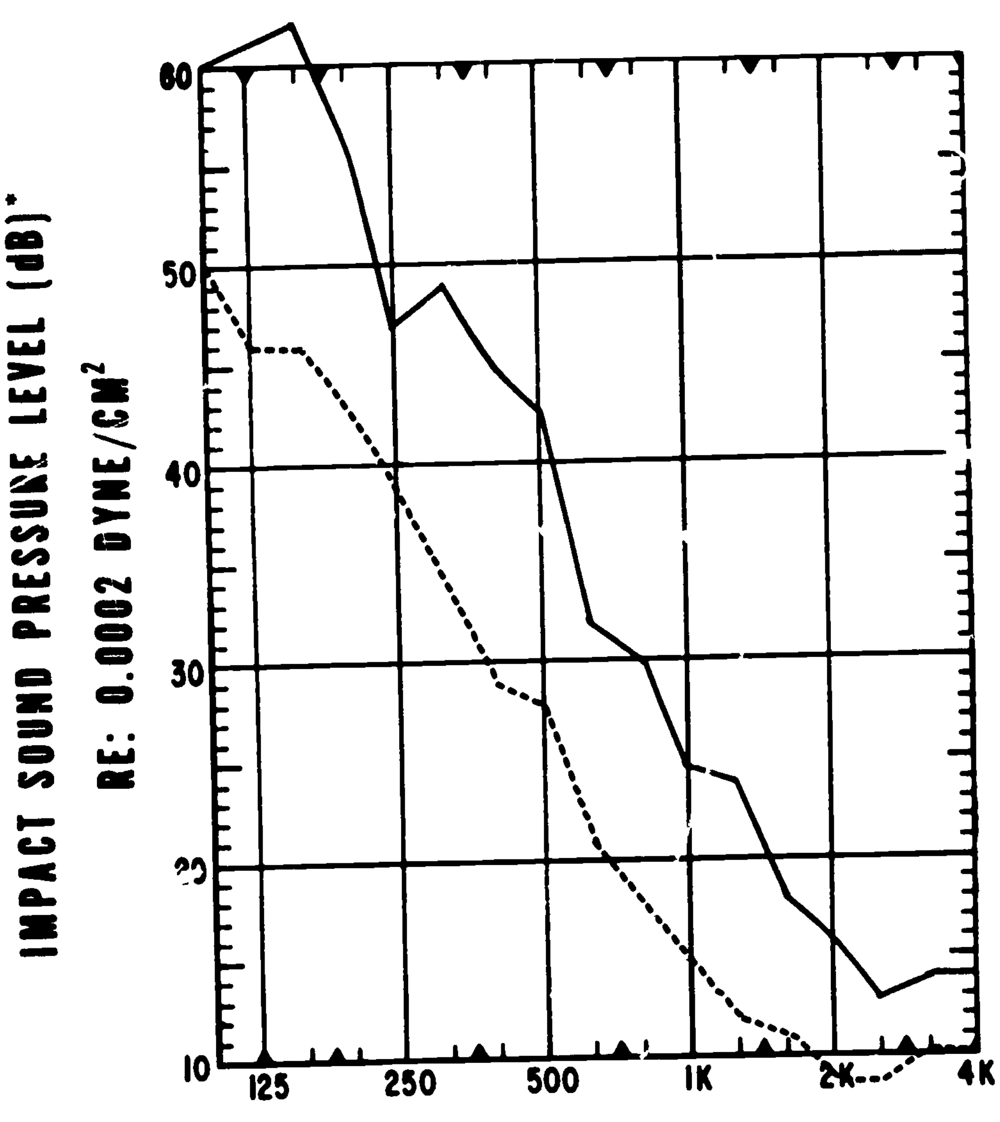


(a)————————STC = 39; IIC = 58; Fire Rating: 1 hr. (est.) - combustible

(b)················STC = 50; IIC = 70; Fire Rating: 1 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

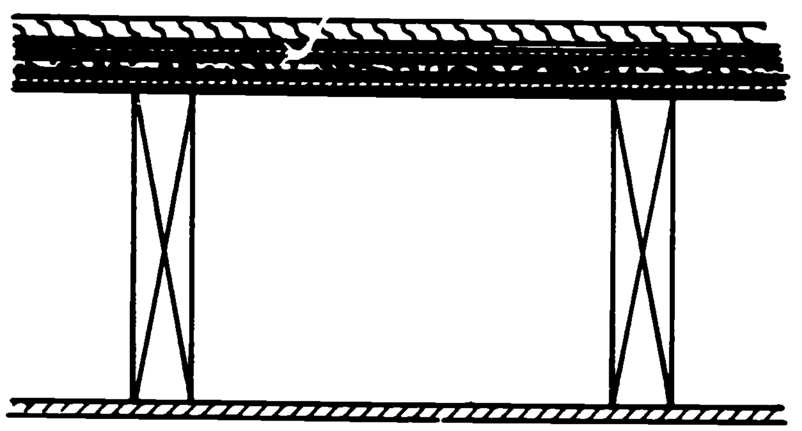
TYPE: WOODEN JOIST

TEST REF: 6-(WIT 3)

DESCRIPTION: 2- by 10-in. wooden joists 16 in. on centers. On the floor side, 1/2-in.-thick plywood subfloor nailed 6 in. on centers to joists, approximately 3/8-in.-thick fibered glass board adhered to plywood subfloor, 1/2-in.-thick tongue-and-groove plywood underlayment stapled 12 in. on centers along the joints; approximately 1/2-in.-thick oak wood flooring on plywood underlayment. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 6 in. on centers to joists. Joints of gypsum board taped and finished.

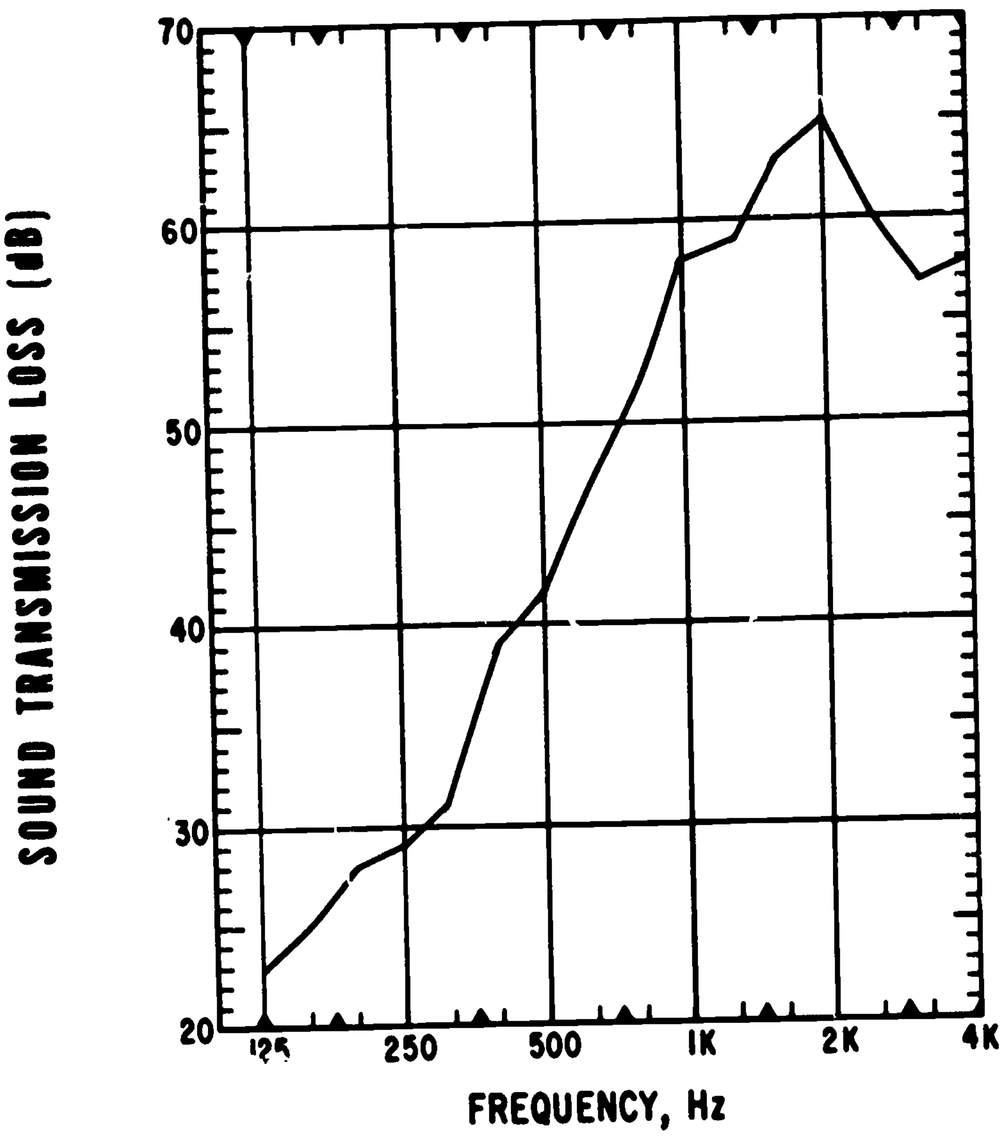
Total thickness: 12 3/8 in.

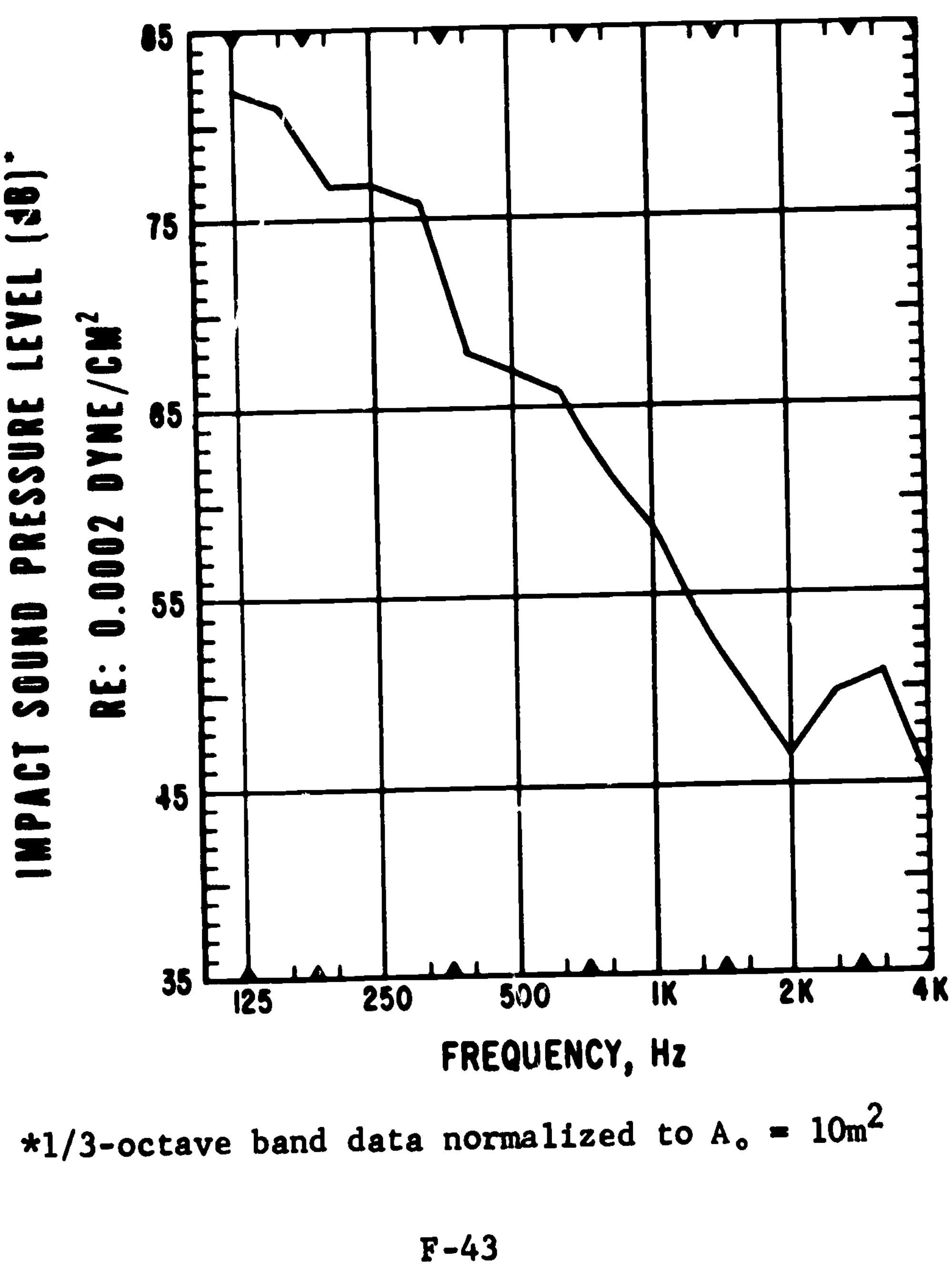
Area weight: 10.7 lb/ft^2



STC = 41; IIC = 38; Fire Rating: 45 min. (est.) - combustible

REMARKS: Our information indicates some slight differences between individual structures measured for airborne and impact sound insulation respectively; however, these differences should not affect the results significantly.





*1/3-octave band data normalized to $A_o = 10m^2$

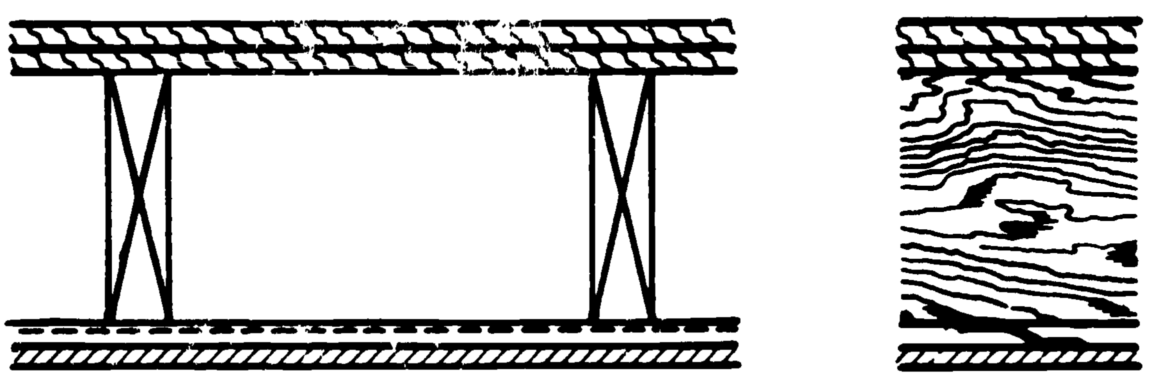
TYPE: WOODEN JOIST, RESILIENT CEILING

TEST REF: 3-(717)

DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 3/4-in.-thick wood subfloor, a layer of building paper, and 3/4-in.-thick tongue-and-groove fir finish flooring. On the ceiling side, resilient runners bridged across joists and nailed 12 in. on centers to the joists; 5/8-in.-thick gypsum wallboard screwed to resilient runners, with all joints taped and finished.

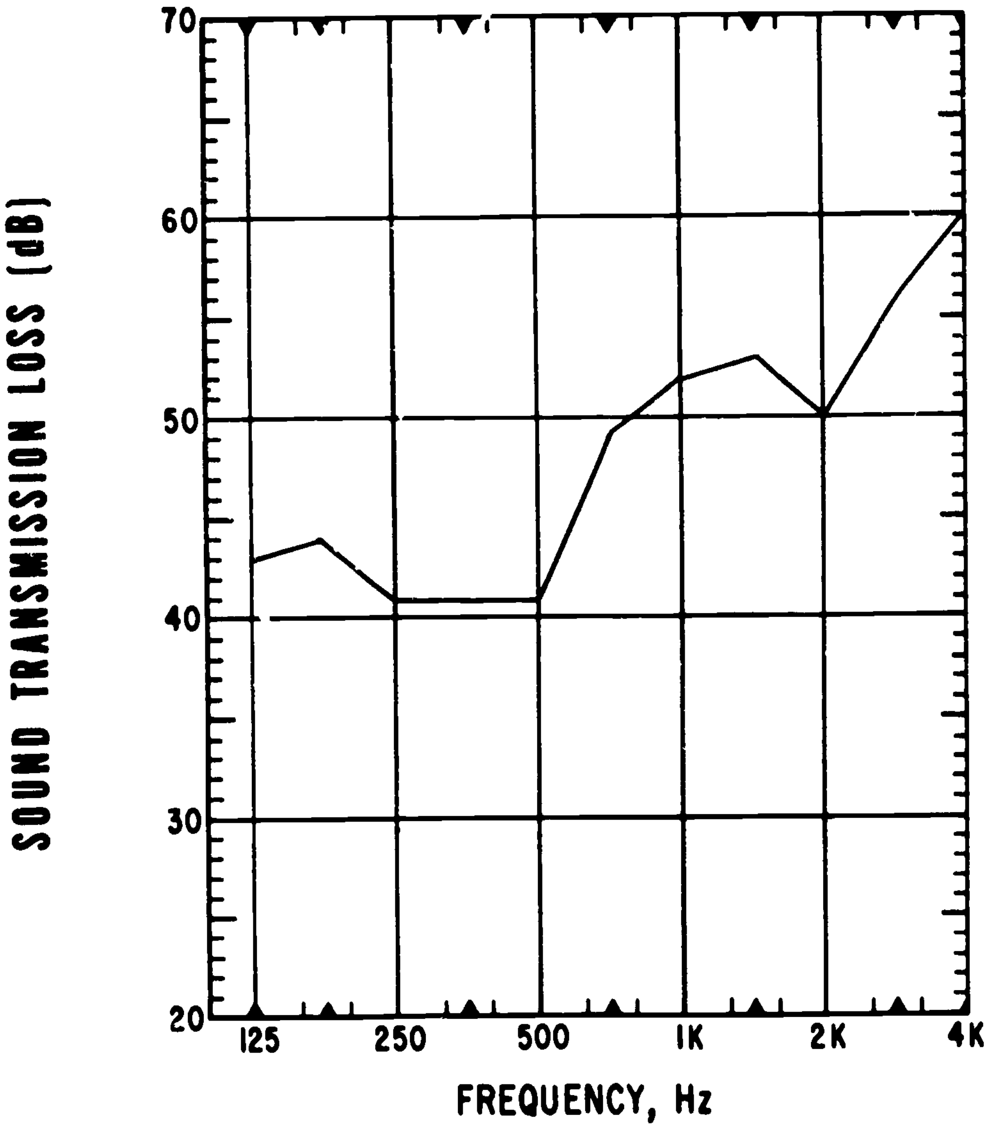
Total thickness: approximately 10 1/2 in.

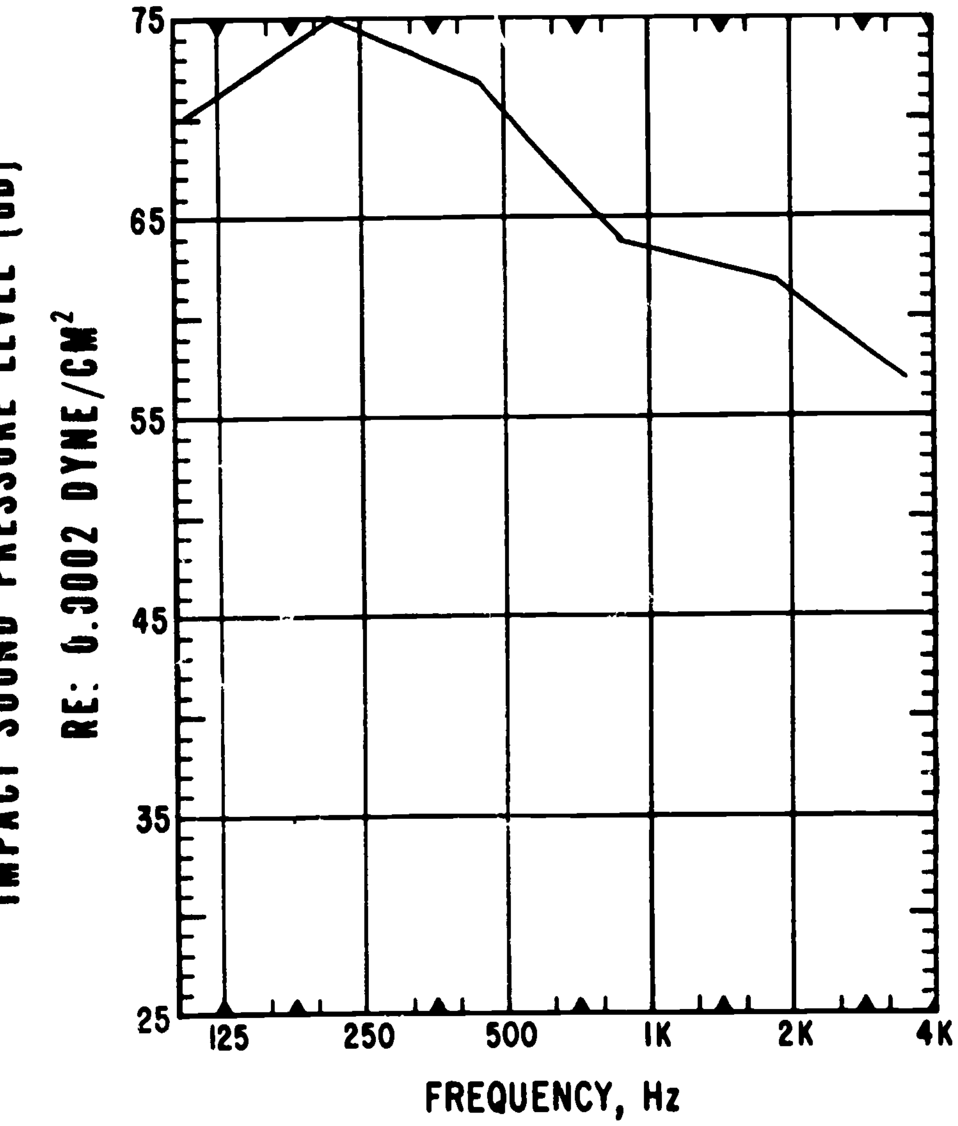
Area weight: 10.1 lb/ft^2



STC = 45; IIC = 44; Fire Rating: 45 min. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST WITH INSULATION, RESILIENT CEILING

TEST REF: (a) 8-(224-2-65, 224-1-65); (b) 8-(224-4-65, 224-3-65)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers with 3-in.-thick fibered glass blankets stapled between joists. On the floor side, 5/8-in. tongue-and-groove, C-D plugged plywood nailed 6 in. on centers along periphery and 10 in. on centers at other bearings, 3/8-in.-thick A-C plywood underlayment stapled 6 in. on centers, 0.075-in.-thick vinyl sheet floor covering. On the ceiling side, resilient channels 24 in. on centers screwed perpendicular to joists, 5/8-in. gypsum board screwed 12 in. on centers to channels. All joints taped and finished with the entire periphery caulked and sealed.

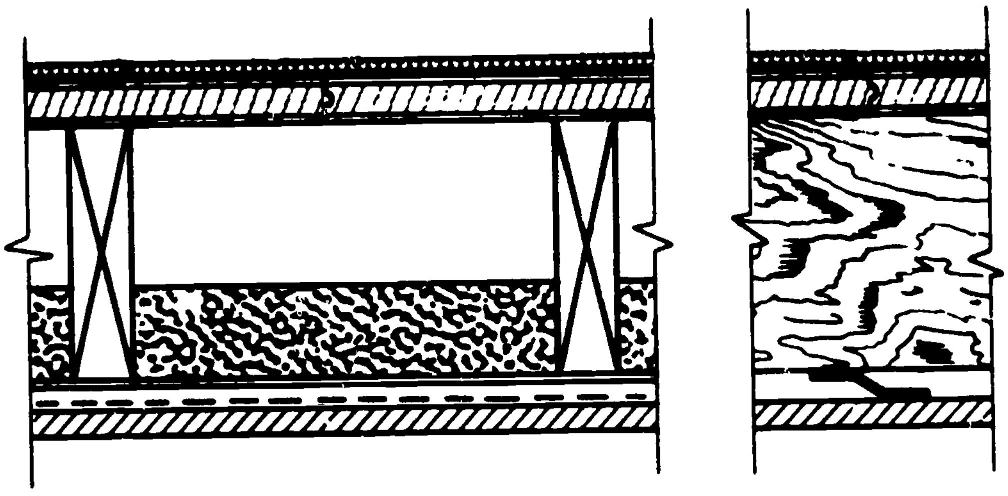
Total thickness: approximately 10 1/8 in.

Area weight: 8.9 lb/ft^2

(b) Similar to (a) except the 3/8-in. plywood underlayment and vinyl sheet were replaced with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in.

Total thickness: approximately 10 1/2 in.

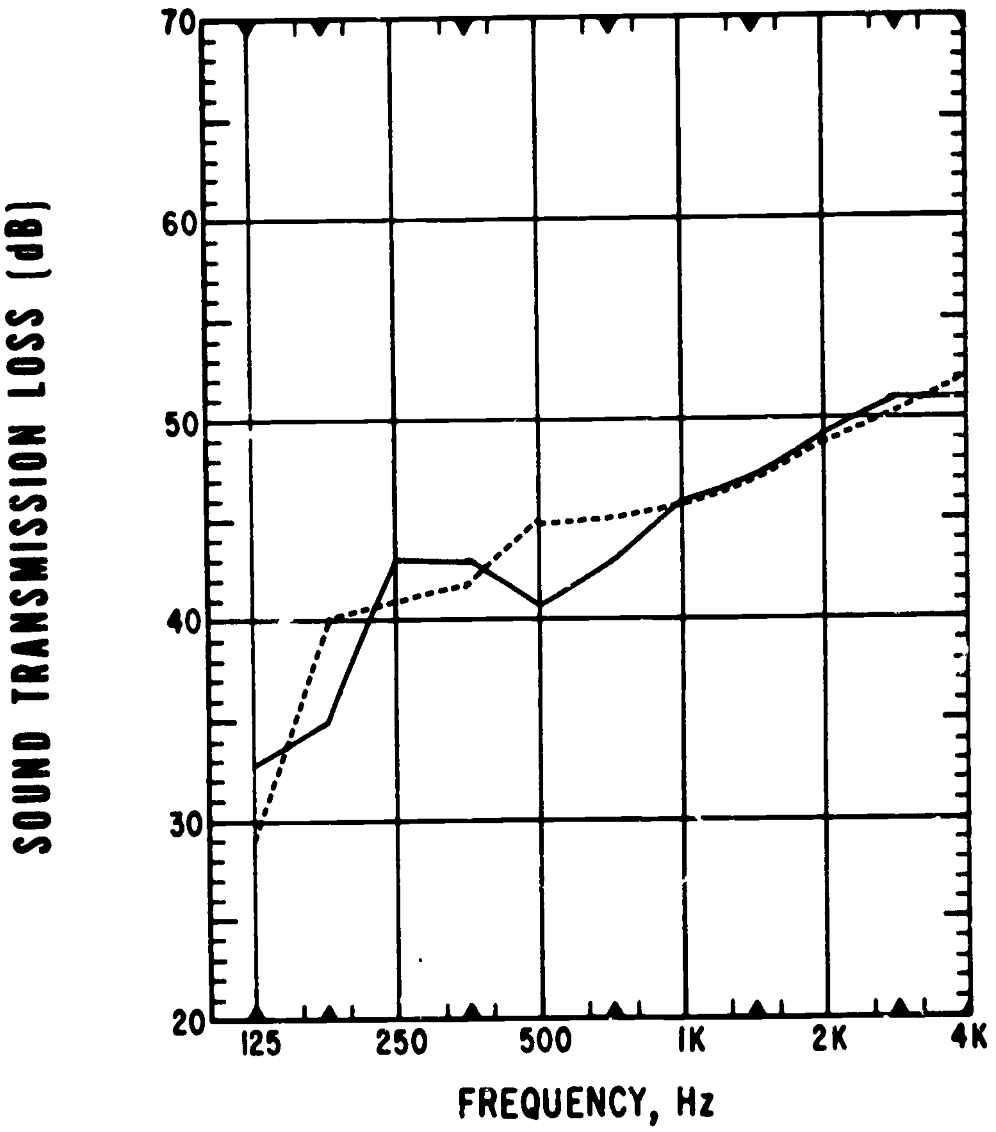
Area weight: 8.6 lb/ft^2

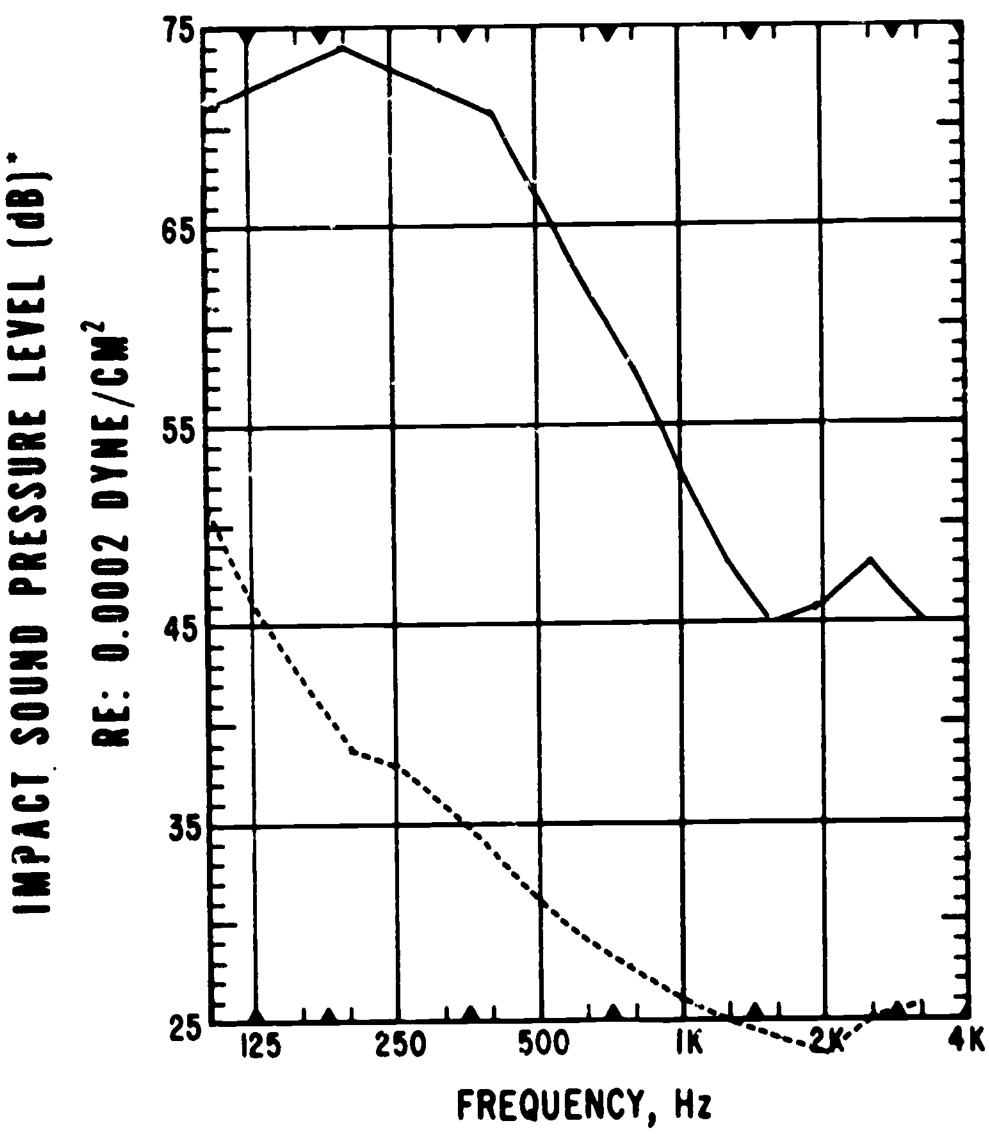


(a) ———— STC = 45; IIC = 44; Fire Rating: 1 hr. (est.) - combustible

(b) ··········· STC = 47; IIC = 69; Fire Rating: 1/2 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installments cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

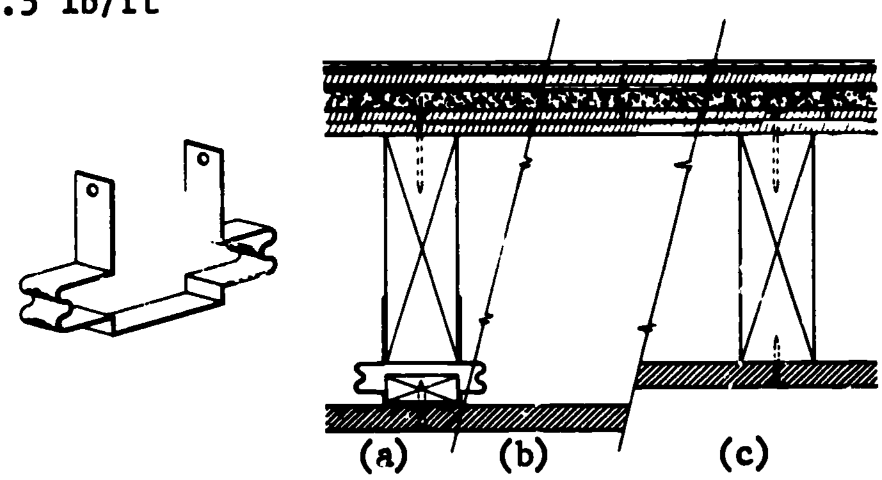
TYPE: WOODEN JOIST, RESILIENT CEILING

TEST REF: (a) 3-(718); (b) 3-(719); (c) 3-(720)

DESCRIPTION: (a) 2- by 6-in. wooden floor joists 16 in. on centers. On the floor side, 5/8-in.-thick plyscore nailed to joists, 1/2-in.-thick wood fiber board (approximate density 20.0 lb/ft^3) stapled to subfloor, 1/2-in.-thick plywood underlayment glued to fiber board, and 3/32-in.-thick vinyl floor covering. On the ceiling side, resilient clips, 24 in. on centers, held 1- by 2-in. furring strips, parallel with joists, to which 5/8-in. gypsum wallboard was screwed 12 in. on centers; all joints taped and finished.

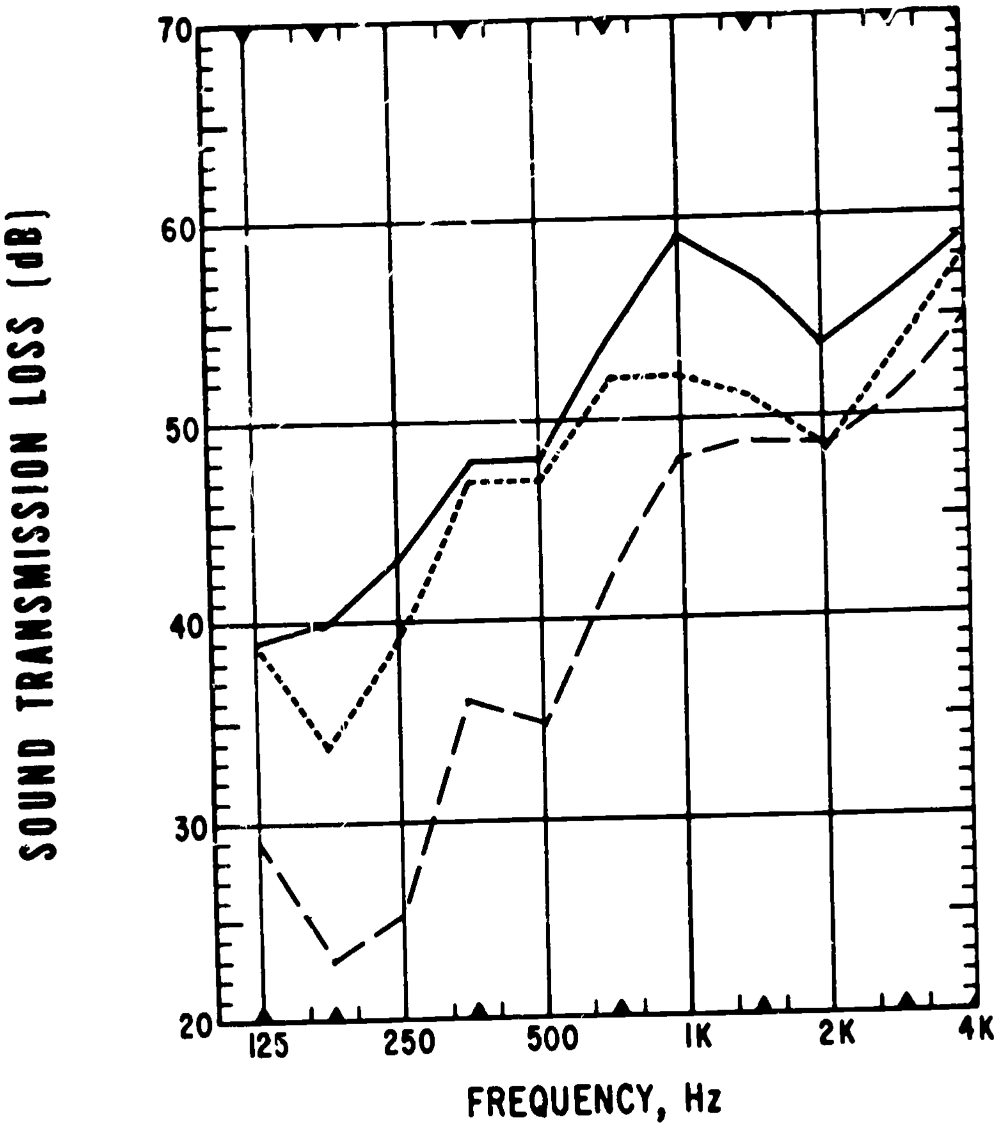
(b) Similar to (a) except the 1/2-in.-thick plywood underlayment board and the 1/2-in.-thick wood fiber board were nailed directly to the 5/8-in.-thick plyscore subfloor.
Total thickness: approximately 10 in.
Area weight: 9.3 lb/ft^2

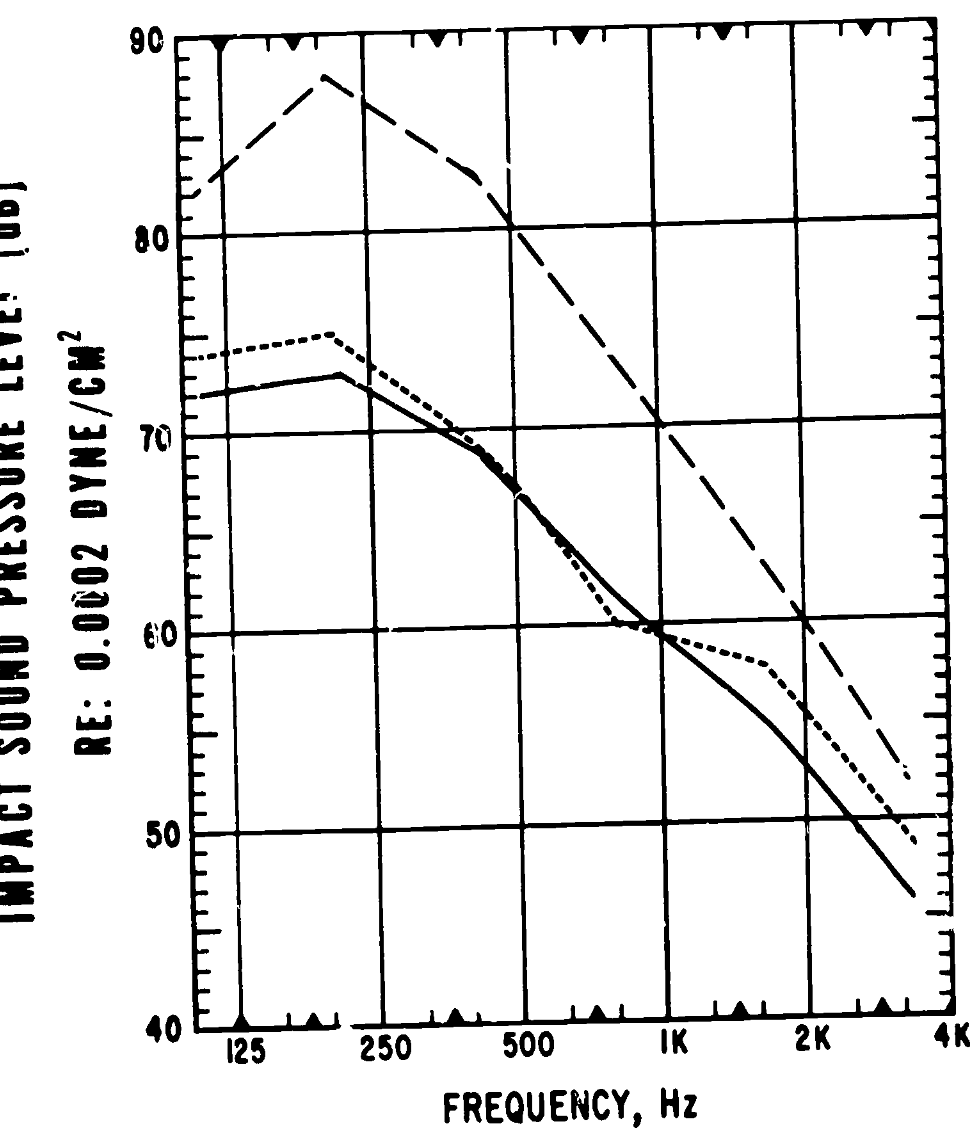
(c) Similar to (a) except the resilient clips were omitted and the 5/8-in. gypsum wallboard was nailed, 7 in. on centers, directly to the floor joists. All joints taped and finished.
Total thickness: 8 3/8 in.
Area weight: 9.5 lb/ft^2



(a)———————STC = 52; IIC = 48; Fire Rating: 45 min. (est.) - combustible
(b)--------------STC = 50; IIC = 47; Fire Rating: 45 min. (est.) - combustible
(c)-—-——— STC = 38; IIC = 34; Fire Rating: 1/2 hr. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/1-octave band data normalized to $A_o = 10m^2$

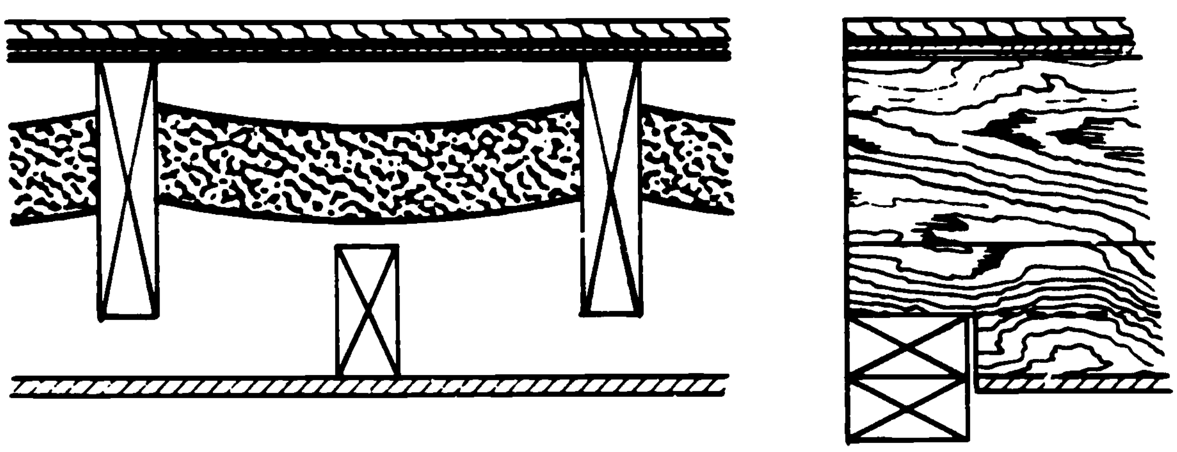
TYPE: WOODEN JOIST WITH INSULATION, SEPARATE CEILING JOIST

TEST REF: 6-(FIT 6)

DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers with approximately 3-in.-thick fibered glass blankets stapled between joists. On the floor side, 1/2-in.-thick plywood subfloor nailed 8 in. on centers to joists, 25/32-in.-thick oak wood flooring on plywood. On the ceiling side, 2- by 4-in. wooden ceiling joists, 24 in. on centers, staggered between floor joists; 1/2-in.-thick gypsum wallboard nailed to ceiling joists. Joints of gypsum board taped and finished.

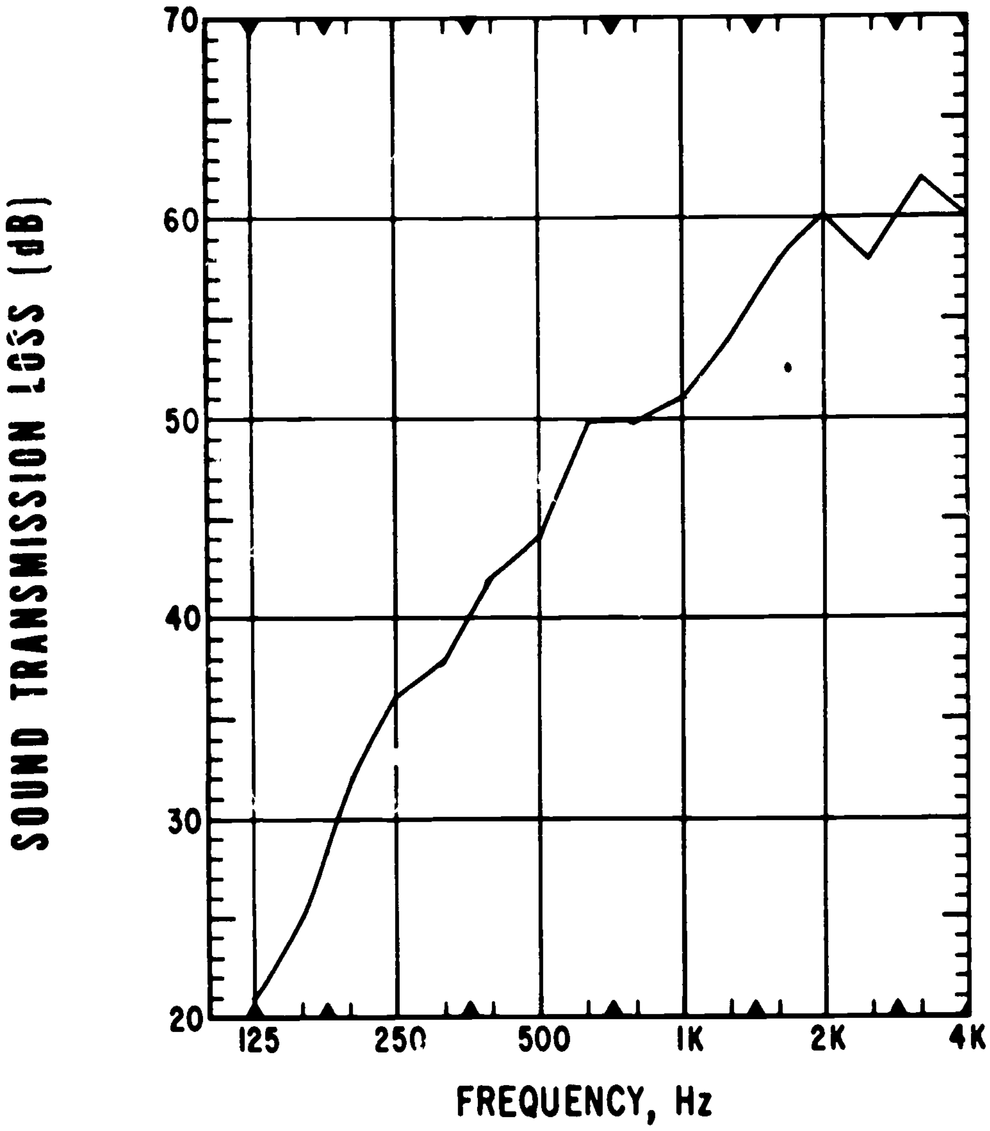
Total thickness: approximately 11 3/4 in.

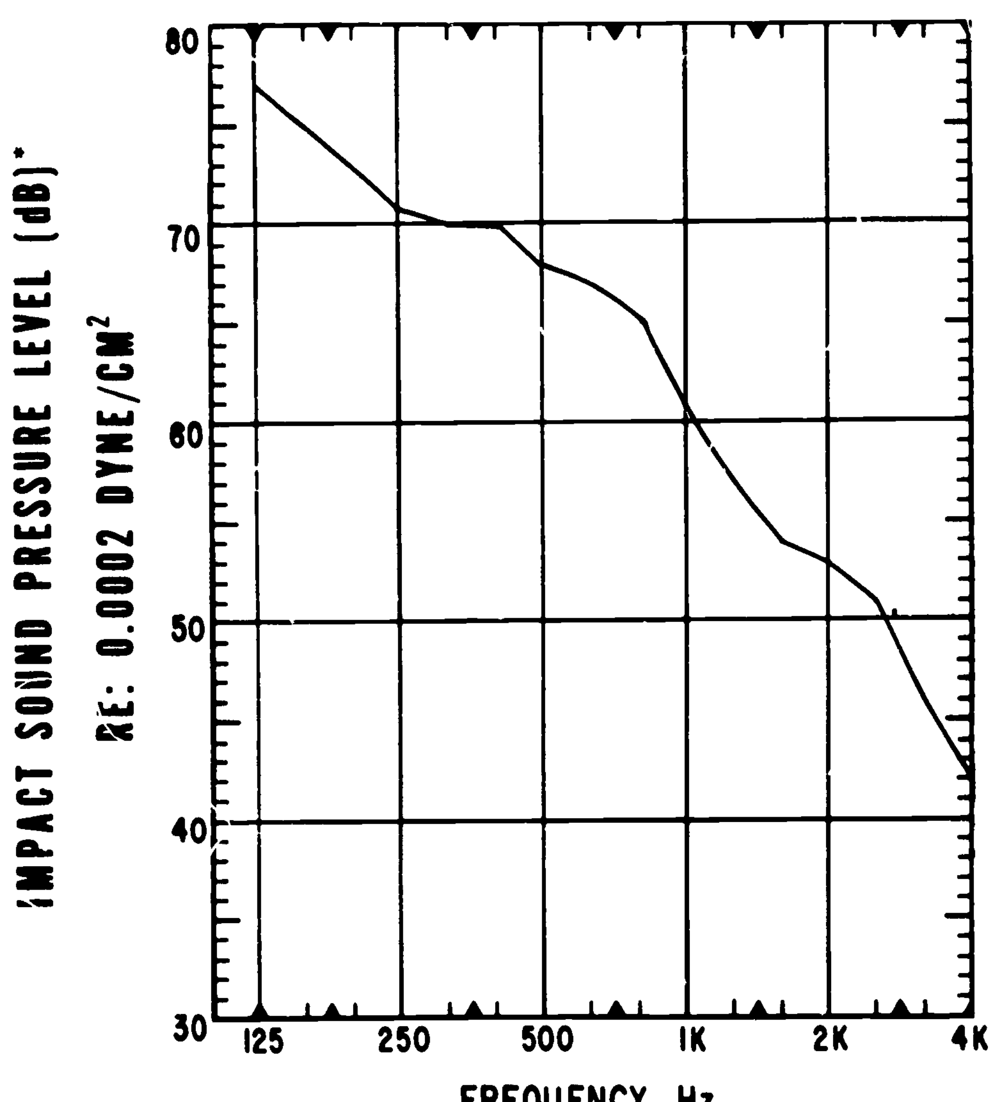
Area weight: 13.0 lb/ft^2



STC = 44; IIC = 43; Fire Rating: 1/2 hr. (est.) - combustible

REMARKS: These measurements were conducted in the field. Exact dimensions of some components not clearly specified in reference.





*1/3-octave band data normalized to $A_o = 10m^2$

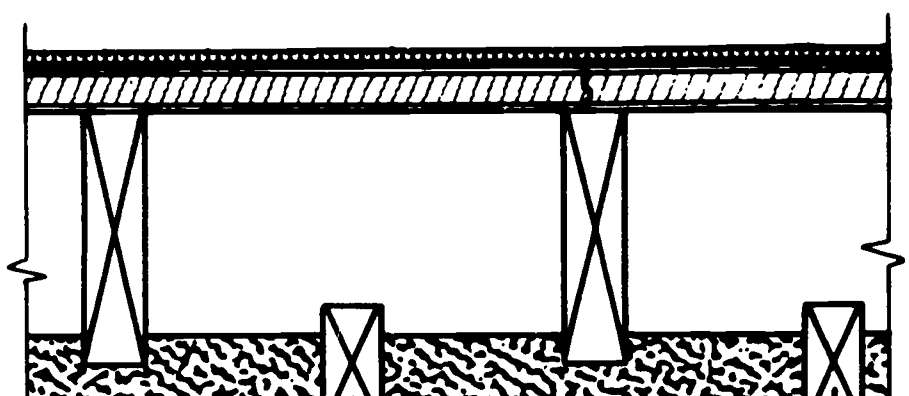
TYPE: WOODEN JOIST, CARPET AND PAD, INSULATED HANGING CEILING

TEST REF: 8-(224-14-65, 224-15-65)

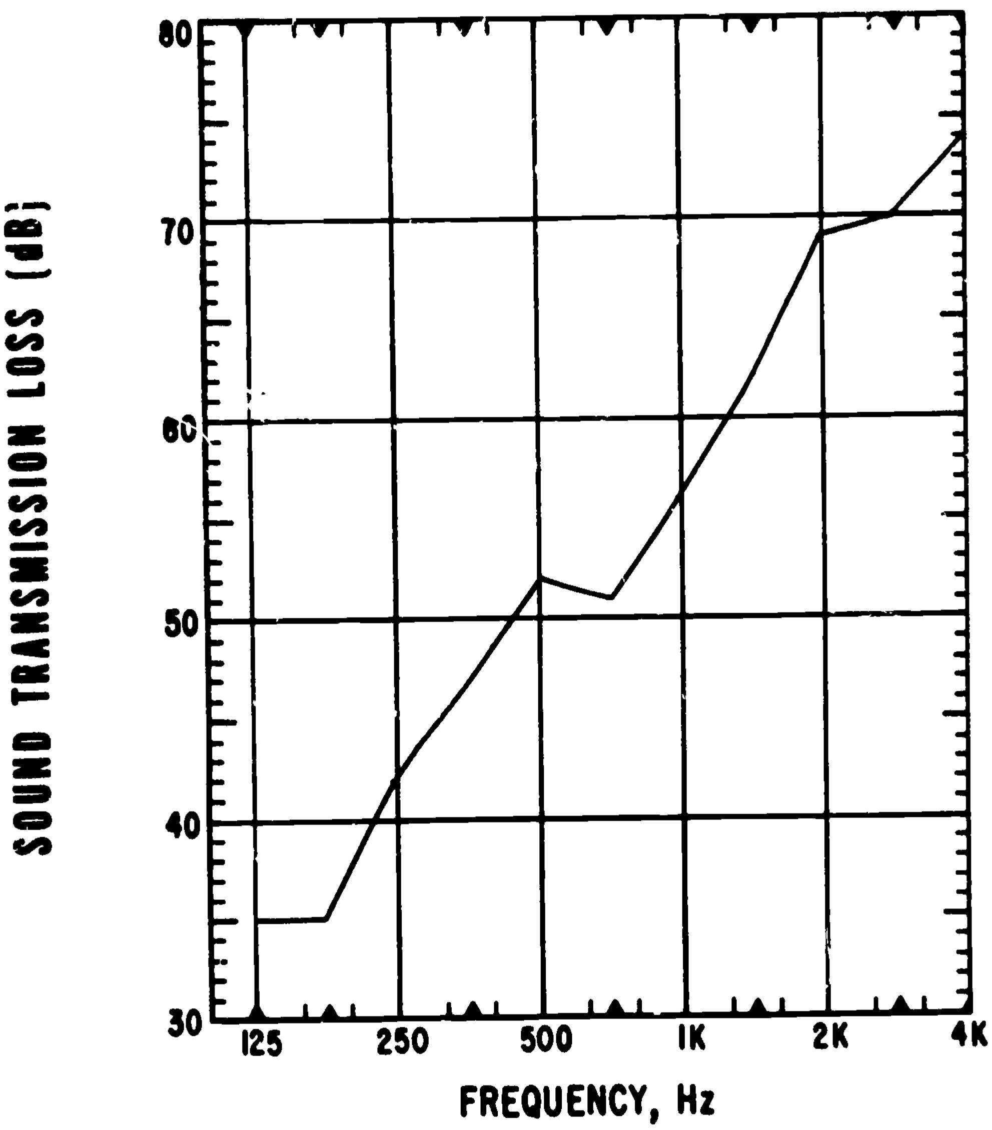
DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 1 1/8-in.-thick regular C-D rough plywood nailed 6 in. on centers along periphery and 16 in. on centers at other bearings, plywood covered with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in. On the ceiling side, 2- by 4-in. wooden joists 16 in. on centers staggered 8 in. on centers relative to the floor joists, 3-in.-thick fibered glass blankets stapled between ceiling joists, 5/8-in.-thick gypsum wallboard nailed to ceiling joists. All joints taped and finished and the entire periphery of the panel caulked and sealed. The ceiling was supported independently from the floor structure.

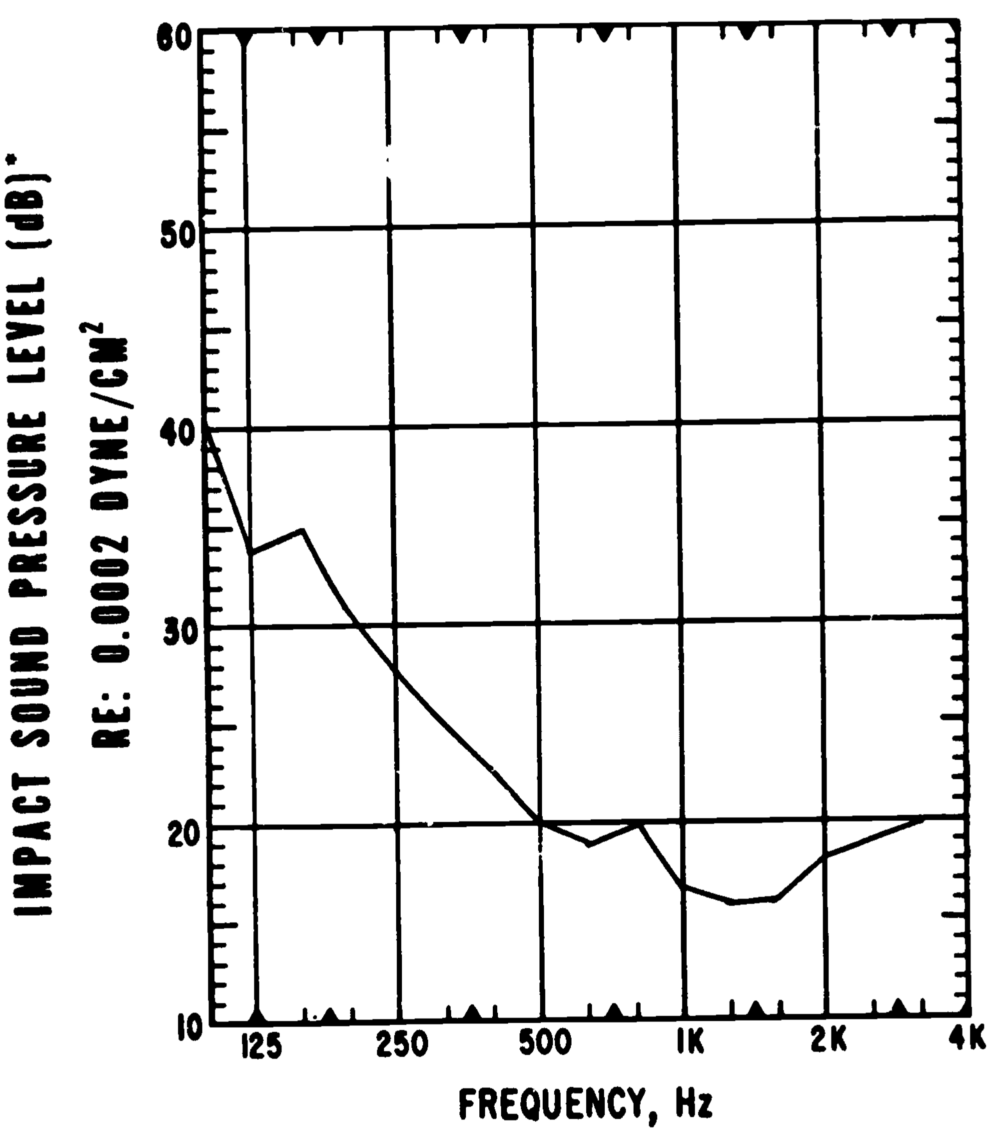
Total thickness: approximately 12 3/8 in.

Area weight: 10.7 lb/ft^2



STC = 52; IIC = 80; Fire Rating: 45 min. (est.) - combustible





*1/3-octave band data normalized to $A_o = 10m^2$

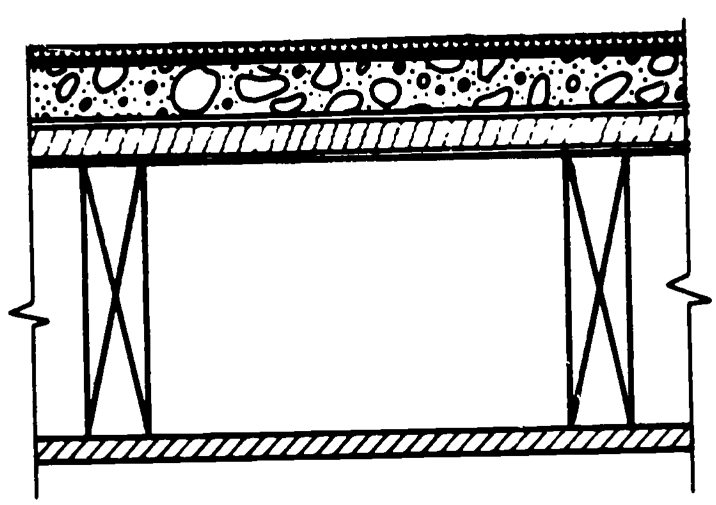
TYPE: WOODEN JOIST, CONCRETE WITH CARPET AND PAD

TEST REF: 8-(224-30-65, 224-29-65)

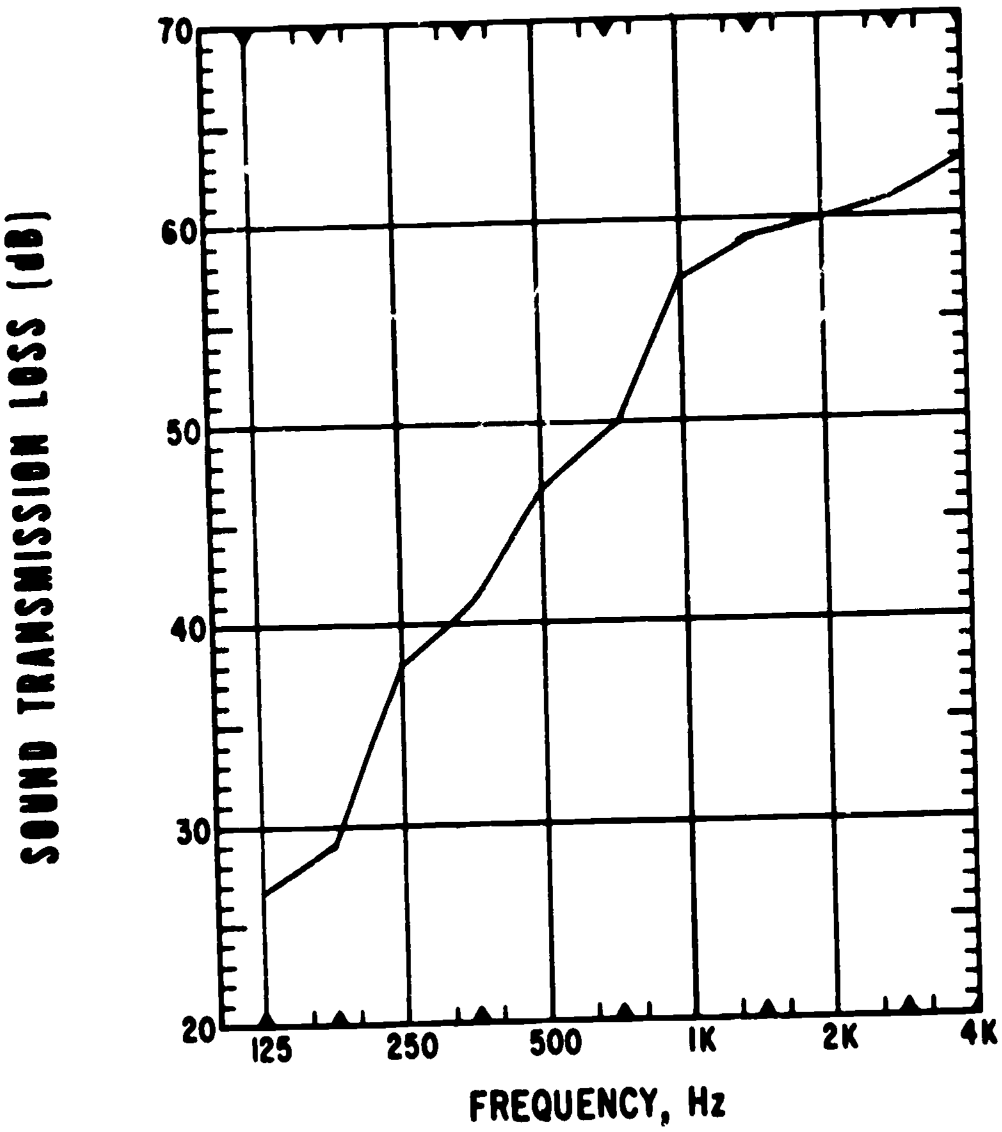
DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 5/8-in.-thick tongue-and-groove, C-D plugged plywood nailed 6 in. on centers along periphery and 10 in. on centers at other bearings, 1 5/8-in.-thick perlite sand concrete, approx. 72 lb/ft^3, over 4 mil polyethylene film on plywood, concrete covered with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed to joists. All joints taped and finished and the entire periphery of the panel caulked and sealed.

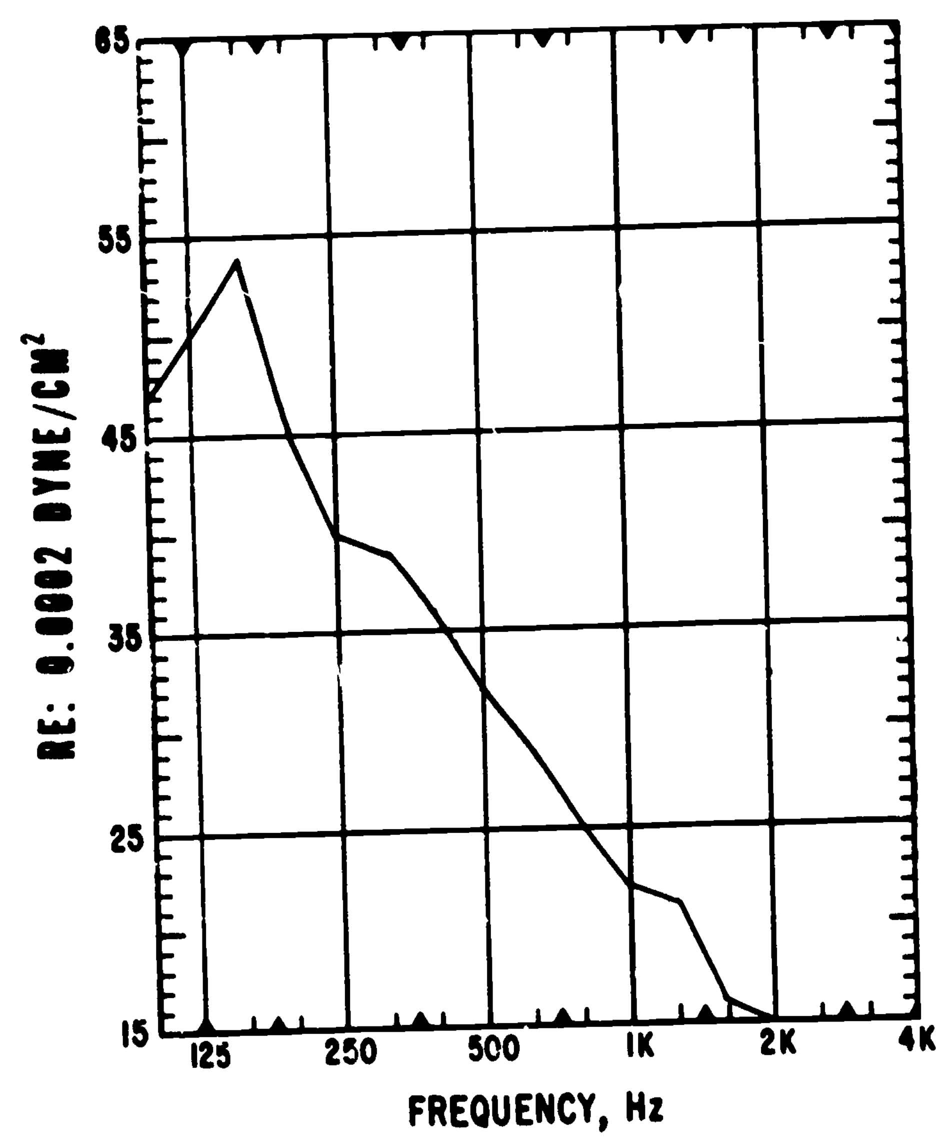
Total thickness: approximately 11 1/2 in.

Area weight: 18.4 lb/ft^2



STC = 47; IIC = 66; Fire Rating: 45 min. (est.) - combustible





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST WITH INSULATION, CONCRETE FLOOR, RESILIENT CEILING

TEST REF: (a) 8-(224-31-65, 224-34-65); (b) 8-(224-28-65, 224-27-65); (c) 8-(224-22-65, 224-23-65)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers with 3-in.-thick fibered glass blankets stapled between joists. On the floor side, 5/8-in. tongue-and-grooved plywood nailed 6 in. on centers along periphery and 10 in. on centers at other bearings, 1 5/8-in.-thick perlite sand concrete, 72 lb/ft^3, slab over 4 mil polyethylene film on plywood, 0.075-in. vinyl sheet glued to concrete slab. On the ceiling side, resilient channels screwed perpendicular to joists 24 in. on centers, 5/8-in. gypsum wallboard screwed 12 in. on centers to channels; all joints taped and finished and the periphery caulked and sealed.

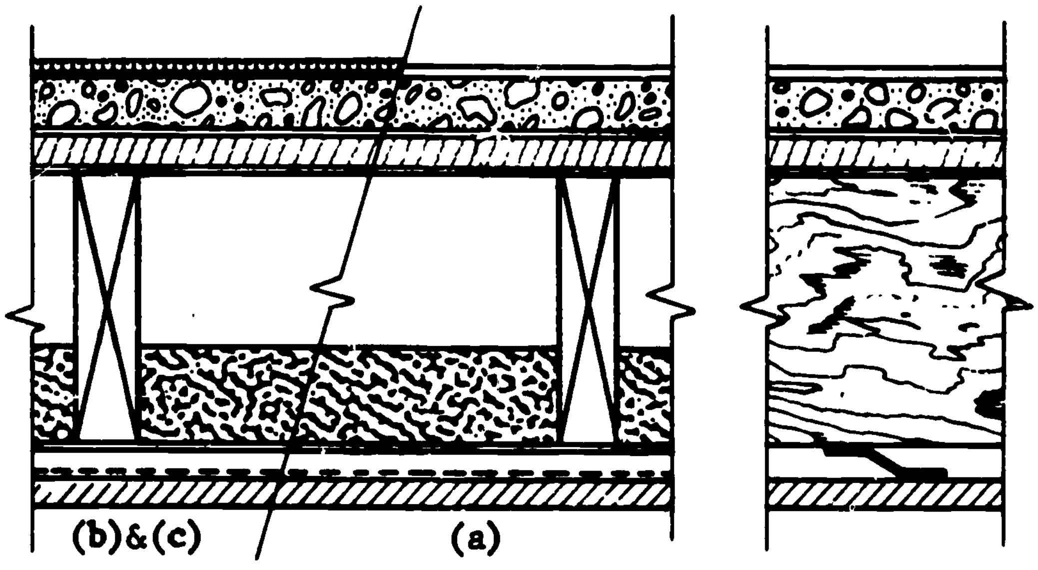
Total thickness: approximately 11 3/8 in.
Area weight: 17.9 lb/ft^2

(b) Similar to (a) except the vinyl sheet was replaced with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in.

Total thickness: approximately 12 in.
Area weight: 20.3 lb/ft^2

(c) Similar to (b) except 1 5/8-in. foamed concrete, 100 lb/ft^3, slab was used.

Total thickness: approximately 12 1/8 in.
Area weight: 22.1 lb/ft^2

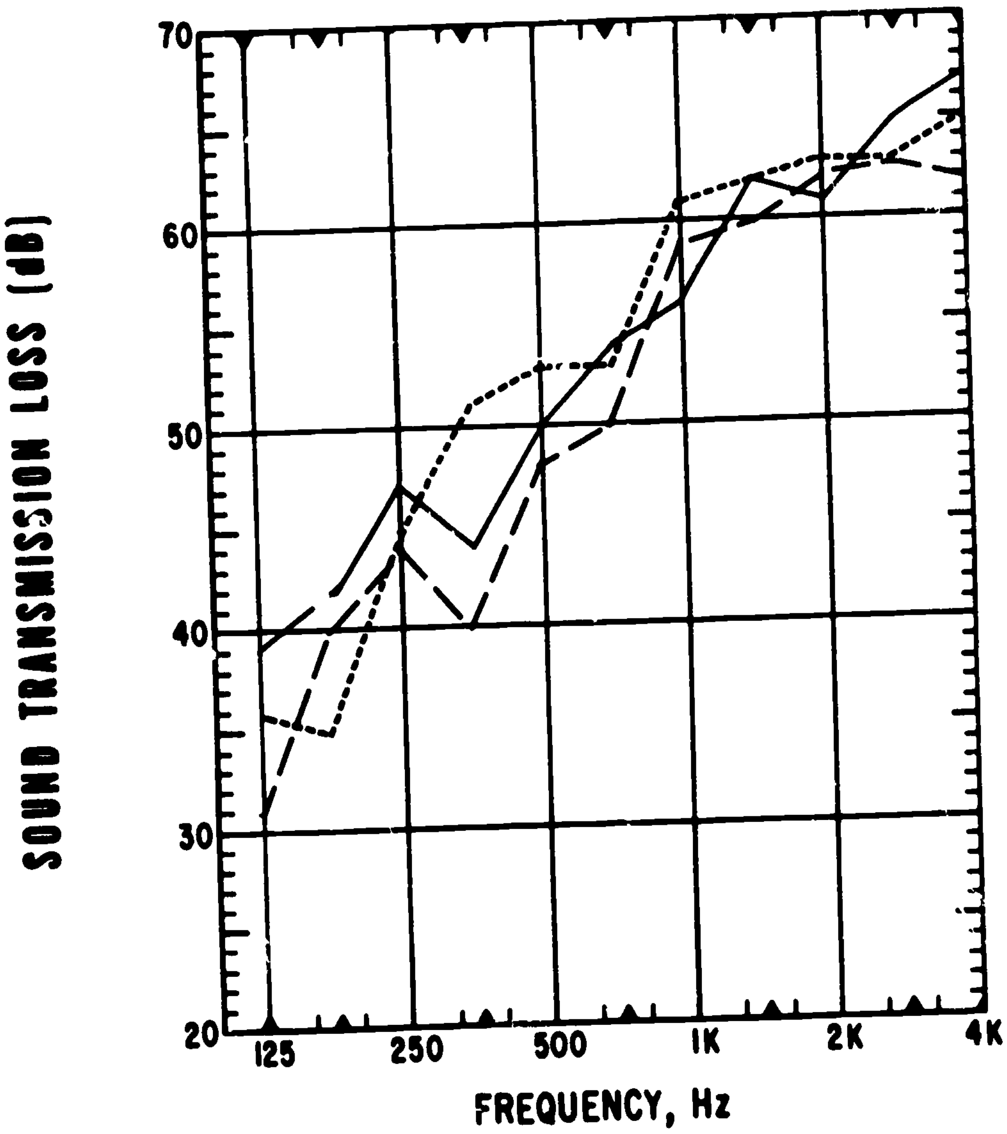


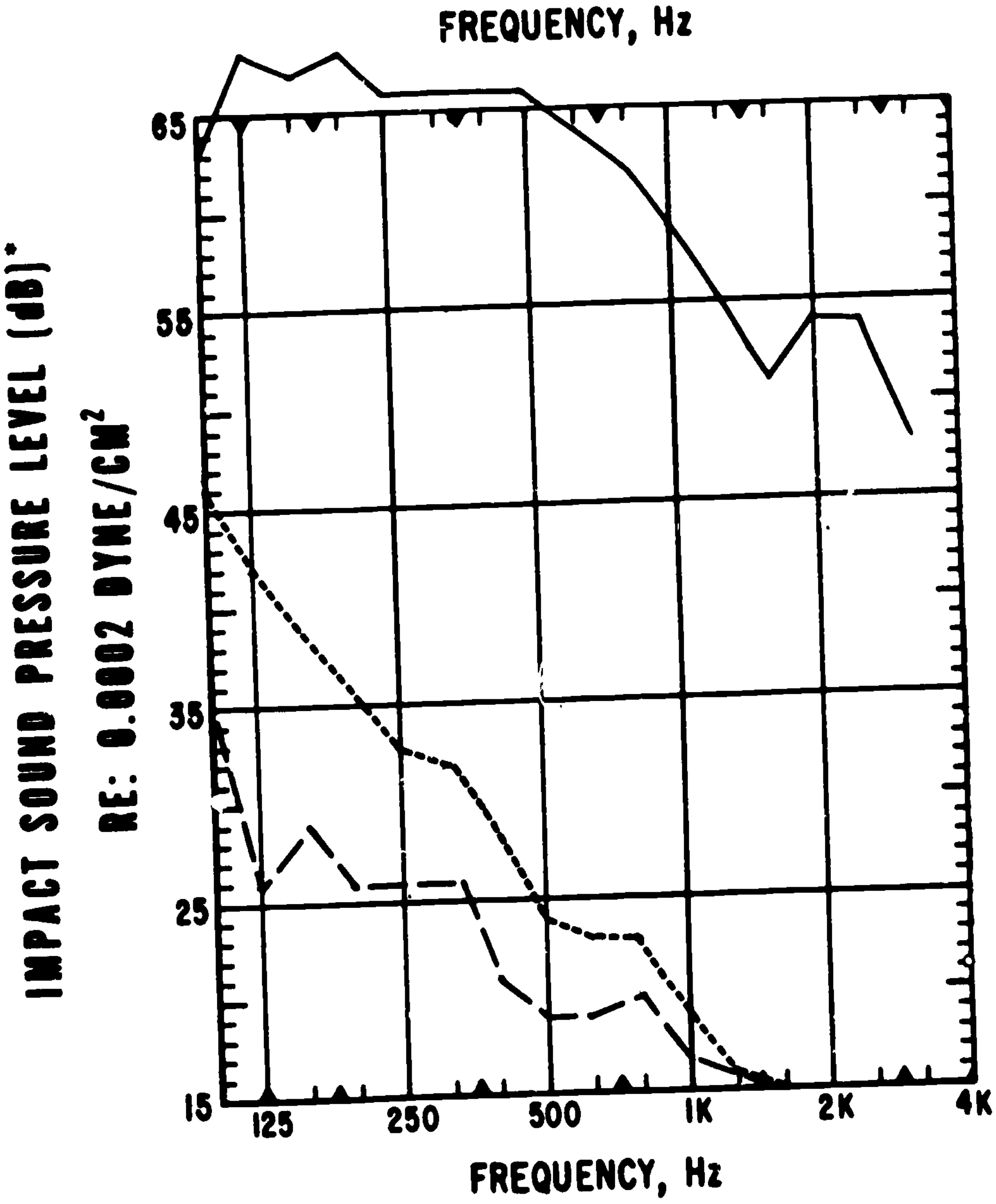
(a)———————STC = 50; IIC = 47; Fire Rating: 45 min. (est.) - combustible

(b)·················STC = 53; IIC = 74

(c)— — — — — -STC = 46; IIC = 85

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST, FLOATING FLOOR

TEST REF: (a) 1-(S311, S312); (b) 1-(S407-S410)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers. On the floor side, 7/8-in.-thick tongue-and-groove wood flooring on approximately 1-in.-thick bitumen-bonded glass-wool quilt, 1- by 2-in. wooden battens nailed to underside of wood flooring midway between the joists. On the ceiling side, 1/2-in. layer of plaster on expanded metal lath.

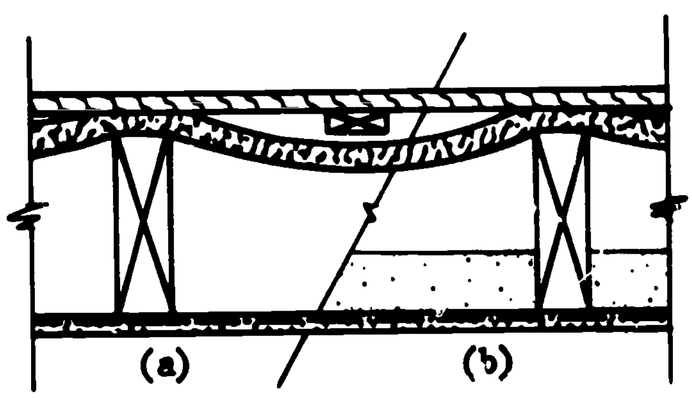
Total thickness: approximately 10 in.

Area weight: 13 lb/ft^2

(b) Similar to (a) except there was a 2-in. layer of sand, 96 lb/ft^3, between joists.

Total thickness: approximately 10 in.

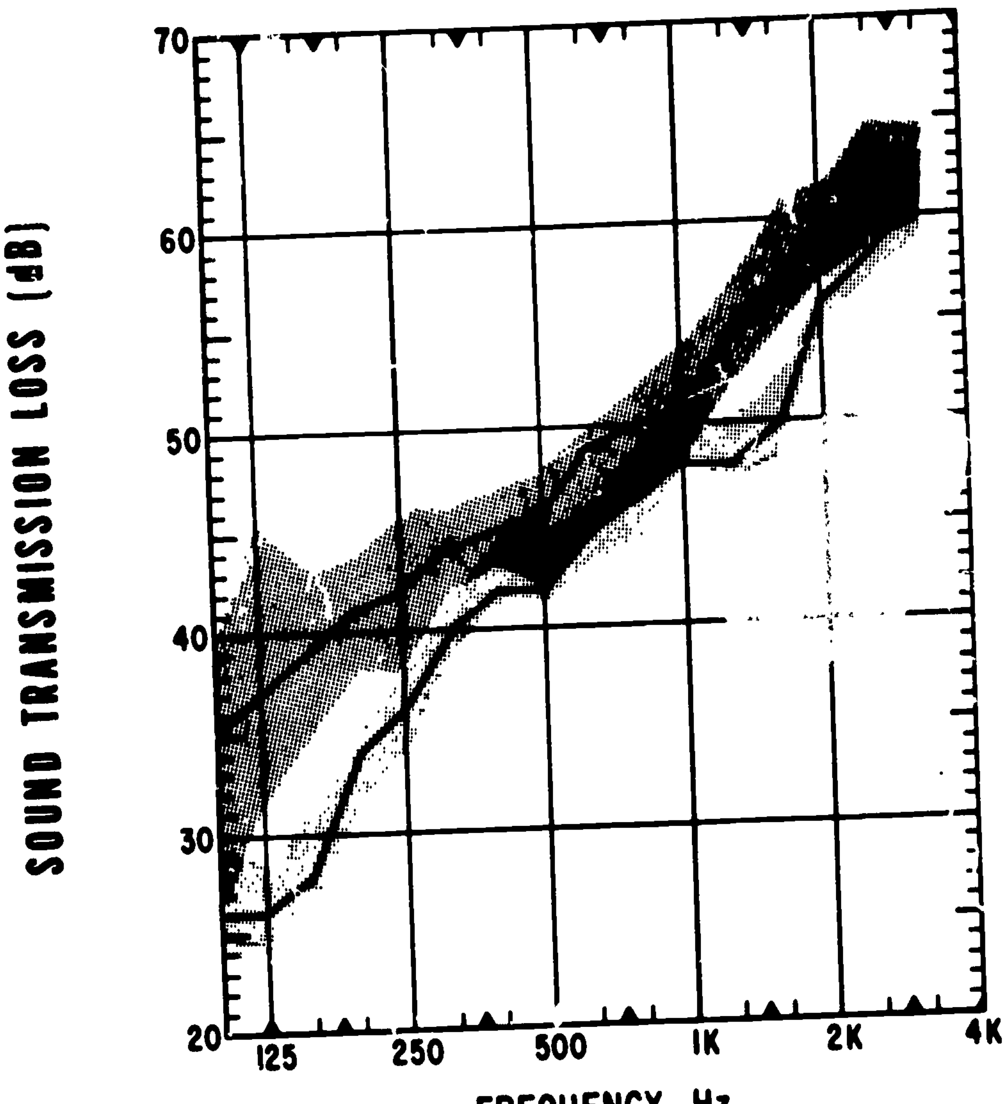
Area weight: 30 lb/ft^2

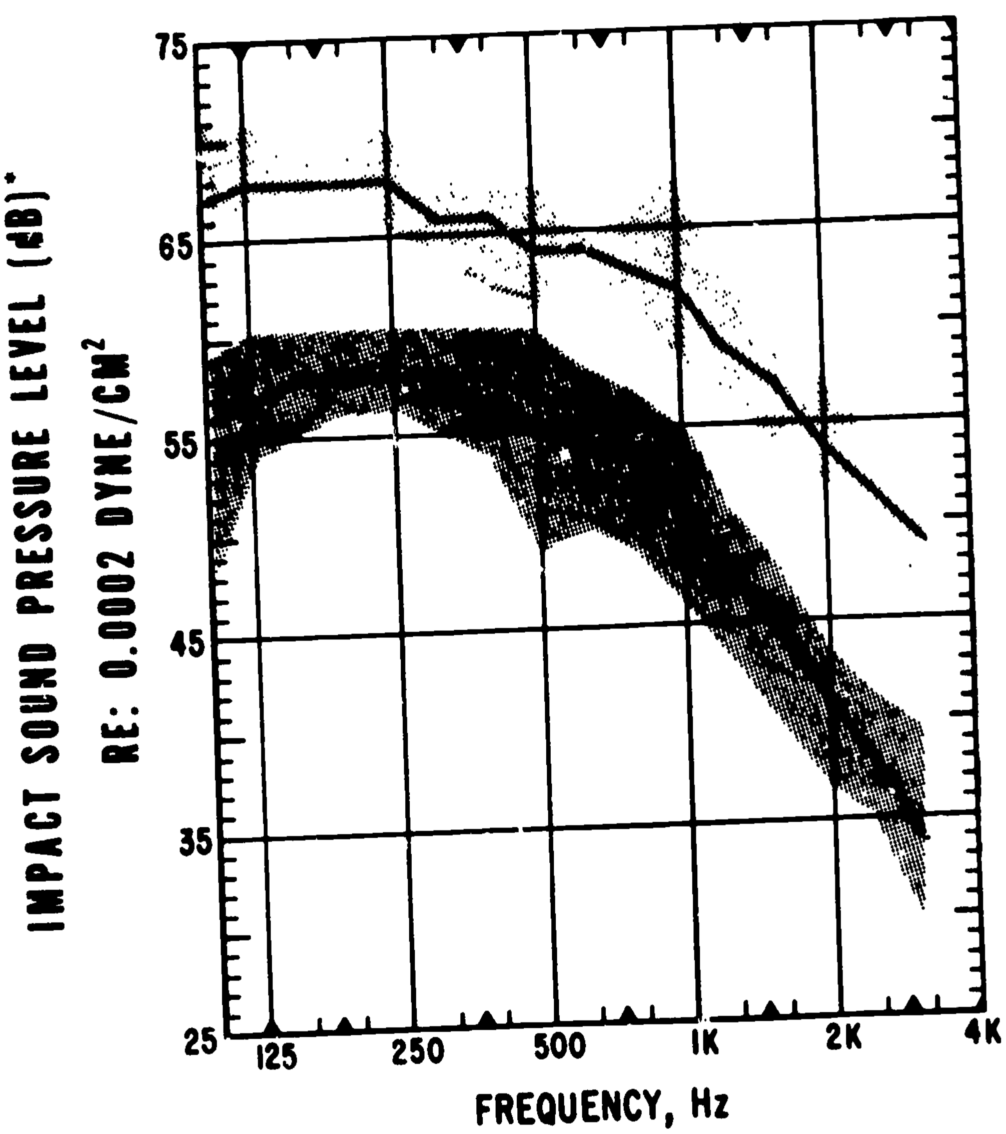


(a) [redacted] STC = 46; IIC = 46; Fire Rating: 45 min. (est.) - combustible

(b) [redacted] STC = 50; IIC = 57; Fire Rating: 45 min. (est.) - combustible

REMARKS: The plotted curves are the average values of field measurements of four nominally identical structures of type (a) and of eight nominally identical structures of type (b). The shaded areas indicate the spreads of the measurements.





*1/3-octave band data normalized to T_o = 0.5 sec.

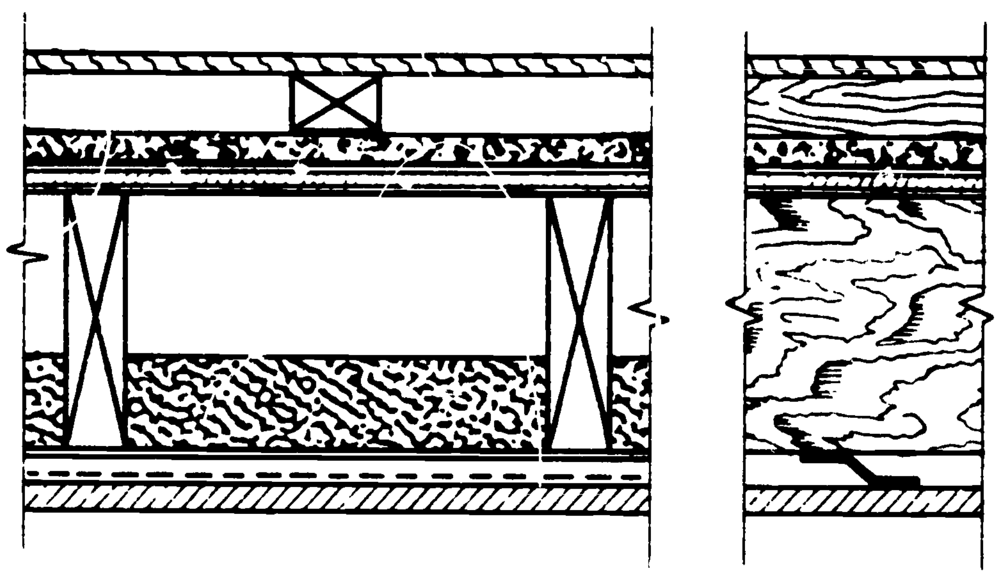
TYPE: WOODEN JOIST WITH INSULATION, FLOATING FLOOR, RESILIENT CEILING

TEST REF: 8-(224-10-65, 224-9-65)

DESCRIPTION: 2- by 8-in. wooden joists 16 in. on centers with 3-in.-thick fibered glass blankets stapled between joists. On the floor side, 1/2-in. square-edged C-D rough plywood nailed 6 in. on centers along periphery and 10 in. on centers at other bearings, 1/2-in. cane fiber board stapled 24 in. on centers to plywood, 2- by 3-in. furring strips glued 16 in. on centers to fiber board parallel to and midway between joists, 25/32-in.-thick wood strip flooring. On the ceiling side, resilient channels, 24 in. on centers, screwed perpendicular to joists, 5/8-in. gypsum wallboard screwed 12 in. on centers to channels. All joints taped and finished and the entire periphery of the panel caulked and sealed.

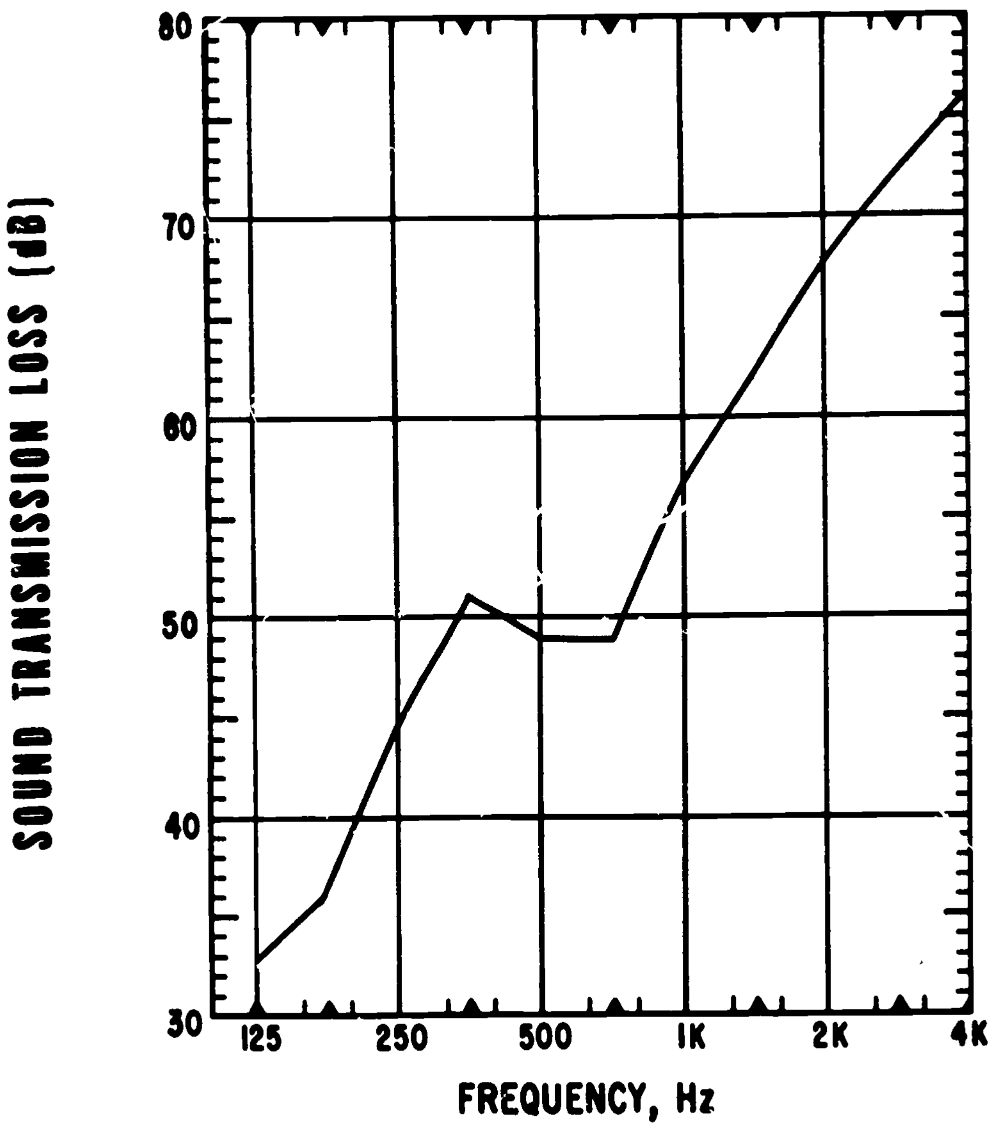
Total thickness: approximately 12 3/4 in.

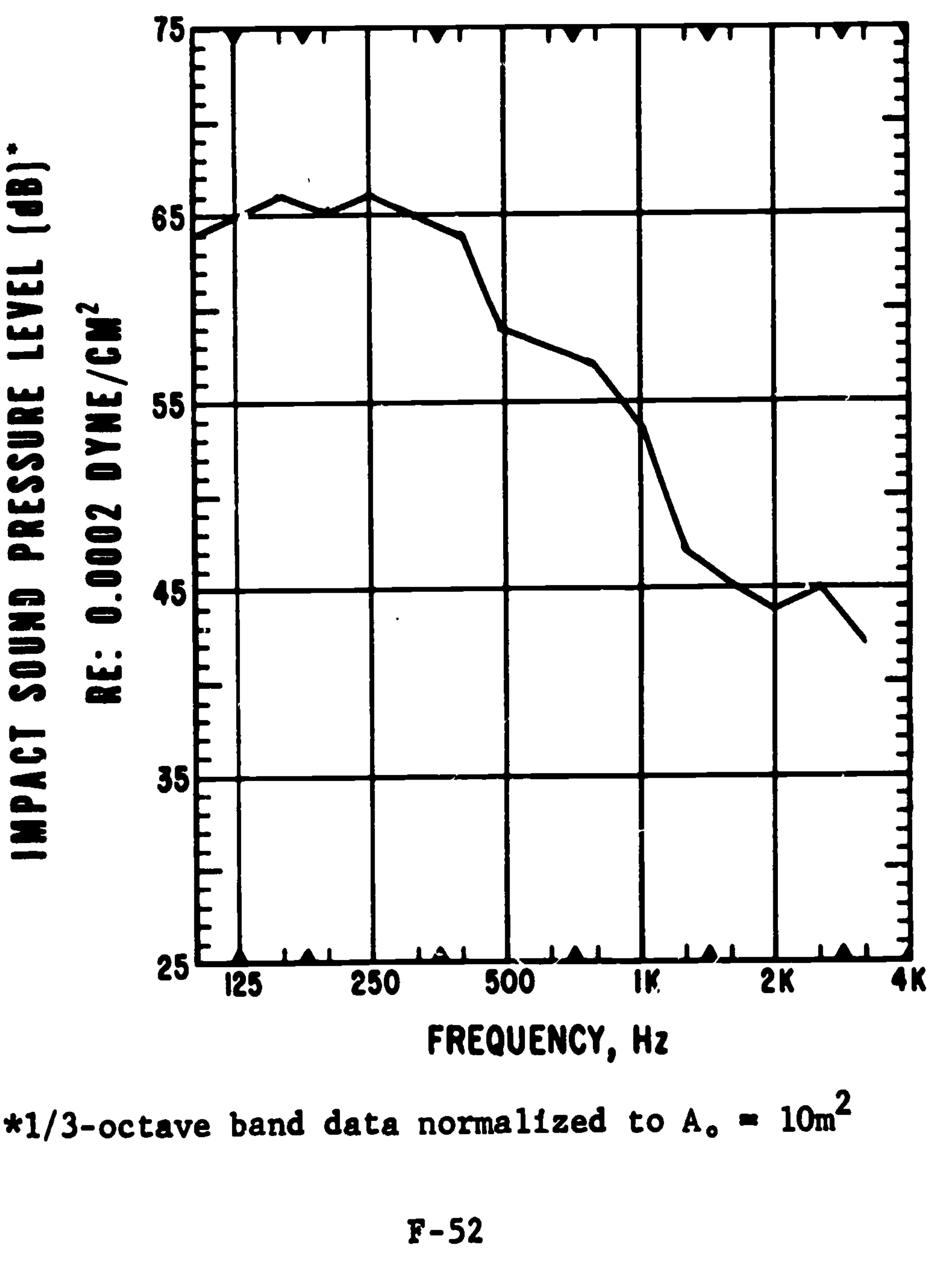
Area weight: 13.0 lb/ft^2



STC = 52; IIC = 51; Fire Rating: 45 min. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: WOODEN JOIST WITH INSULATION, FLOATING FLOOR, RESILIENT CEILING

TEST REF: (a) 8-(224-6-65, 224-5-65); (b) 8-(224-8-65, 224-7-65)

DESCRIPTION: (a) 2- by 8-in. wooden joists 16 in. on centers with 3-in.-thick fibered glass blankets stapled between joists. On the floor side, 1/2-in. plywood nailed 6 in. on centers along periphery and 16 in. on centers at other bearings, 1/2-in. cane fiber board stapled 24 in. on centers to plywood, 2- by 3-in. furring strips glued 16 in. on centers to fiber board parallel to and midway between joists, 5/8-in. tongue-and-groove, C-D plugged plywood underlayment nailed 6 in. on centers at edges and 10 in. on centers at other bearings, .075-in. vinyl sheet adhered to underlayment. On the ceiling side, resilient channels, 24 in. on centers, screwed perpendicular to joists, 5/8-in. gypsum wallboard screwed 12 in. on centers to channels. All joints taped and finished and the periphery of the panel caulked and sealed.

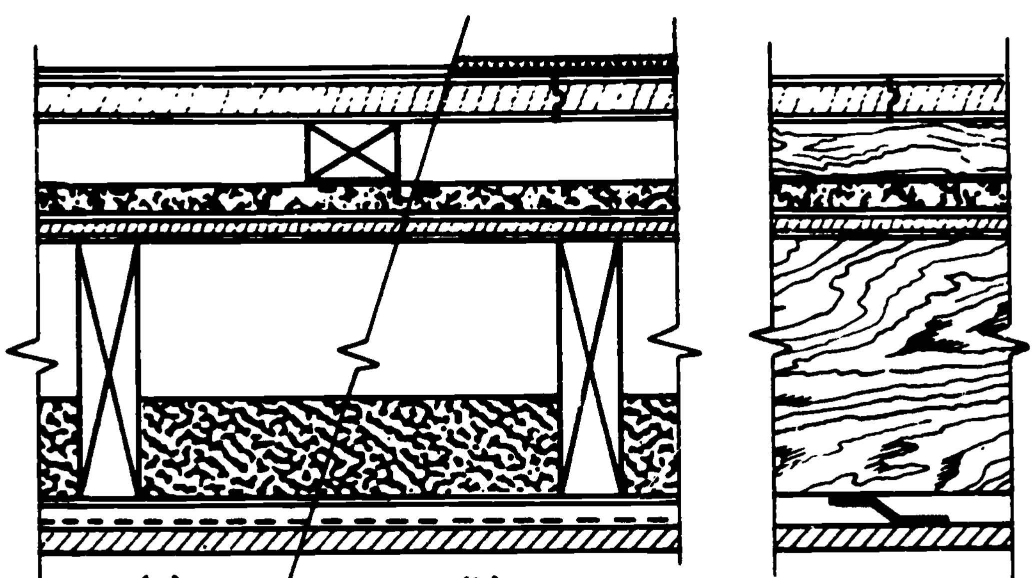
Total thickness: 12 3/4 in.

Area weight: 10.9 lb/ft^2

(b) Similar to (a) except the vinyl sheet was replaced with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in.

Total thickness: approximately 13 1/2 in.

Area weight: 11.7 lb/ft^2

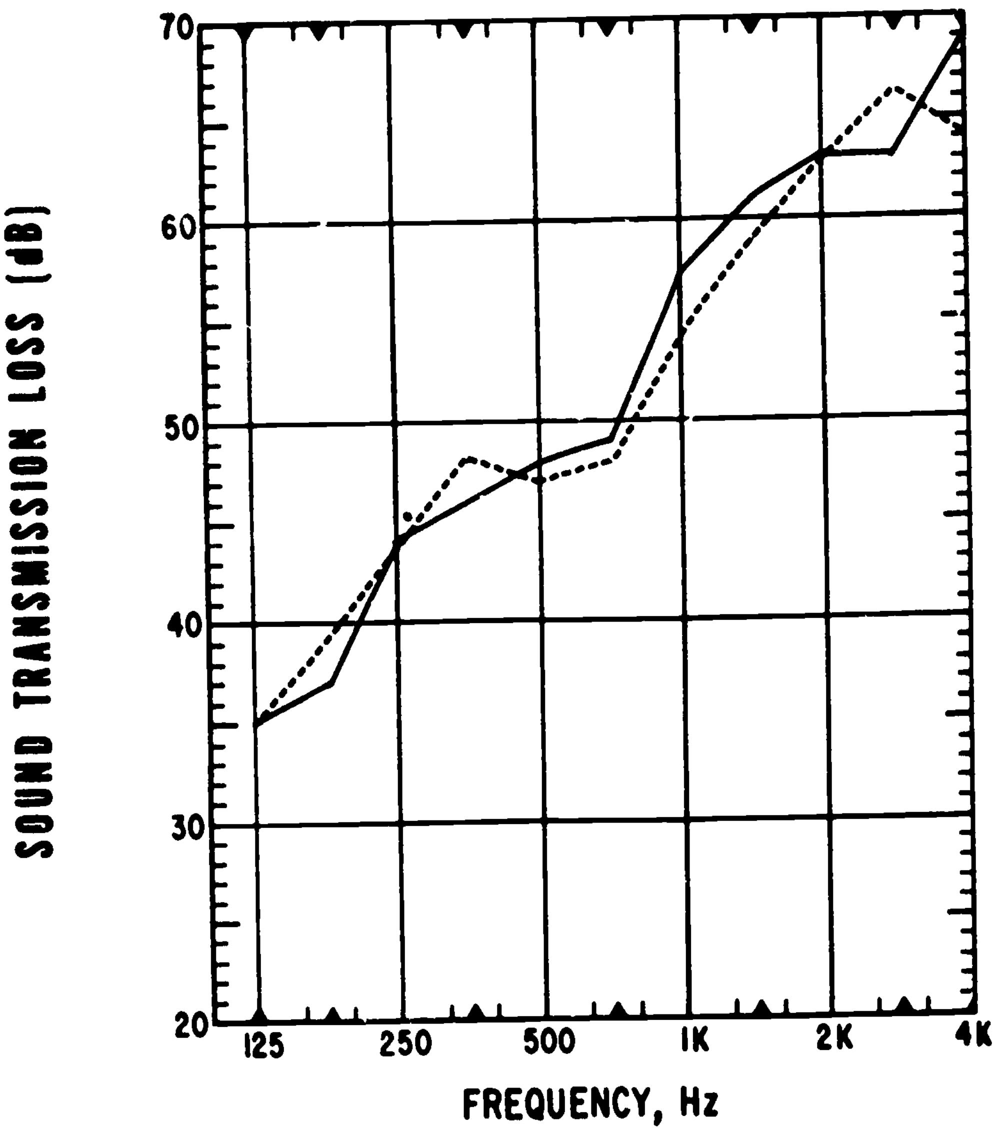


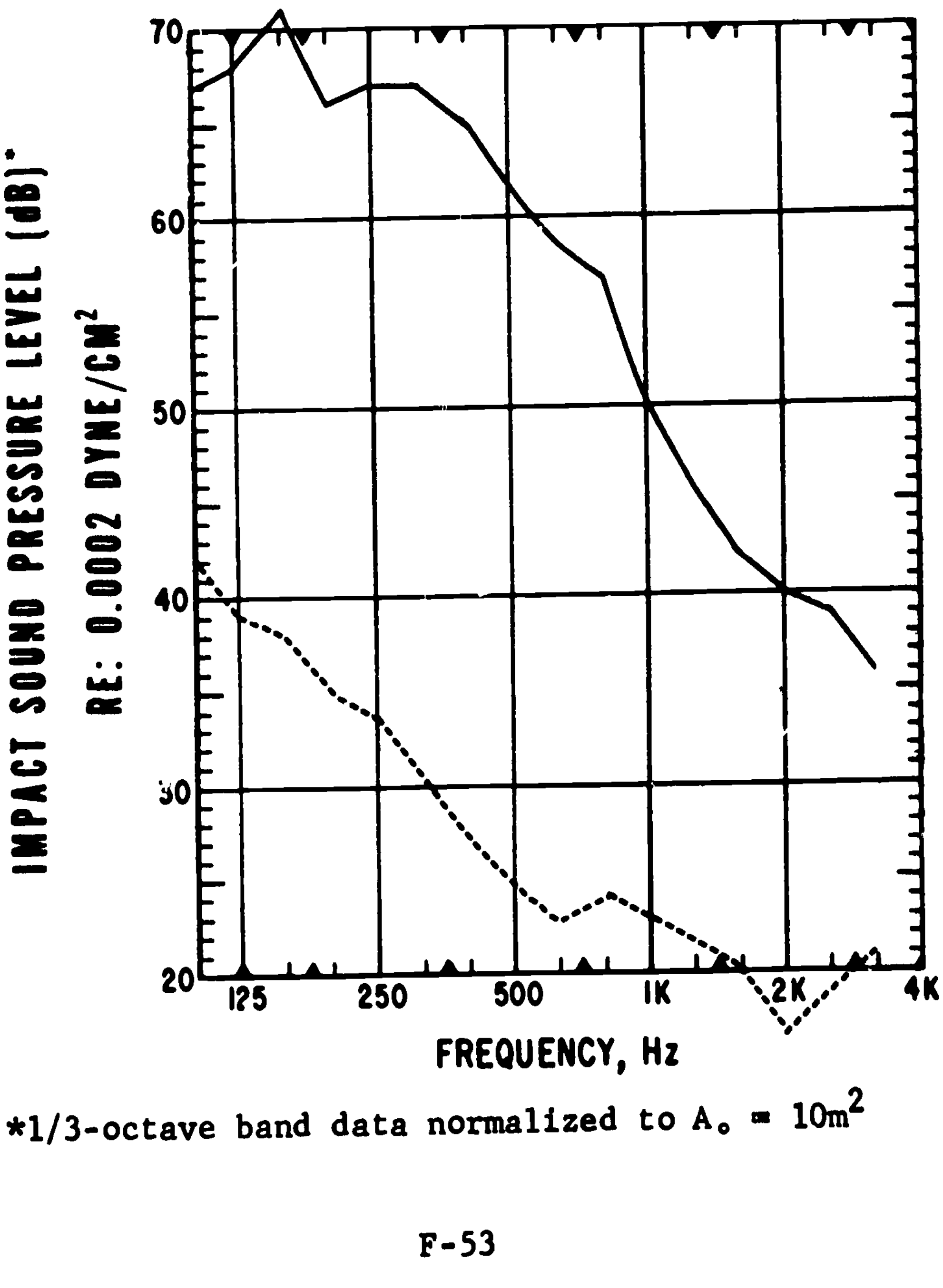
(a) (b)

(a)———— STC = 52; IIC = 49; Fire Rating: 45 min. (est.) - combustible

(b)-------- STC = 51; IIC = 78

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: STEEL JOIST

TEST REF: (a) 3-(721-A); (b) 3-(722-A)

DESCRIPTION: (a) 8-in. steel joists 16 in. on centers. (Joists had 2-in. wide support flanges at top and bottom, 2 1/4-in. diameter holes 30 in. on centers in 1/16-in.-thick body.) On the floor side, 1 11/32- by 23 1/4-in. compressed homogeneous paper pulp building board (approximate density 26.1 lb/ft^3) nailed 8 in. on centers perpendicular to the joists, 1/8-in.-thick hardboard glued to building board, a single layer of 15 lb felt building paper glued to hardboard, and 1/8- by 9- by 9-in. vinyl asbestos tile glued to felt paper. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 12 in. on centers with all joints taped and finished.

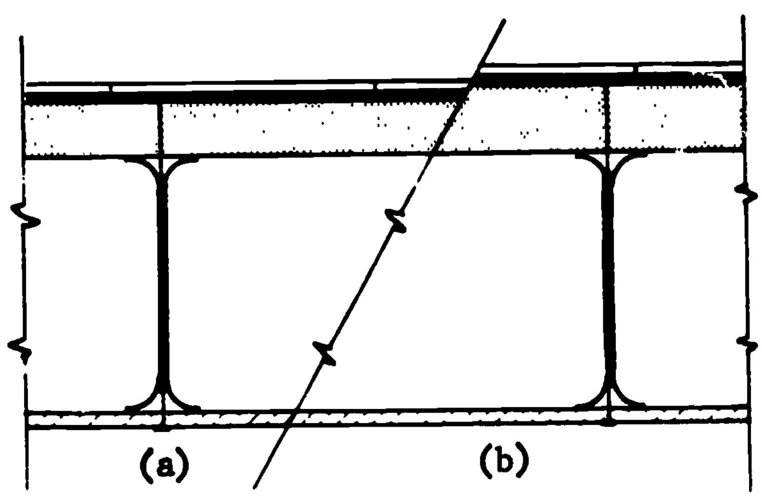
Total thickness: 10 1/8 in.

Area weight: approximately 8.5 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except the steel joists were 24 in. on centers and the building board was 1 27/32 in. thick.

Total thickness: 10 5/8 in.

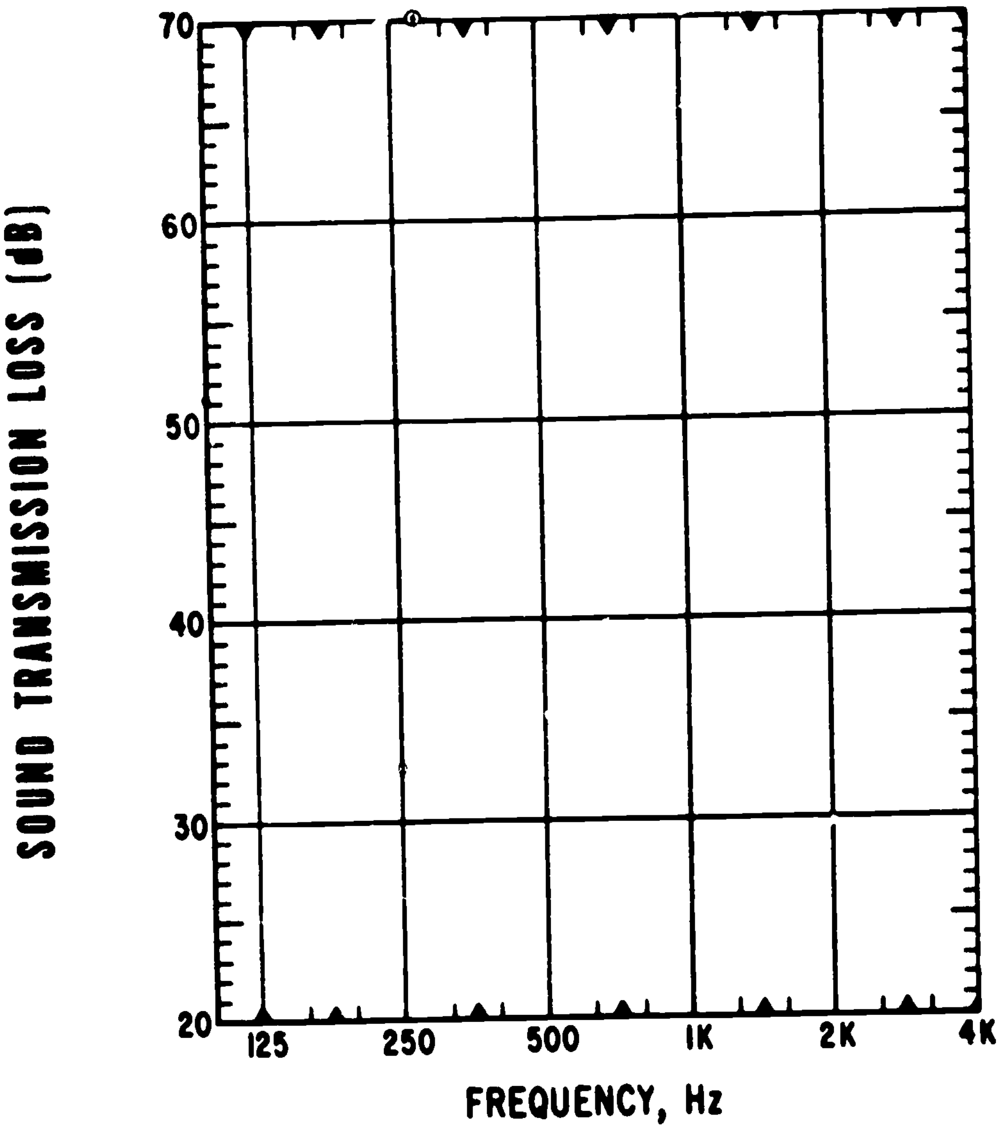
Area weight:. approximately 9 lb/ft^2 (Not specified in reference.)

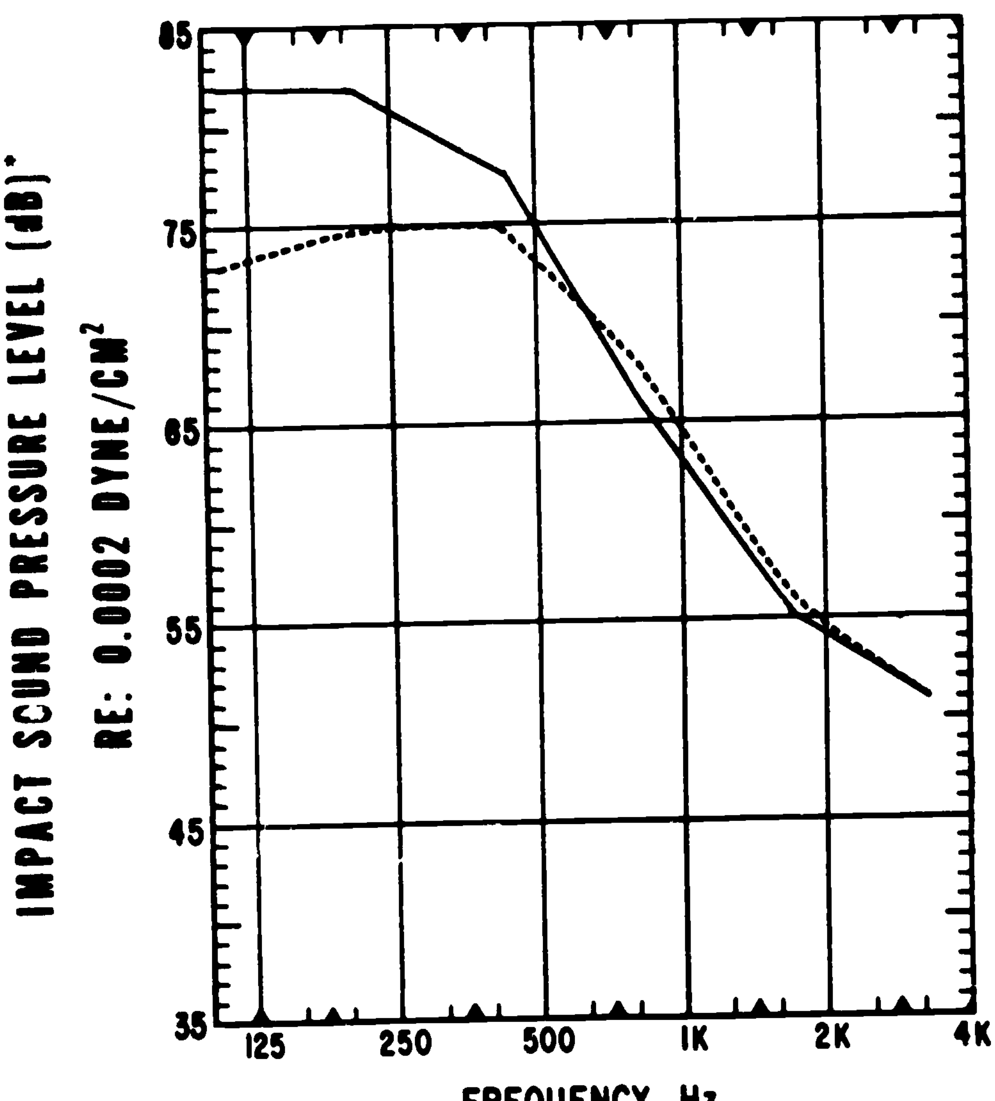


(a)———— STC = 35-38 (est.); IIC = 40; Fire Rating: Not available

(b)- - - - - IIC = 45; Fire Rating: Not available

REMARKS: STC estimated on basis of measurements of similar structures with 2- by 10-in. wooden joists replacing steel joists. See F-36 and F-37.





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: STEEL JOIST, CARPET AND PAD

TEST REF: (a) 3-(721-B); (b) 3-(722-B)

DESCRIPTION: (a) 8-in. steel joists 16 in. on centers. (Joists same as those used in previous report.) On the floor side, 1 11/32- by 23 1/4-in. compressed homogeneous paper pulp building board (approximate density 26.1 lb/ft^3) nailed 8 in. on centers perpendicular to the joists; building board covered with a foam rubber carpet pad and nylon carpet. The carpet pad had an uncompressed thickness of 1/4 in., backed with a woven jute fiber cloth. The nylon carpet had 1/8-in. woven backing and 1/4-in. looped pile spaced 7 loops per inch with a total thickness of 3/8 in. On the ceiling side, 1/2-in.-thick gypsum wallboard nailed 12 in. on centers with all joints taped and finished.

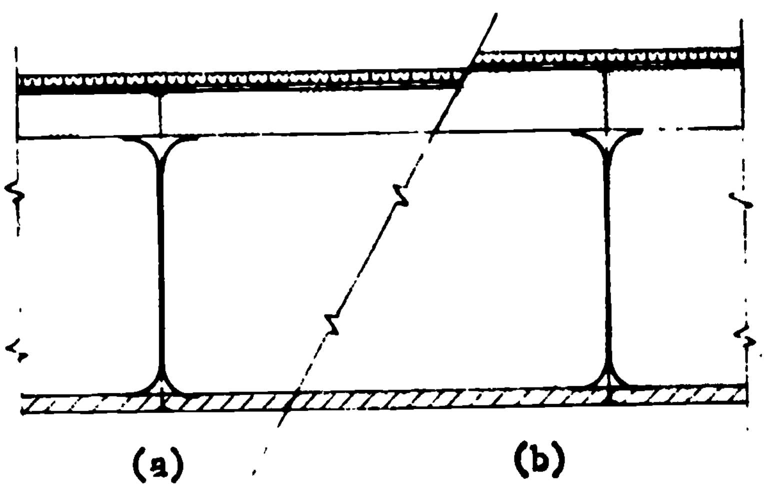
Total thickness: 10 1/2 in.

Area weight: approximately 9 lb/ft^2 (Not specified in reference.)

(b) Similar to (a) except the steel joists were 24 in. on centers and the building board was 1 27/32 in. thick.

Total thickness: 11 in.

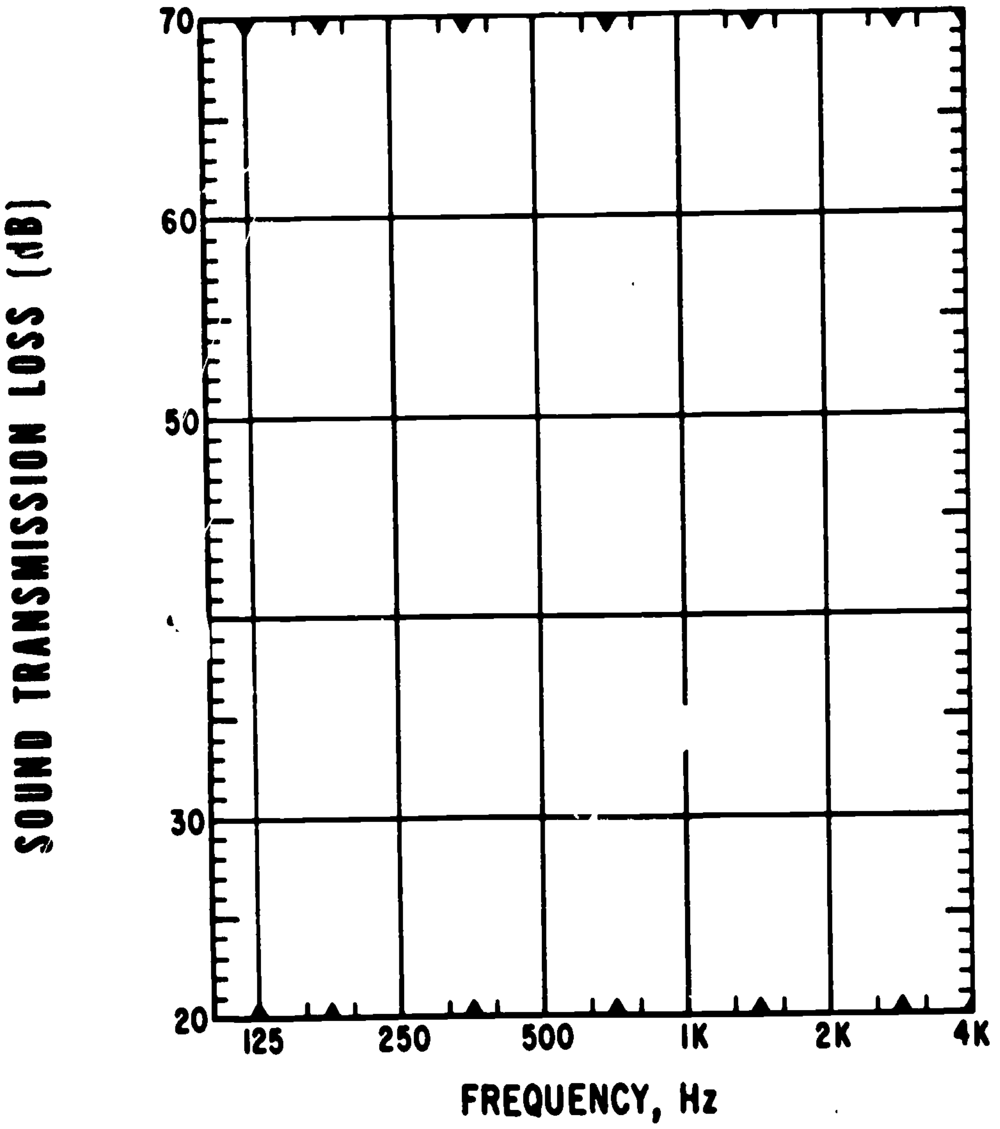
Area weight: approximately 10 lb/ft^2 (Not specified in reference.)

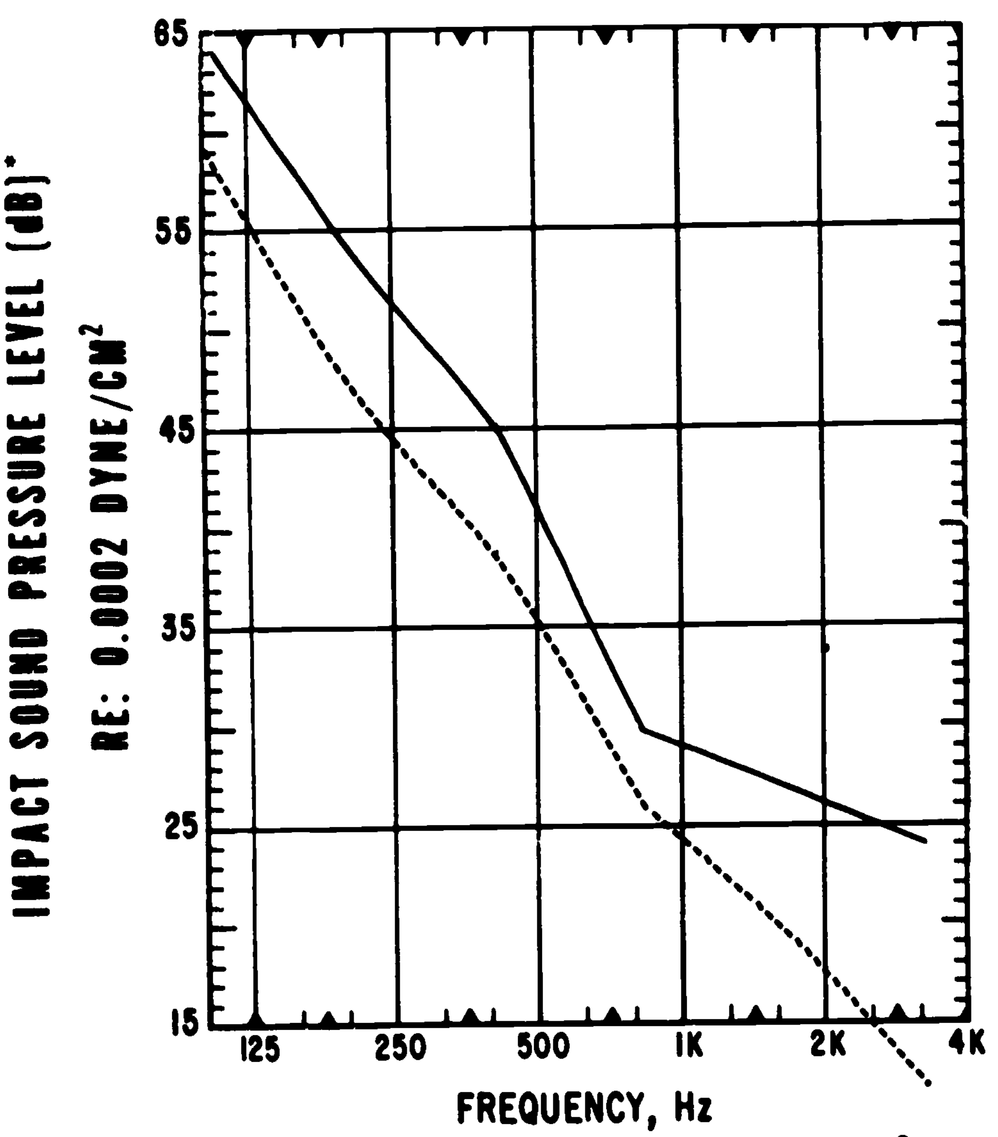


(a) ———— STC = 35-38 (est.); IIC = 58; Fire Rating: Not available

(b) -------- IIC = 63; Fire Rating: Not available

REMARKS: STC estimated on basis of measurements of similar structures with 2- by 10-in. wooden joists replacing steel joists. See F-36 and F-37.





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: STEEL JOIST WITH CONCRETE FLOOR

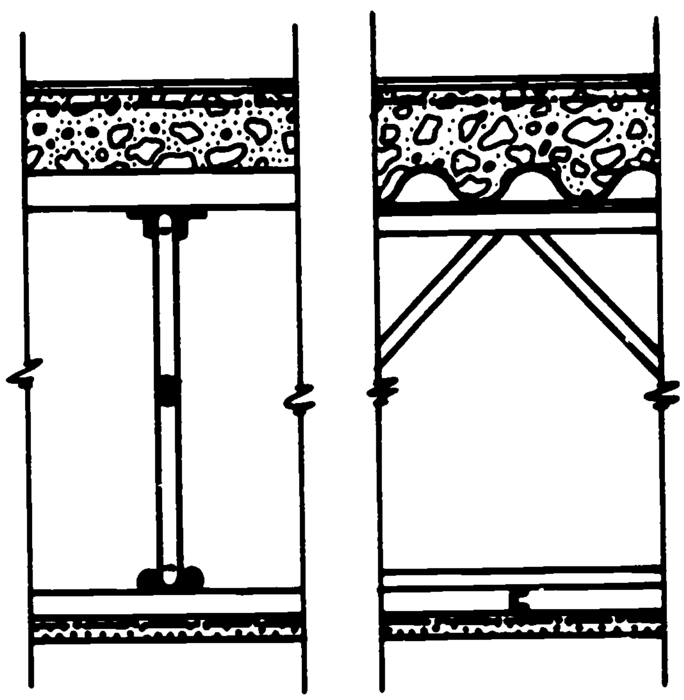
TEST REF: (a) 8-(136-6-63, 136-4-63); (b) 8-(136-6-63, 136-5-63)

DESCRIPTION: (a) 2 1/2-in.-thick sand gravel concrete, 148 lb/ft^3, on 28 gage corrugated steel units supported by 14-in. steel bar joists; 1/8-in.-thick asphalt tile cemented to concrete. On the ceiling side, 3/4-in. furring channels, 13 1/2 in. on centers, wire-tied to joists, 3.4 lb/yd^2 diamond mesh metal lath wire-tied to furring channels; 9/16-in. coat of perlite gypsum plaster with 1/16-in. white-coat finish.

(b) Similar to (a) except the asphalt tile was replaced with a carpet and felt pad.

Total thickness: 18 9/16 in.

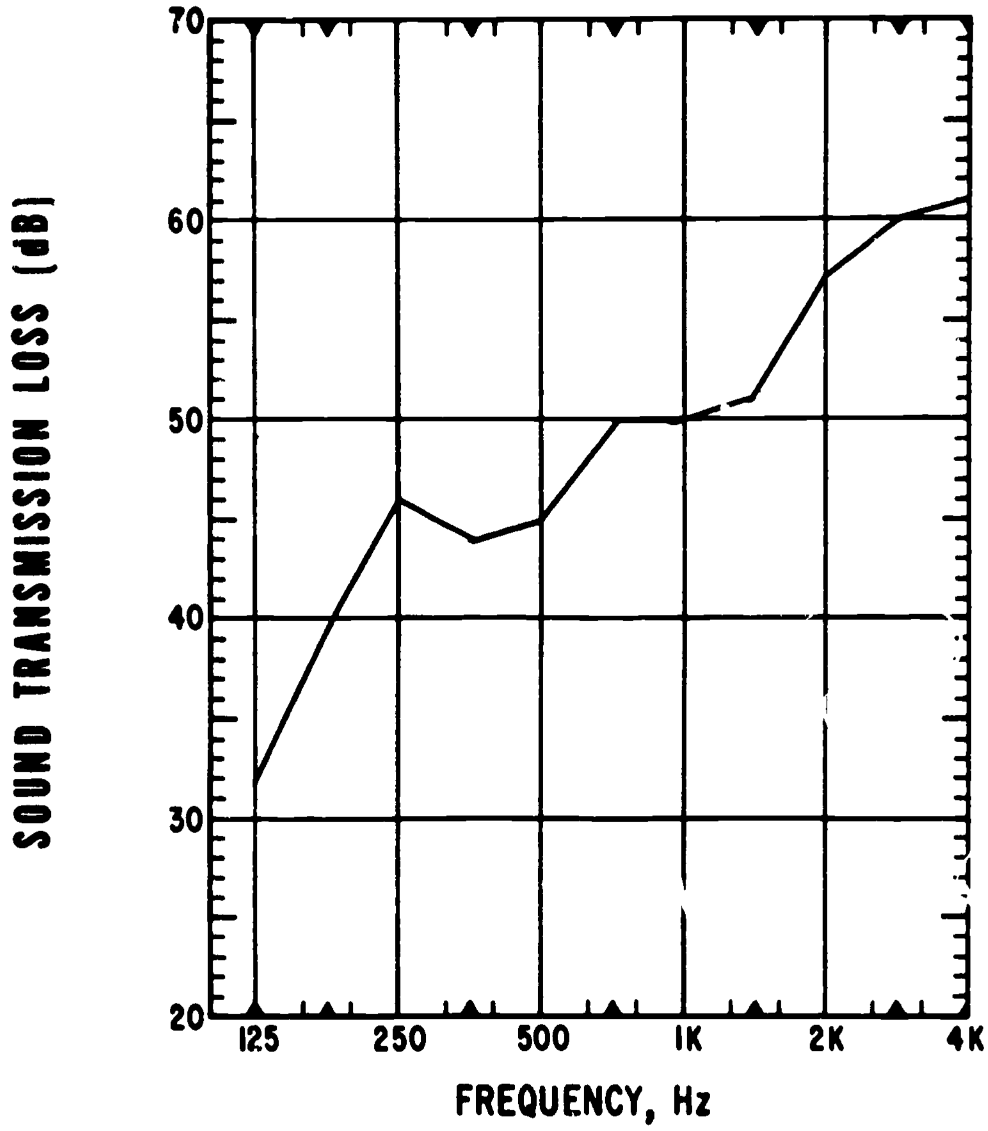
Area weight: 40.9 lb/ft^2

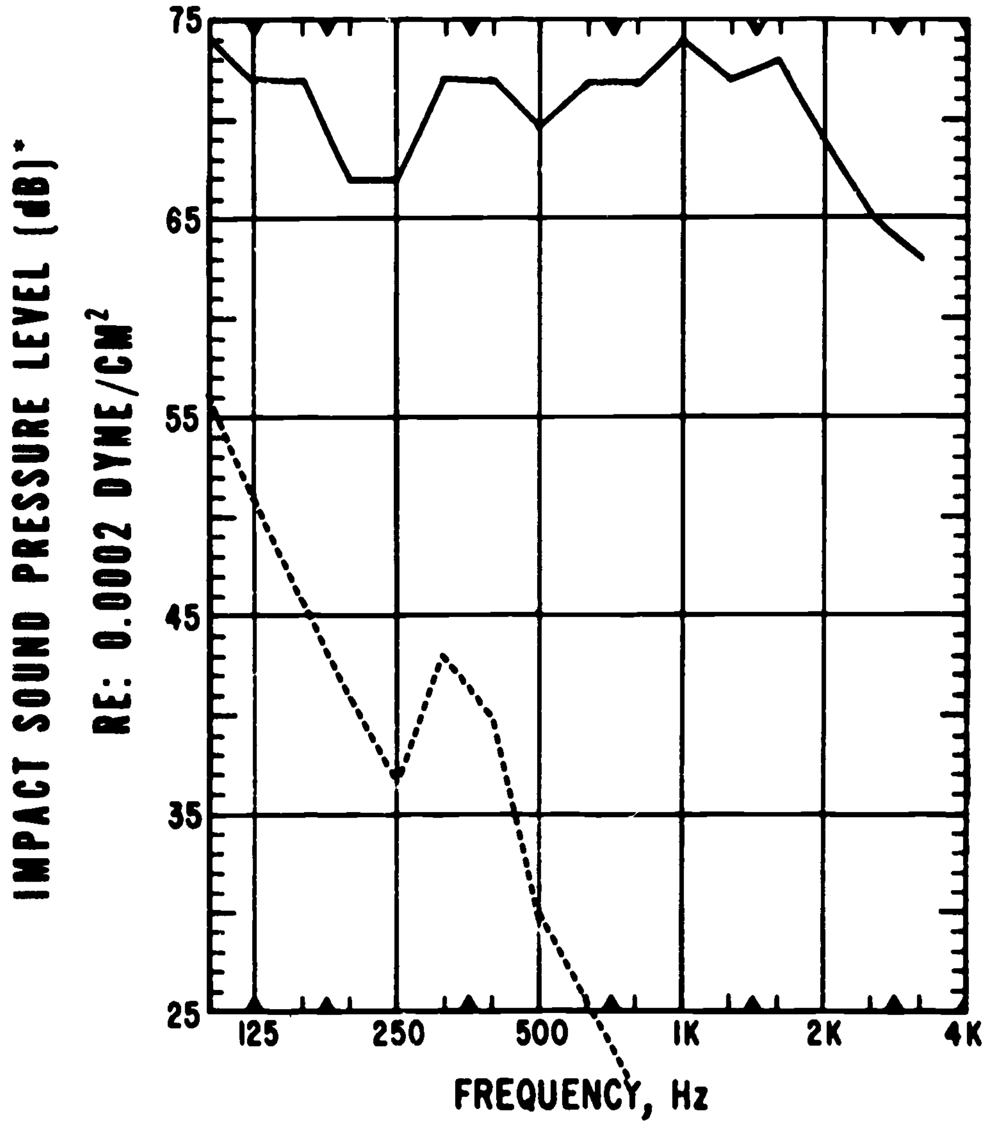


(a)———— STC = 49; IIC = 35; Fire Rating: 3 hrs. (est.)

(b)-------- IIC = 64

REMARKS: The airborne STL measurements were made without the floor coverings; however, these provide little additional airborne sound insulation and the data are applicable to the above structures. See F-57 for similar structure with perlite concrete.





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: STEEL JOIST WITH CONCRETE FLOOR

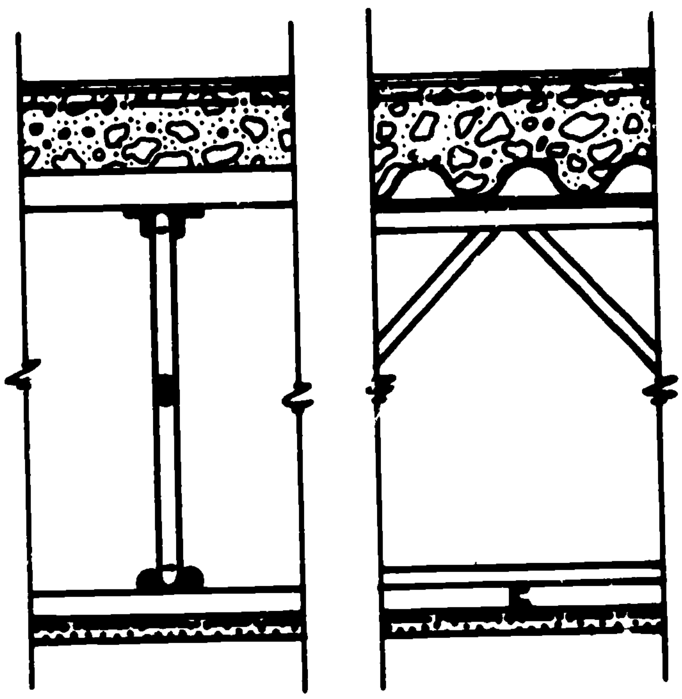
TEST REF: (a) 8-(136-3-63, 136-1-63); (b) 8-(136-3-63, 136-2-63)

DESCRIPTION: (a) 2 1/2-in.-thick perlite concrete, 72 lb/ft^3, on 28 gauge corrugated steel units supported by 14-in. steel bar joists; 1/8-in.-thick asphalt tile cemented to concrete. On the ceiling side, 3/4-in. furring channels, 13 1/2 in. on centers, wire-tied to joists, 3.4 lb/yd^2 diamond mesh metal lath wire-tied to furring channels, 9/16-in. coat of plaster with 1/16-in. white-coat finish.

(b) Similar to (a) except the asphalt tile was replaced with a carpet and felt pad.

Total thickness: 18 9/16 in.

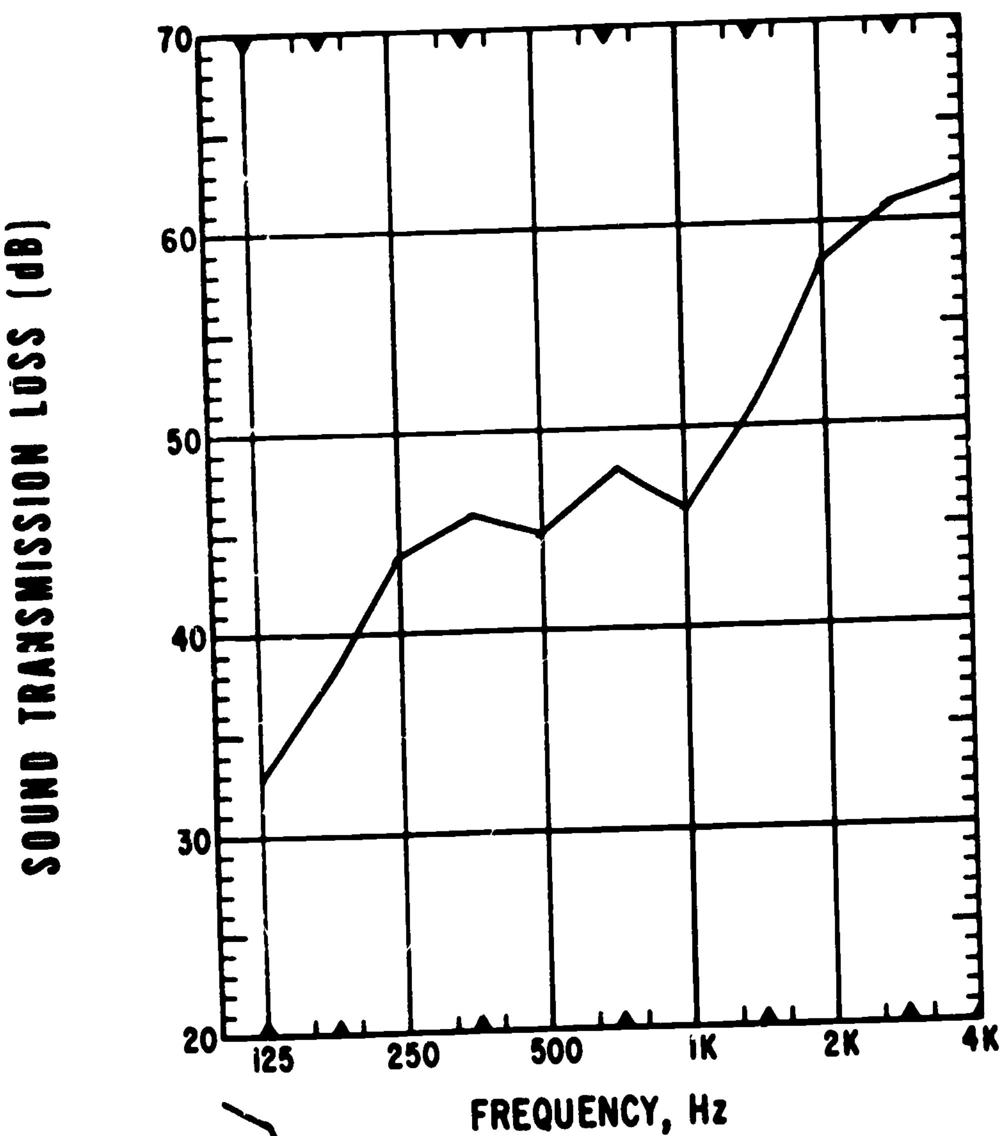
Area weight: 23.2 lb/ft^2

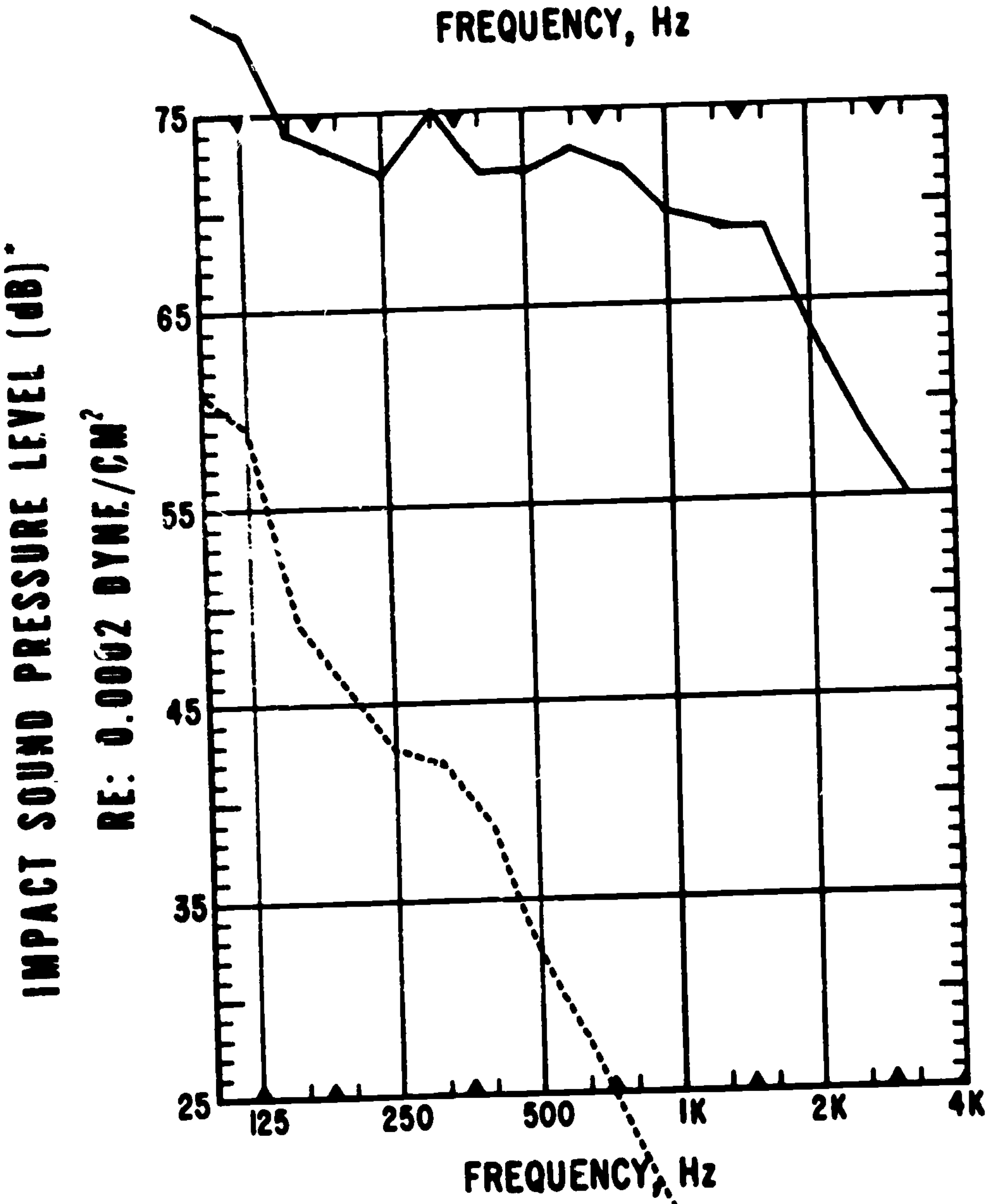


(a) ———— STC = 47; IIC = 37; Fire Rating: 3 hrs. (est.)

(b) ········ IIC = 59

REMARKS: The airborne STL measurements were made without the floor coverings; however, these provide little additional airborne sound insulation and these data are applicable to the above structures. See F-56 for similar structure with sand gravel concrete.





*1/3-octave band data normalized to $A_o = 10m^2$

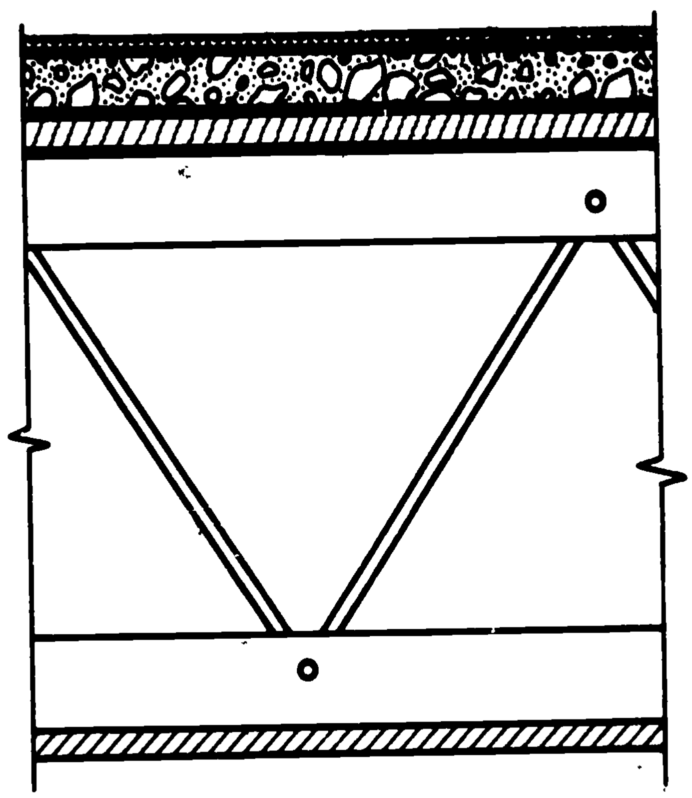
TYPE: STEEL JOIST, CONCRETE WITH CARPET AND PAD

TEST REF: 8-(224-38-65, 224-37-65)

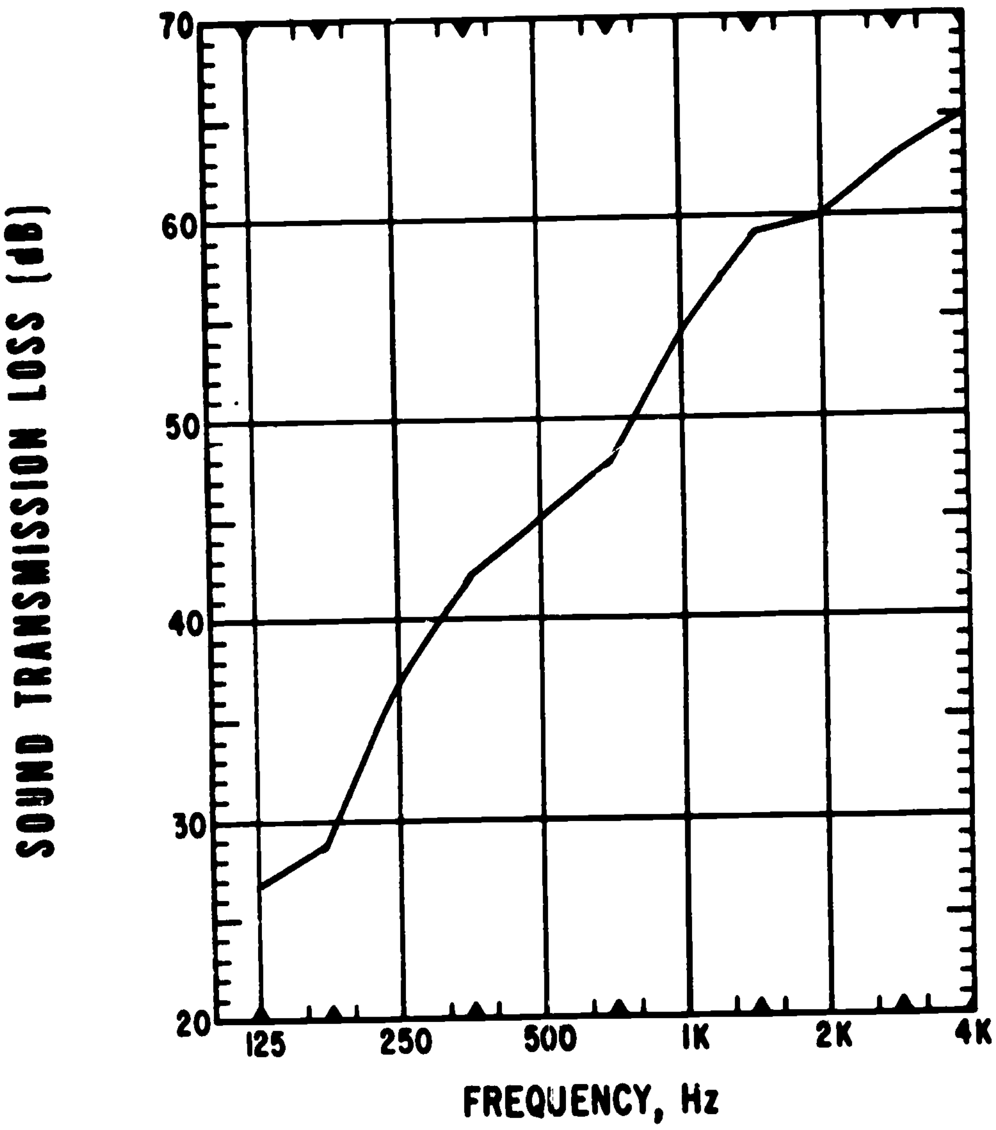
DESCRIPTION: 18-in. steel joists 16 in. on centers. On the floor side, 5/8-in.-thick C-D rough plywood nailed to joists, 1 5/8-in.-thick foamed concrete, 100 lb/ft^3, slab constructed on the plywood; concrete covered with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in. On the ceiling side, 5/8-in.-thick gypsum wallboard nailed to joists. All joints taped and finished and the entire periphery of the panel caulked and sealed.

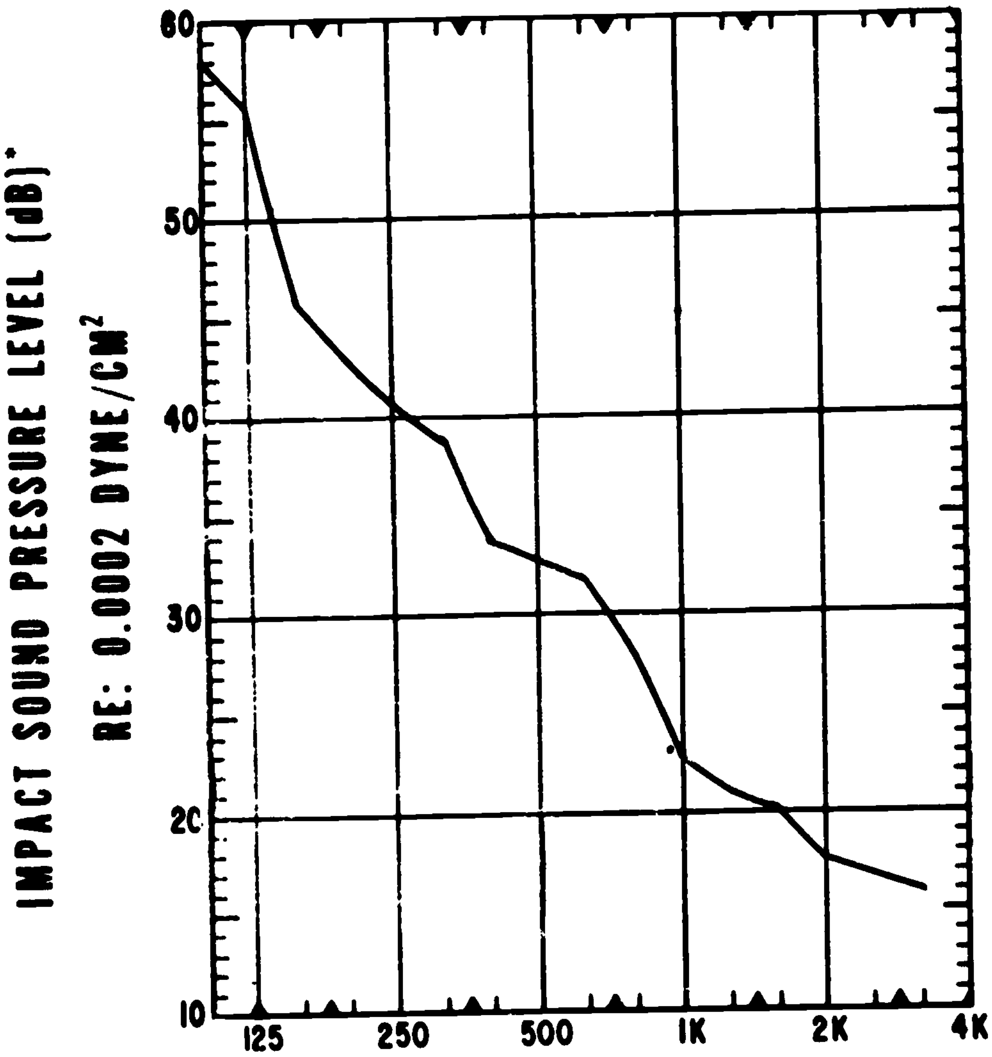
Total thickness: approximately 21 1/2 in.

Area weight: 20.4 lb/ft^2



STC = 47; IIC = 62; Fire Rating: 1 hr. (est.) - combustible





*1/3-octave band data normalized to $A_o = 10m^2$

TYPE: CONCRETE SLAB ON STEEL JOISTS

TEST REF: (a) 3-(725); (b) 3-(726); (c) 3-(727)

DESCRIPTION: (a) 7-in. steel bar joists spaced 27 in. on centers. On the floor side, 3/8-in. metal rib lath attached to top of joists, and 2-in.-thick poured concrete floor. On the ceiling side, resilient clips attached to joists held 3/4-in. metal furring channels 16 in. on centers; 3/8- by 16- by 48-in. plain gypsum lath held with wire clips and sheet metal end joint clips; 7/16-in. sanded gypsum plaster and 1/16-in. white-coat finish.

Total thickness: approximately 12 in.

Area weight: 40.2 lb/ft^2

(b) Similar to (a), except different resilient clips held the 3/4-in. metal furring channels.

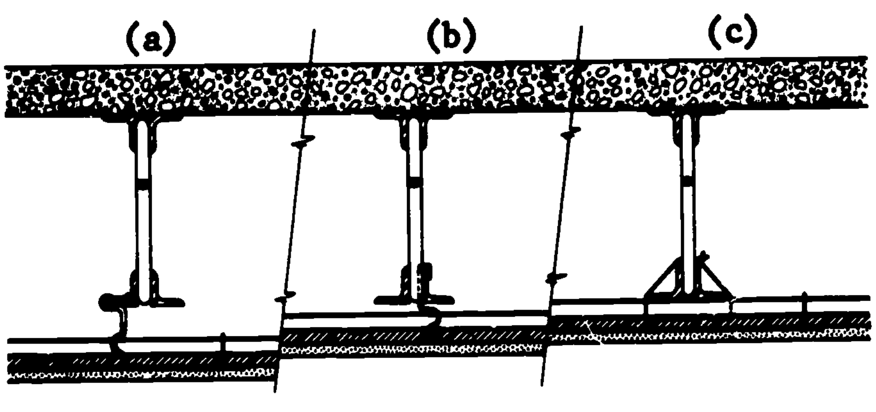
Total thickness: approximately 11 1/2 in.

Area weight: 39.2 lb/ft^2

(c) Similar to (a), except the 3/4-in. metal furring channels were wire-tied directly to the bottom of the joists.

Total thickness: approximately 11 in.

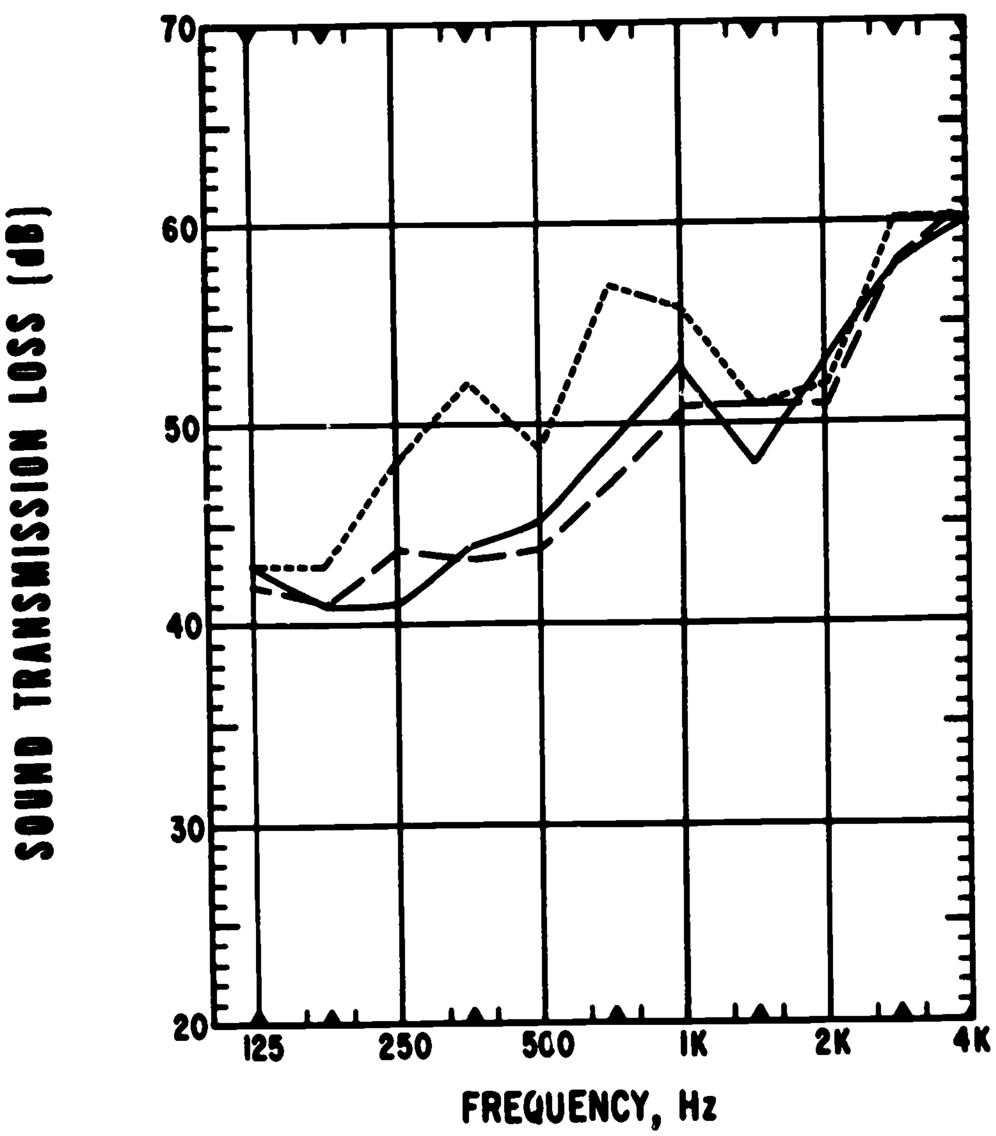
Area weight: 38.2 lb/ft^2

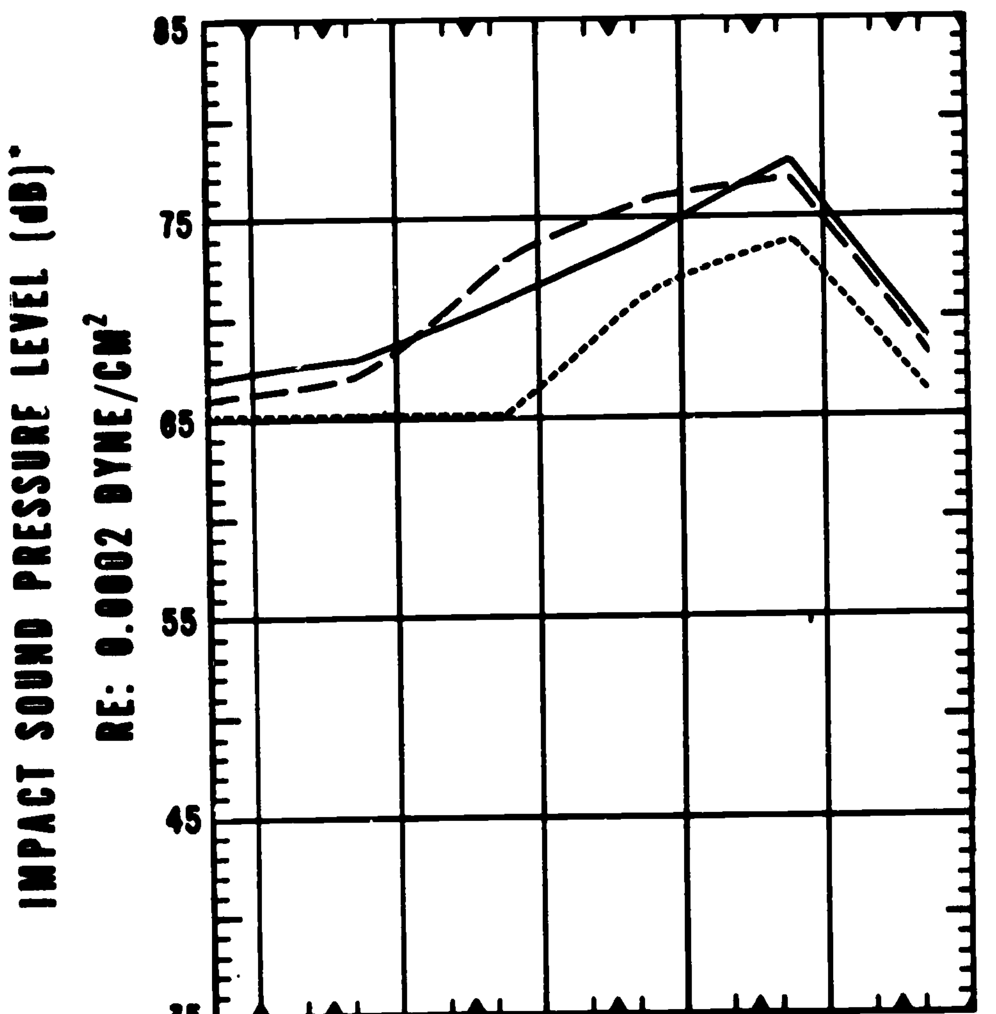


(a)———————STC = 48; IIC = 32; Fire Rating: 1 1/2 hrs. (est.)

(b)---------------- STC = 51; IIC = 35

(c)— — — — — -STC = 48; IIC = 33





*1/1-octave band data normalized to $A_o = 10m^2$

TYPE: CONCRETE SLAB ON STEEL JOISTS WITH FLOOR COVERINGS

TEST REF: (a) 3-(727); (b) 3-(727-A); (c) 3-(727-B); (d) 3-(727-D)

DESCRIPTION: (a) 7-in. steel bar joists spaced 27 in. on centers. On the floor side, 3/8-in. metal rib lath attached to top of joists, and 2-in.-thick poured concrete floor. On the ceiling side, 3/4-in. metal furring channels wire-tied to joists 16 in. on centers; 3/8- by 16- by 48-in. plain gypsum lath held with wire clips and sheet metal end joint clips; 7/16-in. sanded gypsum plaster and 1/16-in. white-coat finish.

Total thickness: approximately 11 in.

Area weight: 38.2 lb/ft^2

(b) Structure (a) with 1/8-in.-thick vinyl asbestos tile glued to concrete floor.

Total thickness: approximately 11 1/8 in.

(c) Structure (a) with nylon carpeting and foam rubber pad placed on the floor. The carpet pad had an uncompressed thickness of 1/4 in., backed with a woven jute fiber cloth. The carpet had 1/8-in. woven backing and 1/4-in. looped pile spaced 7 loops per inch with a total thickness of 3/8 in.

Total thickness: approximately 11 5/8 in.

Area weight: 39.0 lb/ft^2

(d) Structure (a) with 1/4-in.-thick cork tile glued to concrete floor.

Total thickness: approximately 11 1/4 in.

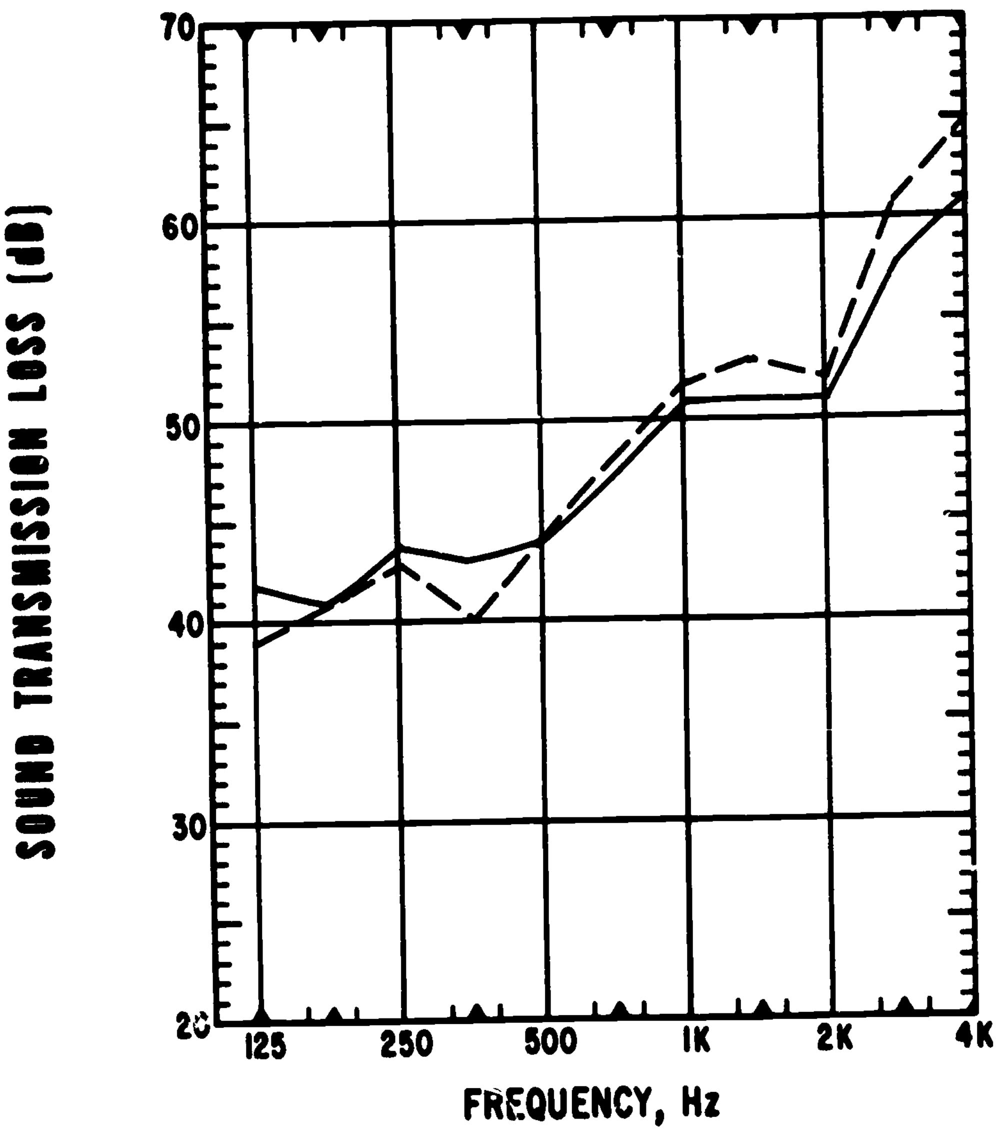
(a)————— STC = 48; IIC = 33; Fire Rating: 1 1/2 hrs. (est.)

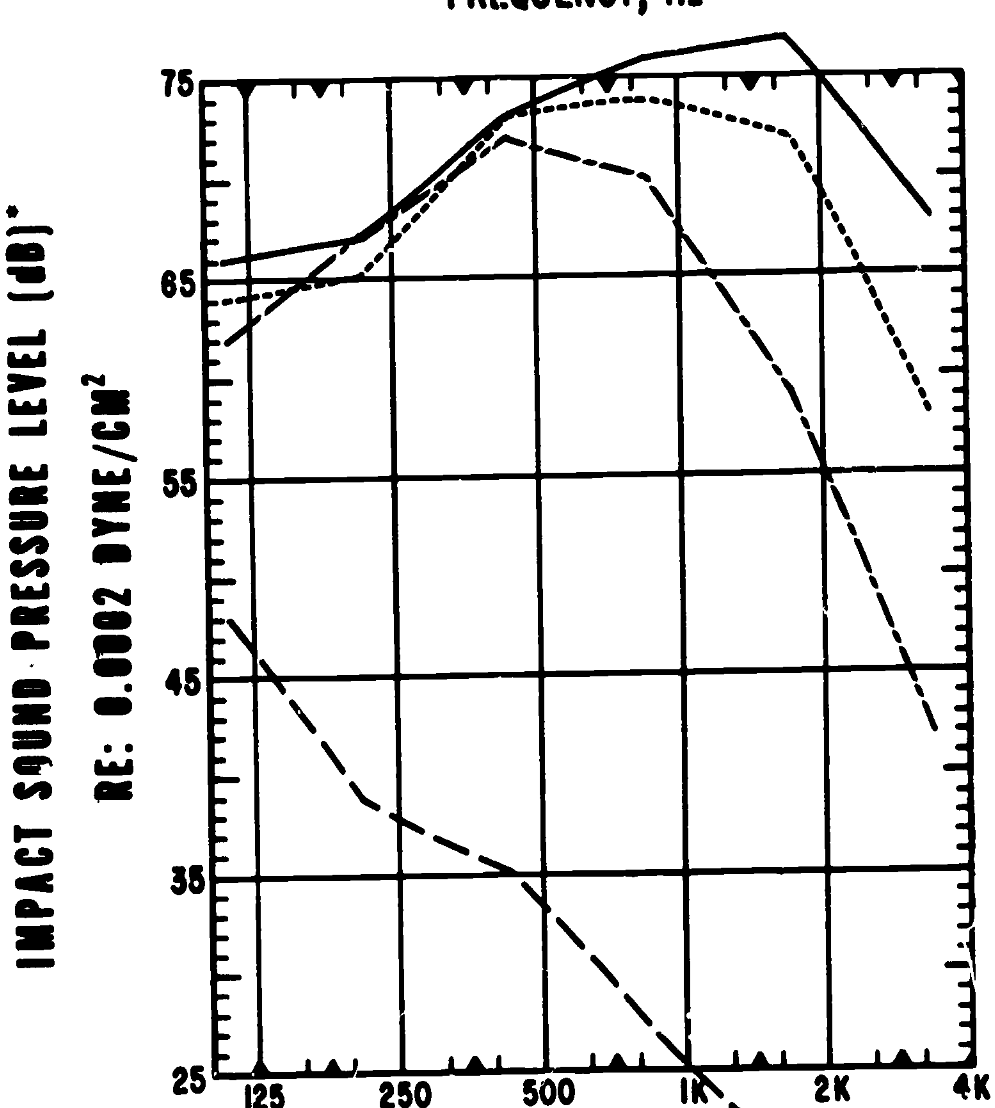
(b)··········· IIC = 38

(c)– – – – – – STC = 46; IIC = 74

(d)·—·—·—·— IIC = 47

REMARKS: See preceding data sheet for variations in ceiling application.





*1/1-octave band data normalized to $A_o = 10m^2$

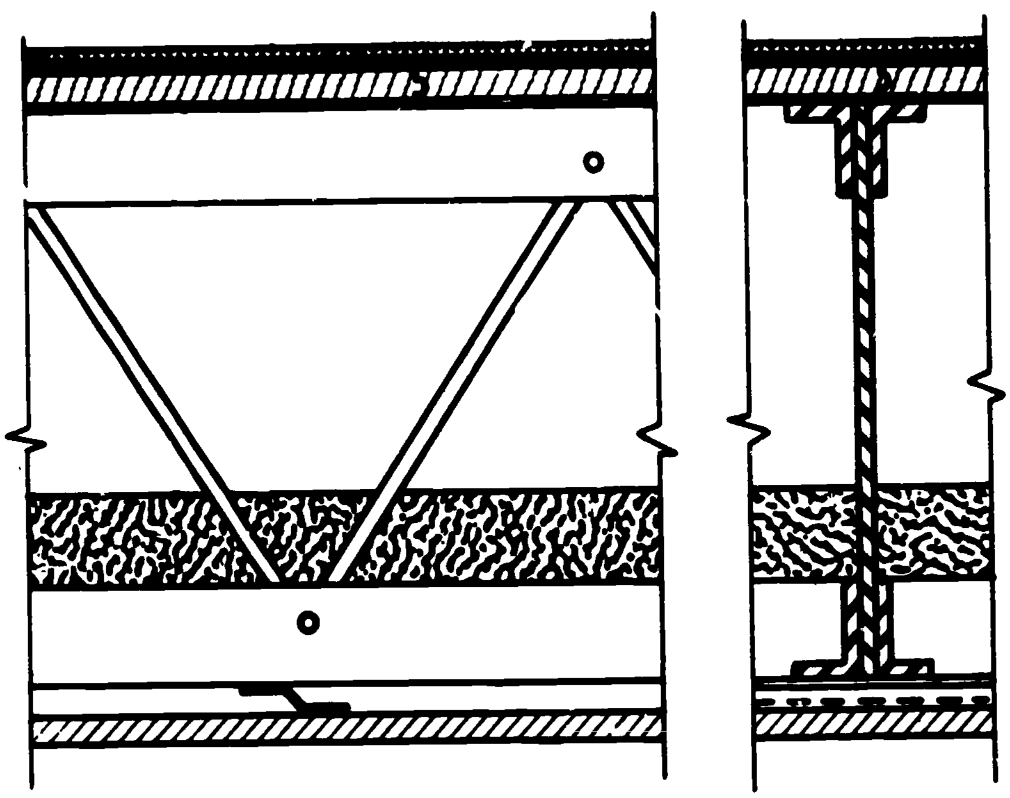
TYPE: STEEL JOIST WITH INSULATION, CARPET AND PAD, RESILIENT CEILING

TEST REF: 8-(224-36-65, 224-35-65)

DESCRIPTION: 18-in. steel joists 32 in. on centers with 3-in.-thick fibered glass blankets placed between joists. On the floor side, 1 1/8-in.-thick tongue-and-groove plywood (grademarked 2-4-1) nailed to joists; plywood covered with an all-hair pad (40 oz/yd^2) and an all-wool pile (44 oz/yd^2) carpet. The total weight of the carpet was 4.14 lb/yd^2 and the total thickness was 3/8 in. On the ceiling side, resilient furring channels, 24 in. on centers, screwed perpendicular to joists. 5/8-in.-thick gypsum wallboard screwed 12 in. on centers to channels. All joints taped and finished and the entire periphery of the panel caulked and sealed.

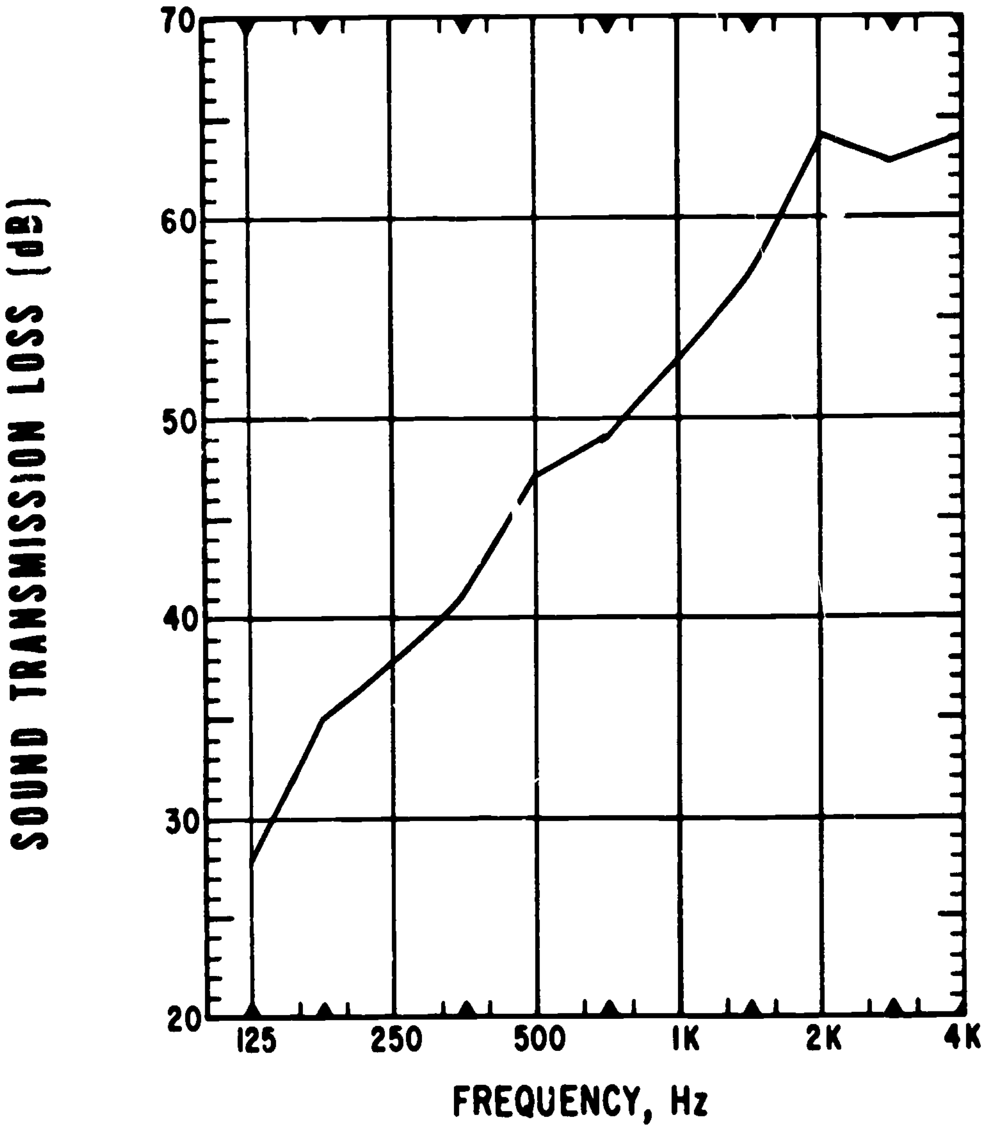
Total thickness: approximately 21 in.

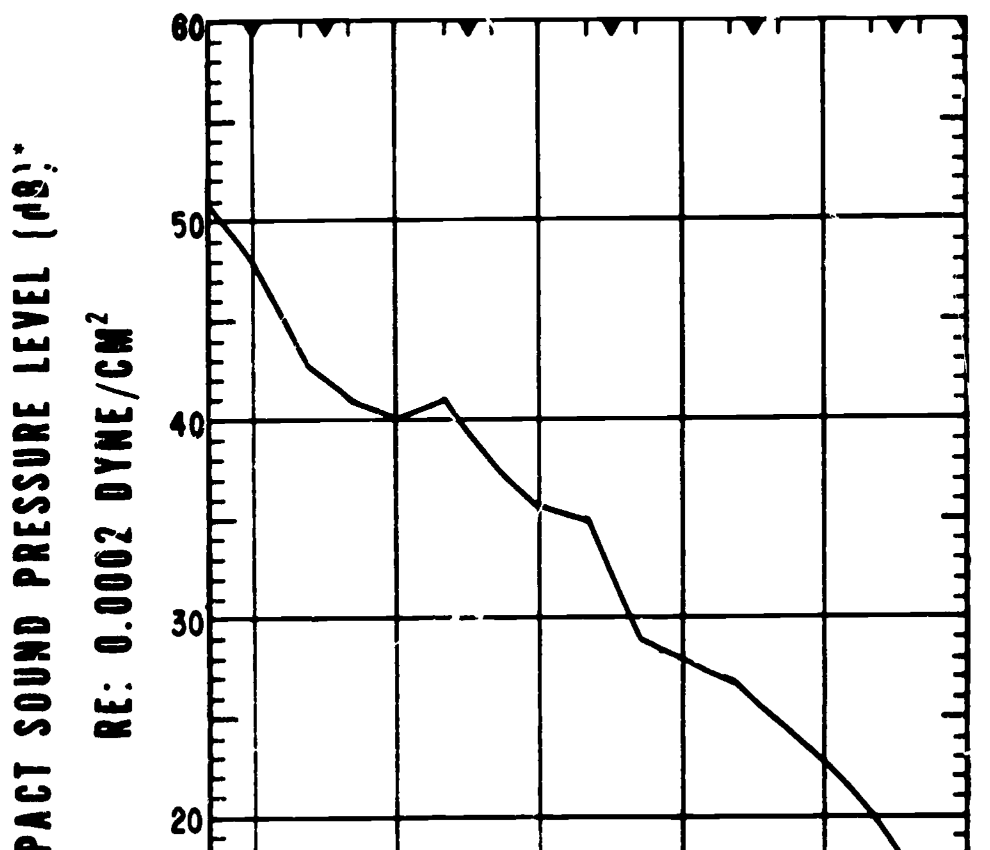
Area weight: 10.5 lb/ft^2



STC = 47; IIC = 69; Fire Rating: 45 min. (est.) - combustible

REMARKS: CAUTION - These measurements were conducted in the laboratory where structure-borne flanking transmission was negligible. Resiliently hung ceiling structures in field installations cannot perform as effectively unless flanking paths along vertical walls are minimized. (See text.)





*1/3-octave band data normalized to $A_o = 10m^2$

LIST OF REFERENCES FOR TEST DATA

1. Parkin, P.H., Purkis, H.J., and Scholes, W.E., Field Measurements of Sound Insulation between Dwellings, (London: Her Majesty's Stationery Office, 1960).

2. Staff of the Sound Section, "Sound Insulation of Wall and Floor Constructions", Building Materials and Structures Report 144, National Bureau of Standards, February 25, 1955.

3. Berendt, R.D., and Winzer, G.E., "Sound Insulation of Wall, Floor, and Door Constructions", National Bureau of Standards Monograph 77, National Bureau of Standards, November 30, 1964.

4. Beranek, L.L., Noise Reduction, (New York: McGraw-Hill Book Company, Inc., 1960).

5. Kodaras, M.J., and Hansen, R.A., "Measurement Sound-Transmission Loss in the Field", The Journal of the Acoustical Society of America, Vol. 36, No. 3 (March 1964), pp. 565-569.

6. Solutions to Noise Control Problems in the Construction of Houses, Apartments, Motels and Hotels, (2nd. Ed.; Toledo, Ohio: Owens-Corning Fiberglas Corporation, February 1964).

7. Riverbank Acoustical Laboratories, Armour Research Foundation of Illinois Institute of Technology, Geneva, Illinois.
   (a) A.I.A. File 20-10-D, 1964.
   (b) A.I.A. File 23-L, 23-M, 1964.

8. Michael J. Kodaras Acoustical Laboratories, New York, New York.

9. Acoustical Consultants, Inc., San Francisco, California.

10. National Research Council, Ottawa, Canada.

11. van den Eijk, J., and Kasteleyn, M.L., "Research Carried Out in the Experimental Dwellings on the Transmission of Air-borne and Impact Sound via Walls and Floors", Report No. 1 of the Research Institute of Public Health Engineering T.N.O. and Report No. 27 of the Technical Physics Department T.N.O. and T.H., (The Hague: Research Institute for Public Health Engineering T.N.O., and Delft: Technical Physics Department T.N.O. and T.H., September 1950).
    (a) Supplement II, "Results of the Measurements carried out on Floors", (November 1950).
    (b) Supplement III, "Results of the Measurements carried out on Floor Coverings", (July 1951).

12. Ingemansson, S., and Kihlman, T., "Sound Insulation of Frame Walls", Transactions of Chalmers University of Technology No. 222, (Gothenburg, Sweden: Chalmers University of Technology, 1959).

13. Cedar Knolls Acoustical Laboratories, Cedar Knolls, New Jersey.

14. National Bureau of Standards

15. Ostergaard, P.B., Cardinell, R.L., and Goodfriend, L.S., "Transmission Loss of Leaded Building Materials", The Journal of the Acoustical Society of America, Vol. 35, No. 6, (June 1963), pp. 837-843.

16. Ostergaard, P.B., and Goodfriend, L.S., "Transmission Loss of Leaded Building Materials-II, Presented at the meeting of the Acoustical Society of America, May 16, 1963, New York, New York.

17. Kasteleyn, M.L., and van den Eijk, J., "Sound Insulation of Floors and the Influence of Floor Coverings", Report No. 22 of the Research Institute for Public Health Engineering T.N.O. and Publication No. 56 of the Technical Physics Department T.N.O. and T.H., (The Hague: Research Institute for Public Health Engineering T.N.O., and Delft: Technical Physics Department T.N.O. and T.H., December 1954).

18. Geiger and Hamme, Inc., Ann Arbor, Michigan.

SELECTED BIBLIOGRAPHY

Beranek, L.L., Noise Reduction, (New York: McGraw-Hill Book Company, Inc., 1960).

Berendt, R.D., and Winzer, G.E., "Sound Insulation of Wall, Floor, and Door Construction", National Bureau of Standards Monograph 77, National Bureau of Standards, November 30, 1964.

Constable, J.E.R., and Constable, K.M., The Principles & Practices of Sound-Insulation, (London: Sir Isaac Pitman & Sons, Ltd., 1949).

Cullum, D.J.W., The Practical Application of Acoustic Principles, (London: E & F. N. Spon, Ltd., 1949).

FHA No. 750, A guide to "Impact Noise Control in Multifamily Dwellings", January 1963.

Harris, Cyril M., Handbook of Noise Control, (New York: McGraw-Hill Book Company, Inc., 1957).

Ingemansson, S., and Kihlman, J., "Sound Insulation of Frame Walls", Transactions of Chalmers University of Technology No. 222, (Gothenburg, Sweden: Chalmers University of Technology, 1959).

Ingerslev, Fritz, Acoustics in Modern Building Practice, (London: The Architectural Press, 1952).

Knudsen, V.O., and Harris, D.M., Acoustical Designing in Architecture, (New York: John Wiley & Sons, Inc., 1950).

Parkin, P.H., and Humphreys, H.R., Acoustics, Noise and Buildings, (New York: Frederick A. Praeger, 1958).

Parkin, P.H., Purkis, H.J., and Scholes, W.E., Field Measurements of Sound Insulation Between Dwellings, (London: Her Majesty's Stationery Office, 1960).

Solutions to Noise Control Problems in the Construction of Houses, Apartments, Motels and Hotels, (2nd. Ed.; Toledo, Ohio: Owens-Corning Fiberglas Corporation, February 1964).

"Sound Insulation of Wall and Floor Constructions", Building Materials and Structures Report 144, National Bureau of Standards, February 25, 1955.

van den Eijk, J., and Kasteleyn, M.L., "Research Carried Out in the Experimental Dwellings on the Transmission of Air-Borne and Impact Sound via Walls and Floors", Report No. 1 of the Research Institute of Public Health Engineering T.N.O. and Report No. 27 of the Technical Physics Department T.N.O. and T.H. (The Hague: Research Institute for Public Health Engineering T.N.O., and Delft Technical Physics Department T.N.O. and T.H., September 1950).
Supplement II, "Results of the Measurements carried out on Floors", (November 1950).
Supplement III, "Results of the Measurements carried out on Floor Coverings", (July 1951).

"Wood Floors for Dwellings", Agriculture Handbook No. 204, U.S. Department of Agriculture Forest Service, Forest Products Laboratory.

CONTRIBUTORS OF DATA

1. Adams and Westlake Company
2. Amerada Glass Corporation
3. American Elumin Company
4. American Plywood Association
5. Celotex Corporation
6. Consolidated Edison Company of New York
7. Decatur Iron and Steel Company
8. Dodge Cork Company
9. Eichler Homes
10. E. L. Bruce Company
11. Fiberboard Paper Products Corporation
12. Frank B. Miller Manufacturing Company
13. General Radio Company
14. Great Lakes Carbon Corporation
15. Gypsum Association
16. Hardwood Products Corporation
17. Hartford Insurance Company
18. Homasote Company
19. Hough Manufacturing Corporation
20. Insulation Board Institute
21. Jamison Cold Storage Door Company
22. Kaiser Gypsum Company
23. Laminated Glass Corporation
24. Lead Industries Association
25. National Bureau of Standards
26. National Gypsum Company
27. National Research Council, Canada
28. Owens-Corning Fiberglas Corporation
29. Perlite Institute
30. Polarpane Corporation
31. Riverbank Acoustical Laboratories
32. Trus-Dek Corporation
33. United States Gypsum Company
34. Vermiculite Institute
35. Wood Conversion Company

INDEX I. Sound Transmission Class of Wall Constructions

Type Code:

a. wooden stud
b. metal stud
c. masonry
d. concrete
e. staggered stud
f. plaster
g. gypsum wallboard
h. w/resilient element
i. absorbent blankets or fill
j. fiber board
k. lead
l. gypsum core board
m. double wall

STC	Type	Data Sheet No.
63	d,f	W-4
62*	c,f,j,m	W-23
60*	c,d,f,m	W-26
56	c	W-7
56*	c,f	W-8
56*	g,i,l,m	W-87
55*	b,g,i	W-62 (b)
55*	b,g,i	W-63
54*	c,f,m	W-22 (b)
54	b,f,h	W-52
54	b,e,g,i	W-68 (a)
54*	g,i,l,m	W-86
53*	d,f	W-2
53	c,f,h	W-15 (b)
53	a,f,h	W-41 (d)
53	b,g,i	W-66
52*	d,f,j	W-3
52*	c,f	W-6
52	c,f,h	W-18 (b)
52*	c,f,h,i	W-20
52*	c,f,m	W-25
52	a,f,h	W-41 (a)
52*	b,g,j	W-59
52	b,g,i	W-61
52*	b,g,i	W-64
52	b,e,g,i	W-68 (b)
51	c,f,h	W-18 (a)
51	a,f,h	W-41 (b)
51	b,f	W-44 (a)
51	b,g,h,i	W-67
51	g,l,m	W-83
50	c,k	W-12 (b)
50	a,f,h	W-41 (c)
50*	b,g,j	W-57
50*	b,g,j	W-58 (a)
50	b,g,i	W-60
50	g,i,l,m	W-85 (b)
49	c,f,h	W-17 (b)
49*	c,f,m	W-22 (a)
48	c,d	W-9
48	a,g,k	W-28 (c)
48	a,e,f,i	W-36 (b)
48	a,g,h	W-39 (b)
48	a,f,h	W-40 (b)

*Field measurement.

INDEX I. Sound Transmission Class of Wall Constructions (Continued)

Type Code:

a. wooden stud
b. metal stud
c. masonry
d. concrete
e. staggered stud
f. plaster
g. gypsum wallboard
h. w/resilient element
i. absorbent blankets or fill
j. fiber board
k. lead
l. gypsum core board
m. double wall

STC	Type	Data Sheet No.	STC	Type	Data Sheet No.
48	b,f,k	W-43 (c)	45	c,d	W-10 (b)
48	b,g	W-46	45	c,f	W-11 (b)
48*	b,f,h	W-51 (b)	45	c,f,h	W-16
48*	b,f,h,i	W-53	45	a,f,i	W-38
48*	b,g,i	W-65	45	b,f,h	W-50 (a)
48	b,f	W-72	45*	b,g,i	W-62 (a)
			45	g,i,l,m	W-84
47	d	W-1	45	g,l,m	W-85 (a)
47	c,f,h	W-17 (a)			
47*	c,f,h	W-19	44	c	W-12 (a)
47	a,g,k	W-28 (b)	44	a,f	W-30 (b)
47	a,f,k	W-31 (b)	44	a,e,g	W-34 (a)
47	a,g,h	W-39 (a)	44	a,e,g	W-34 (b)
			44	a,e,g	W-35 (a)
47	b,f	W-44 (b)	44	a,f,h	W-40 (a)
47*	b,f,h,i	W-48	44*	b,f,h	W-50 (b)
47*	b,f,h	W-51 (a)	44	g,l,k	W-81 (b)
47	b,g	W-55 (b)			
47*	b,g	W-56	43	c,d	W-10 (a)
47*	b,g,j	W-58 (b)	43*	c,f,h	W-18 (c)
47	b,f,m	W-73 (a)	43*	d,j,m	W-21
			43*	c,f,m	W-24
46	c,f	W-11 (a)	43	a,e,f	W-35 (b)
46	c,f,h	W-15 (a)			
46	a,f	W-30 (a)	43	a,e,f	W-36 (a)
46	a,f	W-31 (a)	43	b,f,k	W-43 (b)
46	a,f,k	W-31 (c)	43	b,f,h	W-47
46	a,e,g,i	W-37	43	b,f,h	W-49
46	b,f	W-70 (a)	43	b,f	W-70 (b)

*Field measurement.

INDEX I. Sound Transmission Class of Wall Constructions (Continued)

Type Code:

a. wooden stud
b. metal stud
c. masonry
d. concrete
e. staggered stud
f. plaster
g. gypsum wallboard
h. w/resilient element
i. absorbent blankets or fill
j. fiber board
k. lead
l. gypsum core board
m. double wall

STC	Type	Data Sheet No.	STC	Type	Data Sheet No.
42*	c,f	W-5	37	a,g	W-27
42	c,f	W-14 (a)	37*	b,f	W-45 (b)
42	a,f,j	W-33	37*	b,e,g	W-69
42	b,f	W-44 (c)	37	b,f	W-75 (a)
42	b,e,f	W-71	37	g,l	W-82 (b)
41	a,g	W-32 (b)	36	a,g	W-29
41	b,f	W-42 (c)	36	f	W-74 (a)
41	b,f	W-43 (a)	36	b,f	W-76 (a)
41	b,g	W-55 (a)	36	b,f	W-76 (b)
			36	g,l	W-80
40	c,f	W-13	34*	c,f	W-14 (b)
40	a,g	W-32 (a)	34	f	W-79 (a)
39	a,g	W-27	33	g,l	W-82 (a)
39	a,g	W-28 (a)	32*	b,f	W-77 (b)
39	b,f	W-42 (a)	31	f	W-74 (b)
39	b,f,i	W-42 (b)	31	b,f	W-78 (a)
39	b,g	W-54 (a)	29	b,f	W-75 (b)
39	b,f	W-77 (a)	29*	b,f	W-78 (b)
38	a,g	W-27			
38	b,f	W-45 (a)			
38	b,g	W-54 (b)			
38*	b,f,m	W-73 (b)			
38	f	W-79 (b)			
38	g,l	W-81 (a)			

*Field measurement.

INDEX II. Sound Transmission Class of Floor-Ceiling Constructions

Type Code:

a. wooden joist
b. metal joist
c. concrete or masonry
d. plaster ceiling
e. gypsum board ceiling
f. w/resilient elements
g. w/absorbent blankets
h. w/separate ceiling joists

STC	IIC	Type	Data Sheet No.
55*	57*	c,d,f	F-14
55*	53*	c,d,f	F-19
54*	64*	c,d,f	F-17 (b)
54*	51*	c,d	F-13 (a)
54*	35*	c,d	F-6
53	74	a,c,e,f,g	F-50 (b)
53*	62*	c,d,f	F-17 (a)
53*	53*	c,d	F-13 (b)
52	80	a,e,g,h	F-48
52	51	a,e,f,g	F-52
52	49	a,e,f,g	F-53 (a)
52	48	a,e,f	F-46 (a)
52*	47*	c,d,f	F-18 (a)
51	78	a,e,f,g	F-53 (b)
51*	58*	c,d	F-7 (b)
51*	53*	c,d,f	F-10
51*	48*	c,d	F-7 (a)
51*	47*	c	F-4
51	35	b,c,d,f	F-59 (b)
50	70	a,e,f,g	F-42 (b)
50*	57*	a,d,f	F-51 (b)
50*	53*	c,e,f	F-25
50*	51*	c,e	F-27
50*	49*	c,d,f	F-18 (b)
50*	49*	c,d,f	F-29
50*	48*	c,d	F-16
50	47	a,e,f	F-46 (b)
50	47	a,c,e,f,g	F-50 (a)
50*	46*	c,d	F-20 (c)
49*	48*	c,d	F-9
49	46	a,e,f,g	F-40 (b)
49	35	b,c,d	F-56 (a)
49*	30*	c,d	F-15
49*	26*	c,d	F-5 (b)
48*	47*	c,d	F-12
48	33	b,c,d	F-59 (c)
48	33	b,c,d	F-60 (a)
48	32	b,c,d,f	F-59 (a)
47	69	a,e,f,g	F-45 (b)
47	69	b,e,f,g	F-61
47	66	a,e,f	F-41 (b)
47	66	a,c,e	F-49
47	62	b,c,e	F-58
47*	60*	c,d	F-20 (b)
47*	46*	c,d	F-5 (c)
47*	42*	c,d	F-24
47*	40*	c,d	F-20 (a)
47	39	a,e,f	F-39 (b)
47	37	b,c,d	F-57 (a)
47*	31*	c,d	F-5 (a)

*Field measurement.

INDEX II. Sound Transmission Class of Floor-Ceiling Constructions (Continued)

Type Code:

a. wooden joist
b. metal joist
c. concrete or masonry
d. plaster ceiling
e. gypsum board ceiling
f. w/resilient elements
g. w/absorbent blankets
h. w/separate ceiling joists

STC	IIC	Type	Data Sheet No.	STC	IIC	Type	Data Sheet No
46	85	a,c,e,f,g	F-50 (c)	38	57	a,e	F-37 (a)
46	74	b,c,d	F-60 (c)	38	56	a,e	F-41 (a)
46*	47*	c,d	F-11	38	34	a,e	F-46 (c)
46*	46*	a,d,f	F-51 (a)	37	33	a,e	F-38 (a)
46*	42*	c,d	F-23	37	32	a,e	F-39 (a)
46*	30*	c,d	F-21 (a)	35	39	a,e	F-36 (a)
46*	24*	c,d	F-21 (b)	35*	36*	a,e	F-31
45	44	a,e,f	F-44	34*	32*	a,e	F-30
45	44	a,e,f,g	F-45 (a)	29*	32*	a,e	F-35 (a)
45*	31*	c,d	F-26				
44*	48*	c,d	F-28				
44*	43*	a,e,g,h	F-47				
44	25	c	F-1 (a)				
43*	43*	a,d	F-32 (b)				
42*	32*	c	F-22				
41	38	a,e	F-43				
41*	36*	a,d	F-32 (a)				
40	32	a,e,g	F-40 (a)				
39	58	a,e,g	F-42 (a)				
39*	45*	a,d	F-33 (b)				
39*	40*	a,d	F-33 (a)				
39*	37*	a,e	F-34				

*Field measurement.

INDEX III. Impact Insulation Class of Floor-Ceiling Constructions

Type Code:

a. wooden joist
b. metal joist
c. concrete or masonry
d. plaster ceiling
e. gypsum board ceiling
f. w/resilient ceiling element
g. w/resilient floor element
h. w/carpeting
i. w/absorbent blankets
j. w/separate ceiling joists

IIC	STC	Type	Data Sheet No.
85	46	a,c,e,f,h,i	F-50 (c)
84	44†	c,h	F-2 I(b)
80	52	a,e,h,i,j	F-48
80	44†	c,h	F-2 I(a)
78	51	a,e,f,g,h,i	F-53 (b)
74	53	a,c,e,f,h,i	F-50 (b)
74	46	b,c,d,h	F-60 (c)
70	50	a,e,f,h,i	F-42 (b)
69	47	a,e,f,h,i	F-45 (b)
69	47	b,e,f,h,i	F-61
66	47	a,e,f,h	F-41 (b)
66	47	a,c,e,h	F-49
64*	54*	c,d,g	F-17 (b)
64	49†	b,c,d,h	F-56 (b)
63	35†	b,e,h	F-55 (b)
62*	53*	c,d,g	F-17 (a)
62	47	b,c,e,h	F-58
60*	47*	c,d,h	F-20 (b)
59	47†	b,c,d,h	F-57 (b)
58*	51*	c,d,h	F-7 (b)
58	39	a,e,h,i	F-42 (a)
58	35†	b,e,h	F-55 (a)
57*	55*	c,d,g	F-14
57*	50*	a,d,g	F-51 (b)
57	38	a,e,h	F-37 (a)
57	38†	a,e,h	F-37 (b)
56	38	a,e,h	F-41 (a)
56*	29†	a,e,h	F-35 (b)
53*	55*	c,d,g	F-19
53*	53*	c,d,g	F-13 (b)
53*	51*	c,d,g	F-10
53*	50*	c,e,g	F-25
53	37†	a,e,h	F-38 (b)
52	44†	c,g	F-3 I(e)
51*	54*	c,d,g	F-13 (a)
51	52	a,e,f,g,i	F-52
51*	50*	c,e	F-27
49	52	a,e,f,g,i	F-53 (a)
49*	50*	c,d,g	F-18 (b)
49*	50*	c,d,g	F-29
49	48†	c,g	F-8 (b)

*Field measurement.

†Estimated on the basis of similar structures.

INDEX III. Impact Insulation Class of Floor-Ceiling Constructions (Continued)

Type Code:

a. wooden joist
b. metal joist
c. concrete or masonry
d. plaster ceiling
e. gypsum board ceiling
f. w/resilient ceiling element
g. w/resilient floor element
h. w/carpeting
i. w/absorbent blankets
j. w/separate ceiling joists

IIC	STC	Type	Data Sheet No.
48	52	a,e,f,g	F-46 (a)
48*	51*	c,d	F-7 (a)
48*	50*	c,d	F-16
48*	49*	c,d,g	F-9
48	44†	c,g	F-3 I(b)
48	44†	c,g	F-3 II(b)
48*	44*	c,d	F-28
47*	52*	c,d,g	F-18 (a)
47*	51*	c,g	F-4
47	50	a,e,f	F-46 (b)
47	50	a,c,e,f,i	F-50 (a)
47	48†	c,g	F-8 (a)
47*	48*	c,d	F-12
47	48†	b,c,d	F-60 (d)
47*	46*	c,d	F-11
46*	50*	c,d	F-20 (c)
46	49	a,e,f,i	F-40 (b)
46*	47*	c,d,g	F-5 (c)
46*	46*	a,d,g	F-51 (a)
45	44†	c	F-2 II(a)
45*	44†	c	F-2 II(b)
45	44†	c,g	F-3 I(d)
45	44†	c,g	F-3 II(a)
45*	39*	a,d,h	F-33 (b)
45	35†	b,e	F-54 (b)

IIC	STC	Type	Data Sheet No.
44	45	a,e,f	F-44
44	45	a,e,f,i	F-45 (a)
43	44†	c,g	F-3 I(c)
43	44†	c,g	F-3 II(c)
43*	44*	a,e,i,j	F-47
43*	43*	a,d	F-32 (b)
43	35†	a,e	F-36 (b)
42*	47*	c,d	F-24
42*	46*	c,d	F-23
42	44†	c,g	F-3 II(d)
41	44†	c	F-3 I(a)
40*	47*	c,d	F-20 (a)
40*	39*	a,d	F-33 (a)
40	35†	b,e	F-54 (a)
39	47	a,e,f	F-39 (b)
39	35	a,e	F-36 (a)
38	48†	b,c,d	F-60 (b)
38	41	a,e,g	F-43
37	47	b,c,d	F-57 (a)
37*	39*	a,e	F-34

*Field measurement.

†Estimated on the basis of similar structures.

INDEX III. Impact Insulation Class of Floor-Ceiling Constructions (Continued)

Type Code:

a. wooden joist
b. metal joist
c. concrete or masonry
d. plaster ceiling
e. gypsum board ceiling
f. w/resilient ceiling element
g. w/resilient floor element
h. w/carpeting
i. w/absorbent blankets
j. w/separate ceiling joist

IIC	STC	Type	Data Sheet No.
36*	41*	a,d	F-32 (a)
36*	35*	a,e	F-31
35*	54*	c,d	F-6
35	51	b,c,d,f	F-59 (b)
35	49	b,c,d	F-56 (a)
34	38	a,e,g	F-46 (c)
33	48	b,c,d	F-59 (c)
33	48	b,c,d	F-60 (a)
33	37	a,e	F-38 (a)
32	48	b,c,d,f	F-59 (a)
32*	42*	c	F-22
32	40	a,e,i	F-40 (a)
32	37	a,e	F-39 (a)
32*	34*	a,e	F-30
32*	29*	a,e	F-35 (a)
31*	47*	c,d	F-5 (a)
31*	45*	c,d	F-26
30*	49*	c,d	F-15
30*	46*	c,d	F-21 (a)
29	44†	c	F-1 (c)
28*	44†	c	F-1 (d)
26*	49*	c,d	F-5 (b)
25	44	c	F-1 (a)
25*	44†	c	F-1 (b)
24*	46*	c,d	F-21 (b)

*Field measurement.

†Estimated on the basis of similar structures.

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APPENDIX A

FIRE RESISTANCE PERFORMANCE AND RATINGS OF WALL AND FLOOR-CEILING CONSTRUCTIONS

Prepared by Harry Shoub, National Bureau of Standards

The ratings for fire resistance shown for the various structures in this guide are based on published test data and compiled lists of ratings. Where it was necessary to estimate ratings, they were derived from the available published material and are indicated as estimates.

Fire endurance tests, which determine the ratings, were conducted principally under the requirements of ASTM E119, Standard Methods of Fire Tests of Building Construction and Materials. Although deviations from the standard procedure have occurred, mainly in early fire tests, the differences usually have not been of such magnitude as to affect the validity of the results or to require any significant change in the value of the ratings. Some of the ratings are based on British fire endurance tests, as specified in British Standard 476: Part 1, Fire Tests of Building Materials and Structures. These tests are conducted under methods similar to those of ASTM E119, with somewhat comparable criteria of failure. However, because of differences in the measurement of temperatures, the results of these tests should be considered as giving estimated rather than demonstrated fire resistance ratings.

In conducting standard fire endurance tests of a wall, the structure is designed to form one side of a test furnace, so that one face of the wall is exposed to the fire in the furnace. Floors are placed in the top of a specially built furnace in order to expose the underside or ceiling surface to the fire. The temperature in the furnace is controlled to follow an established time-temperature curve having the following points:

Temp. - °F	Time - min.
1000	5
1300	10
1550	30
1700	60
1850	120
2000	240

The temperature is taken as the average of at least nine thermocouples distributed in the furnace near all parts of the test sample. In the ASTM method the thermocouples are protected in porcelain or metal tubes, while under the British standard, the thermocouples are placed uncovered in the furnace. Except in tests of approximately 30 min. or less duration, the less severe exposure of a specimen under the British system would probably cause only a slight deviation in the results, usually not as great as that which might be attributed to experimental error.

The minimum size of the exposed surface of a wall is 100 ft^2, with no dimension less than 9 ft. Floors must be at least 180 ft^2, with neither side less than 12 ft. During the fire endurance test, a load intended to develop the designed working stresses in the structure may be applied to the wall or floor assembly.

The criteria of failure, which limit the fire resistance of a structure, are as follows:

1. An average temperature rise of 250 degrees F above the initial temperature on the unexposed surface of a wall or floor, as measured by all the thermocouples placed under asbestos cover pads on the unexposed surface; or a rise of 325 degrees F at any one of the thermocouples. In tests conducted under British Standard 476, the thermocouples are not covered. This tends to result in better apparent performance of the structure, a fact which has been considered in making estimates of fire endurance.

2. Structural failure of the wall or floor assembly.

3. The passage of flame or gases hot enough to ignite cotton waste placed on the unexposed surface.

The fire endurance of a structure determined from the above limiting criteria is a measure of the performance of the structure in the fire test, and in no way indicates its suitability for use after the fire exposure.

The fire resistance of a structure is often expressed in a standardized rating system in which the categories are 30 and 45 min., and 1, 1 1/2, 2, 2 1/2, 3, 4, etc. hours. The 45-min. and 2 1/2-hr. categories are sometimes omitted. When using this system, the actual endurance time exhibited by a structure in the fire test is reduced to the next lower standard time. A rating of 1 1/4-hr. has been indicated in some instances where the construction is better than that required for 1 hr. but may not achieve 1 1/2 hrs. However, some inequities may occur. For example, structures showing actual fire endurance times of 3 hrs. 1 min. and 3 hrs. 59 min. will both be rated as having 3 hr. fire resistance, while the addition of a single minute to the endurance time of the latter will increase its rating to 4 hrs.

Some of the ratings shown in the report as 4 hrs. actually represent a considerably higher fire endurance, but as most building codes have requirements not exceeding 4 hrs. fire resistance, references often express that value as a maximum. In some instances of ratings under 1 hr., the fire endurance has been reduced to the next lower 5-min. period, and are shown as such where available. The indication "combustible" following a rating signifies that the structure contains combustible elements of such quantity as to continue flaming after termination of the fire test, or constructed with materials that do not classify as "noncombustible" in NFPA No. 220-Standard Types of Building Construction, in the National Fire Codes.

In attempting to assess the fire endurance capability of the selected floors and walls of this guide, it was often found that the structures for which sound insulation data were available were not strictly comparable to those on which fire tests had been performed. Wherever possible, estimates were made of probable performances based on similarities of construction if no identities could be found. Estimates were made conservatively, so that possible errors would be on the side of safety. In the following, some of the general considerations applicable to the determination of the probable fire endurance of structures are presented.

In some cases, where the dissimilarity arose from differences in thickness of protective materials, the expected performance could be derived or extrapolated. National Bureau of Standards Report BMS 92, Fire-Resistance Classifications of Building Constructions gives methods of estimating the fire resistance periods for walls of different laminar components and for homogeneous walls of differing thicknesses. The increased fire resistance derived from the addition of plaster coatings on walls is also indicated.

The effectiveness of plaster as a fire protective coating is dependent on several factors. The mix is of importance, particularly with gypsum plasters. A richer mix gives a better fire resistance, which also may be obtained by the use of perlite or vermiculite aggregate instead of sand. The method of application of the plaster has a bearing on its effectiveness, as the protection it may provide is lost as soon as the plaster falls from the fire-exposed surface. This is also true of gypsum wallboards applied to increase fire resistance. Special gypsum boards and coreboards are available with greater fire resistance than that afforded by conventional board products.

The type of aggregate used in concrete determines to a considerable extent its probable fire resistance characteristics. With other factors equal, concrete made with siliceous aggregates, especially those largely of chert or flint, exhibit the lowest fire endurance, while concrete made with pumice or expanded slag or shale has a considerably greater resistance to the effects of fire. Cinder and calcareous gravel aggregate concrete tend to fall between the extremes in fire performance.

For hollow masonry walls, or hollow units in such walls, the fire resistance is determined principally by the thickness of the solid material in the structure, rather than by the total thickness of the wall.

In addition to the fact that small differences in construction may lead to large variation in fire resistance characteristics, the establishment of estimated fire endurance times is often complicated by lack of knowledge of the criterion of failure by which the basic rating was determined. It can be seen that if failure of a loaded structure occurred by excessive rise of temperature on the unexposed surface, a modification of the structure that would increase its loadbearing capability would probably not increase the time to failure by heat transmission.

In the following listing, by data sheet number, the fire rating, the basis or reference for the fire rating, and pertinent information concerning the given fire rating are presented. The reference is given directly under the fire rating and is indicated by a number which refers to the list of fire testing references on p. A-17. Where possible, page, section or table numbers are included in the parenthesis. It should be noted that the values listed here as ratings are the ratings already assigned by recognized rating organizations, or which probably would be allowed by authorized regulatory agencies.

W-1 Rating: approximately 30 min. (est.)
1-(p.11) - 4-in. solid concrete wall, no reinforcement has 1-hr rating.

W-2 Rating: 3 hrs. (est.)
1-(p.111) - 6 in. solid concrete wall, no reinforcement has 2-hr rating. Adding 1/2-in. sanded gypsum plaster to both sides increases rating approximately 1 hr. 4-(p.69).

W-3 Rating: over 3 hrs. (est.)
1-(p.111) - 5 1/2-in. monolithic, unreinforced concrete wall has 2-hr. rating. 6-(p.11) 6-in. siliceous aggregate concrete has 2 1/2-hr. resistance. Rating increased because of clinker aggregate and 1/2-in. plaster on both sides.

W-4 Rating: over 4 hrs.
7-(Table 4) - 12-in. wall, 33 percent voids, no plaster, no combustible members framed in, had fire endurance of 5 hrs. 33 min.

W-5 Rating: 2 1/2 hrs.
4-(p.27) - interior wall; no combustible members framed in.

W-6 Rating: over 4 hrs.
1-(p.107) - 8-in. wall; 4-(p.27) - with no combustible members framed in, rating is 7 hrs.

W-7 Rating: over 4 hrs.
4-(p.27) - no combustible members framed in, rating is 10 hrs; with combustible members, 8 hrs.

W-8 Rating: over 4 hrs.
1-(p.115) - 12-in. solid masonry wall has 4-hr. rating.

W-9 Rating 4 hrs.
1-(p.114) - with combustible members framed in, rating is 2 hrs; siliceous gravel aggregate. 4-(Table 23) gives 5-hr. rating.

W-10 Rating: (a and b) 1 hr. (est.)
1-(p.114) - siliceous aggregate concrete with 3-in. minimum equivalent thickness; with cinder aggregate, nonloadbearing, 61 per cent solid, rating is 1 1/2 hrs., 1-(p.113).

W-11 Rating: (a) 2 hrs.
(b) 1 1/2 hrs.
4-(p.31) - cinder aggregate; (a) 65 percent solid, (b) 73 percent solid.

W-12 Rating: (a and b) 1 1/2 hrs. (est.)
1-(p.113-14) - solid block, pumice or expanded shale or slag aggregate. Lead and plywood in (b) will probably not increase endurance significantly.

W-13 Rating: 3 hrs.
8-(sec. a1165)

W-14 Rating (a and b) 4 hrs.
1-(p.115)

W-15 Rating: (a) 3 hrs.
(b) 4 hrs.
1-(p.115) - extra 1/4-in. plaster on metal lath will not raise ratings 1 hr.

W-16 Rating: 3 hrs.
1-(p.115) - extra 3/4-in. plaster will not raise rating 1 hr.

W-17 Rating: (a) 3 hrs.
(b) 4 hrs.
1-(p.115) - extra 3/4-in. plaster on 3-in. gypsum block wall will raise rating to approximately 3.4 hrs. 4-(p.69).

W-18 Rating: (a, b and c) 3 hrs.
1-(p.115) - extra 3/8-in. gypsum lath will not increase rating 1 hr.

W-19 Rating: 4 hrs.
1-(p.115) - more plaster than required for rating.

W-20 Rating: 3 hrs. (est.)
1-(p.115) and 8-(sec. a1155) - gypsum lath on 2-in. wood furring strips with 1 1/2-in. mineral wool blanket at least equivalent to 3/8-in. gypsum lath on resilient clips.

W-21 Rating: Not available.
Estimated rating, based on siliceous aggregate concrete would be less than 1/2 hr.

W-22 Rating: over 4 hrs.
4-(p.27) - indicates rating of 7 hrs.

W-23 Rating: over 4 hrs.
4-(p.27) indicates rating of 7 hrs.

W-24 Rating 3 hrs. (est.)
4-(p.28, table 22) - gives 4-hr. rating with greater thickness of plaster.

W-25 Rating: over 4 hrs.
4-(p.29) - indicates rating of 5 hrs.

W-26 Rating: over 2 hrs. (est.)
4-(p.31, table 26) - 4-in. cinder aggregate block with 1/2-in. plaster both sides has 2-hr. rating; the interior panels and spaces will probably increase endurance.

W-27 Rating 1/2 hr. - combustible
4-(p.34) - indicates rating of 40 min.

W-28 Rating: (a, b and c) 1/2 hr. - combustible
4-(p.34, table 30) - indicates rating of 40 min; lead sheet will probably not increase endurance significantly - no data available.

W-29 Rating: 1 hr. - combustible
1-(p.138)

W-30 Rating: (a) 45 min. - combustible
4-(p.34) - with fibered gypsum and sand plaster rating is 1 hr. - combustible. 1-(p.135)
(b) 1 hr. - combustible
4-(p.34) - with 1:2, 1:2 gypsum and sand plaster on gypsum lath with no more than one 3/4-in. diameter hole per 16 in^2 surface.

W-31 Rating: 45 min. - combustible
4-(p.34, table 30) - 1:2, 1:2 gypsum and sand plaster; with perforated lath or fibered plaster, rating is 1 hr. 1-(pp.134 and 135)

W-32 Rating (a) 1 hr. - combustible
1-(p.138)
(b) 1 1/2 hrs. (est.) - combustible
1-(p.137) - rating reduced because both sheets apparently applied vertically.

W-33 Rating: 1/2 hr. - combustible
4-(p.34) - 35 min. endurance with 1:2, 1:2 gypsum and sand plaster.

W-34 Rating: (a) 1/2 hr. (est.) - combustible
4-(p.34, table 30) - with 2- by 4-in. studs, not staggered, endurance was 40 min.
(b) 45 min. (est.) - combustible
1-(p.38) - with 2- by 4-in. studs, not staggered, rating was 1 hr.

W-35 Rating: (a) 1 1/2 hrs. (est.) - combustible
1-(p.137) - rating reduced because of undersize studs, and gypsum boards both in same direction.
(b) 1 hr. (est.) - combustible (nonloadbearing)
4-(p.34, table 30) - perforated lath; on plain lath, endurance 45 min.

W-36 Rating: (a) 45 min. (est.) - combustible
1-(p.135) - rating reduced for plain lath.
(b) 1 hr. (est.) - combustible
1-(p.135) - increase in endurance from insulating fill probably compensates for use of plain lath.

W-37 Rating: 1/2 hr. (est.) - combustible
4-(p.34, table 30) - 1/2-in. board on 2- by 4-in. studs, not staggered, had 40-min. endurance.

W-38 Rating: 1 hr. (est.) - combustible
8-(sec. a1375) - without insulating batts, endurance was 45 min.
1-(p.34) - rating 1 hr. without batts, with fibered gypsum plaster. 1-(p.135)

W-39 Rating: (a) 1 hr. (est.) - combustible
1-(p. 138)
(b) 1 hr. (est.) - combustible
Similar to (a); added 1/2-in. board should increase rating.

W-40 Rating: (a and b) 1 hr. - combustible
4-(p.34, table 30) - perforated gypsum lath required; on plain lath, endurance probably 45 min.

W-41 Rating: (a, b and c) 45 min. - combustible
4-(p.34, table 30) - sanded gypsum plaster on plain lath.
(d) 1 hr. - combustible
1-(p.134) - perforated lath, metal clips, plaster mix 2 or 2 1/2 ft^3 perlite to 100 lb gypsum.

W-42 Rating: (a) 1 1/4 hr.
4-(p.34, table 31) - 1:2, 1:2 gypsum and sand plaster.
(b) 1 1/2 hr. (est.)
4-(p.34, table 31) - same as (a), with endurance increased by mineral wool batts.
(c) 1 hr.
4-(p.34, table 31) - 1:2, 1:2 gypsum and sand plaster.

W-43 Rating: (a, b and c) 45 min. (est.)
1-(p.128) - 1:2 1/2 gypsum and sand plaster, perforated lath, lath ends secured with metal finger clips; 1:2 gypsum and sand plaster on perforated lath secured to 1/4-in. rods on studs, rating is 1 hr.

W-44 Rating: (a) 1 hr. (nonloadbearing)
1-(p.128) - 1:2, 1:2 gypsum and sand plaster.
(b) 1 hr. (nonloadbearing)
1-(p.128) - 1:2, 1:2 gypsum and sand plaster.
(c) 1 1/4 hrs. (est.) (nonloadbearing)
1-(p.127) - 1/2-in. 1:2 1/2 gypsum and perlite plaster has 1 hr. rating; rating increased for 5/8-in. 1:2 gypsum and perlite plaster.

W-45 Rating: 45 min. (est.) (nonloadbearing)
1-(p.127) - with perforated lath, rating is 1 hr.

W-46 Rating: 1 hr. (est.) (nonloadbearing)
1-(p.132) - rating for single layer 5/8-in. board.

W-47 Rating: 45 min. (est.) (nonloadbearing)
1-(p.128) - 1/2-in. gypsum and sand plaster on perforated metal lath has 1-hr. rating.

W-48 Rating: 1 hr. (est.) (nonloadbearing)
1-(p.128) - lack of perforation in lath probably compensated for by 2-in. mineral wool blanket between studs.

W-49 Rating: 45 min. (est.) (nonloadbearing)
1-(p.127) - with perforated lath, rating is 1 hr.

W-50 Rating: 45 min. (est.) (nonloadbearing)
1-(p.128) - with perforated lath attached with special clips, rating is 1 hr.

W-51 Rating: (a and b) 1 hr. (nonloadbearing)
1-(p.128)

W-52 Rating: 1 hr. (nonloadbearing)
4-(p.34, table 31) - 1:2, 1:2 gypsum and sand plaster.

W-53 Rating: 1 hr. (est.) (nonloadbearing)
1-(p.128) - plain lath probably compensated for by 2-in. mineral wool blanket between studs.

W-54 Rating: (a) 1/2 hr. (est.) (nonloadbearing)
4-(p.34) - based on endurance of a wood stud wall.
(b) 1 hr. (nonloadbearing)
8-(sec. a1205)

W-55 Rating: (a) 1 hr. (nonloadbearing)
1-(p.132)
(b) 2 hrs. (nonloadbearing)
1-(p.132)

W-56 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
1-(pp. 131 and 132) - one 5/8-in. layer has 1 hr. rating; two 5/8-in. layers has 2 hr. rating.

W-57 Rating: 1 1/2 hrs. (est.) (nonloadbearing)
8-(sec. a1205) - rating reduced for thinner wall board.

W-58 Rating: 2 hrs. (est.) (nonloadbearing)
8-(sec. a1205)

W-59 Rating: 1 1/2 hrs. (est.) (nonloadbearing)
8-(sec. a1205) - same as W-57; 2-hr. rating (est.) if fire on double thickness side.

W-60 Rating: 1 hr. (nonloadbearing)
1-(p.132)

W-61 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
1-(pp. 131 and 132) - Two 5/8-in. layers board on 3 5/8-in. studs has 2-hr. rating; rating reduced for narrow studs and 1/2 in. less wallboard; partially compensated by addition of mineral wool insulation.

W-62 Rating: (a and b) 2 hrs. (nonloadbearing)
1-(p.131)

W-63 Rating: 2 hrs (est.)(nonloadbearing)
1-(p.131) - added insulation in wall will probably not increase endurance to higher rating category.

W-64 Rating: 2 hrs. (est.) (nonloadbearing)
1-(p.131) - see comment W-63

W-65 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
1-(pp. 131 and 132) - see comment W-61.

W-66 Rating: 1 1/2 hrs. (est.) (nonloadbearing)
1-(p.131) - rating reduced because of 2 1/2-in. rather than 3 5/8-in. studs, and inclusion of combustible cork.

W-67 Rating: 2 hrs. (est.) (nonloadbearing)
1-(p.131) - added 3-in. insulating batt may raise rating, but data not available.

W-68 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
Similar to W-65; although 1/2-in. less gypsum board than in W-65, either set of the double row of studs is protected by 1-in. gypsum board and additionally by 2-in. mineral wool insulation.

W-69 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
1-(pp.131 and 132) - two thicknesses 5/8-in. board has 2 hr. rating; rating reduced for 1/2-in. board.

W-70 Rating: (a) 1 hr. (est.) (nonloadbearing)
1-(p.128) - similar to rated panel except for greater thickness of channel frame.
(b) 1 hr. (est.) (nonloadbearing)
Same as (a) except that frame is formed of two 3/4-in.-thick channels rather than one 1 1/2-in.

W-71 Rating: Not available.
With perforated lath or extra-fibered gypsum on 2 1/2-in. studs, rating is 1 hr. (nonloadbearing). 1-(p.127) - narrow channel studs probably reduce rating.

W-72 Rating: 45 min. (est.) (nonloadbearing)
1-(p.128) - endurance reduced by use of plain lath rather than perforated.

W-73 Rating: 1 hr. (est.) (nonloadbearing)
4-(p.34, table 31) - dual 3/4-in. channels give approximately 3-in. airspace, and probably equivalent to regular steel studs of similar size.

W-74 Rating: (a) 1 hr. (nonloadbearing)
1-(p.126) - 1:2 gypsum and sand plaster.
(b) 1 1/4 hrs. (est.)
1-(pp. 124 and 126) - rating increased for perlite aggregate plaster.

W-75 Rating: (a) 1 hr. (nonloadbearing)
1-(p.124) - 1:2, 1:2 gypsum and sand plaster; 4-(p.34, table 32) - 1:1, 1:1 gypsum and sand plaster.
(b) 1 1/14 hrs. (est.) (nonloadbearing)
Same as (a), rating increased for vermiculite aggregate.

W-76 Rating: (a and b) 1 hr. (nonloadbearing)
1-(p.126)

W-77 Rating: 1 hr. (nonloadbearing)
4-(p.34, table 32) - 1:2, 1:3 gypsum and sand plaster.

W-78 Rating: 1 1/4 hrs. (est.) (nonloadbearing)
1-(p.124) - Rating for 2 1/2-in. thickness 2 hrs, for 1 1/2-in. 1 hr.

W-79 Rating: (a) 1 hr. (nonloadbearing)
1-(p.122) - 1:1, 1:2 gypsum and sand plaster, steel runners top and bottom.
(b) 1 1/4 hrs. (est.) (nonloadbearing)
Same as (a) with endurance increased for extra thickness. 4-(p.69).

W-80 Rating: 1 hr. (nonloadbearing)
1-(p.119)

W-81 Rating: (a) 1 hr. (nonloadbearing)
Same as W-80
(b) 45 min. (est.) (nonloadbearing)
Same as W-80, except rating reduced because of lesser thickness of board; effect of lead sheet unknown although it may act as heat sink.

W-82 Rating: (a) 1 hr. (est.) (nonloadbearing)
1-(p.117) - reduction of core to 5/8-in. probably will not affect fire endurance.
(b) 1 hr. (nonloadbearing)
1-(p.117)

W-83 Rating: 2 hrs. (nonloadbearing)
1-(p.116)

W-84 Rating: 2 hrs. (est.) (nonloadbearing)
8-(sec. a1075) - rated wall has 1 1/2-in. insulating batts; coreboard spaced 3 in. apart.

W-85 Rating: (a and b) 3 hrs. (est.) (nonloadbearing)
1-(p.117) and 4-(p.69) - mineral wool insulation in (b) will increase endurance, but probably not to 4 hrs.

W-86 Rating: 2 hrs. (est.) (nonloadbearing)
8-(sec. a1075)

W-87 Rating: 2 hrs. (est.) (nonloadbearing)
8-(sec. a1075)

F-1 Rating: 1 hr. (est.)
1-(p.47) - siliceous aggregate concrete; fire-rated floor has 3/4-in. protection to steel reinforcement.

F-2 Rating: 1 hr. (est.) - combustible
1-(p.47) - same as F-1; if failure is by temperature rise on unexposed surface, the combustible floor surfaces applied over the concrete may increase endurance by adding insulation.

F-3 Rating: 1 hr. (est.) - combustible
Same as F-2.

F-4 Rating: 2 hrs. (est.)
1-(pp. 46 and 47) - with siliceous or traprock aggregate, 3/4-in. protection to steel, or calcareous gravel or crushed limestone aggregate, 1-in. protection to steel; linoleum floor cover combustible, will add little to endurance; 1/2-in. fiberboard ceiling may provide 5 min. protection to concrete.

F-5 Rating: 3 hrs. (est.)
1-(p.46) - traprock, calcareous or siliceous aggregate and 1-in. cover for reinforcement; 1/2-in. gypsum and sand plaster ceiling will increase fire endurance, but probably not to next higher rating.

F-6 Rating: 3 hrs. (est.)
1-(p.46) - traprock, calcareous or siliceous aggregate and 1-in. cover for reinforcement (6-in. slab); 7/8-in. screed and 1/2-in. gypsum and sand plaster may raise rating to 4 hrs. (if failure is by temperature rise on unexpected surface).

F-7 Rating: 2 hrs. (est.)
1-(pp.46 and 47) - with screed, equivalent to approximately 5-in. thickness (see F-4); with 3/8-in. plaster ceiling, endurance probably 2 1/2 hrs.

F-8 Rating: 2 hrs. (est.) - combustible
1-(pp. 46 and 47) - siliceous or traprock aggregate, 3/4-in. protection to steel, or calcareous gravel or crushed limestone aggregate, 1-in. protection to steel; combustible flooring may increase time to failure by temperature rise on unexposed surface, but may decrease time to load failure by containing heat within slab.

F-9 Rating: 2 hrs. (est.)
1-(pp. 46 and 47) - see F-8; 3/8-in. gypsum and sand plaster ceiling equivalent to adding approximately 1/2 in. to 4 1/2-in. slab. 6-(p.7)

F-10 Rating: 2 1/2 hrs. (est.)
1-(pp.46 and 47) - for aggregate and steel cover, see F-4; 1/2-in. gypsum and sand plaster ceiling; equivalent thickness of slab and ceiling is 5 3/4 in., 6-(p.7); noncombustible floor topping may increase time to thermal failure, but decrease time to load failure, see F-8.

F-11 Rating: 4 hrs. (est.)
3-(p.82) - 4 3/4-in. gravel aggregate concrete, 1/2-in. plaster ceiling.

F-12 Rating: 3 hrs. (est.)
1-(pp.46 and 47) - concrete slab and topping 5 in., 2-hr. rating; add 1 hr. for plaster which is equivalent to 1 1/4 in. of slab, 6-(p.7).

F-13 Rating: 3 hrs. (est.)
1-(p.46) - traprock, calcareous or siliceous aggregate concrete; 1/2-in. gypsum and sand plaster ceiling makes equivalent thickness of slab over 6 in., 6-(p.7). Wood flooring on battens will increase endurance to failure by temperature rise on unexposed surface.

F-14 Rating: 3 hrs. (est.)
1-(p.46) - traprock, calcareous or siliceous aggregate; 1/2-in. gypsum and sand plaster ceiling and wood flooring on mineral wool insulation may increase endurance to 4 hrs.

F-15 Rating: 2 hrs. (est.)
3-(pp.124 and 125) - 1/2-in. plaster ceiling; floor finish may add to time to failure by temperature rise on unexposed surface.

F-16 Rating: 2 hrs. (est.)
3-(pp.124 and 125) - 1 1/2-in. screed replaces cover of tiles; 1/2-in. plaster ceiling; extra depth of tiles and wood block flooring may increase endurance.

F-17 Rating: 2 hrs. (est.)
3-(pp.124 and 125) - 1/2-in. plaster ceiling; extra 1/2-in. concrete and wood flooring may increase fire endurance.

F-18 Rating: 2 hrs. (est.)
3-(pp.124 and 125) - 1 1/2-in. extra concrete screed, glass wool and floor tile may increase time to failure by temperature rise on unexposed surface.

F-19 Rating: 2 hrs. (est.)
3-(pp.124 and 125) - suspended 1/2-in. plaster ceiling equivalent to equal thickness on the slab directly; extra screed, glass wool and flooring may increase time to failure by temperature rise on unexposed surface.

F-20 Rating: (a) 1 hr. (est.)
No data available for clay tile beams with concrete at sides only: rating based on the protection to the steel reinforcement provided by the covering concrete and plaster ceiling.
(b) Same as (a).
(c) Thick plaster ceiling may increase fire endurance; plaster lath probably combustible.

F-21 Rating: (a) 2 hrs. (est.)
5-(Design No. 28 - 2 hrs.) - with plaster ceiling, equivalent thickness is 7 1/2 in., rated design is 8-in. total; pumice concrete in slabs probably compensates for lesser thickness of floor topping.
(b) 1 hr. (est.)
6-(p.11) - based on equivalent thickness of 3 3/4 in.

F-22 Rating: 45 min. (est.)
6-(p.11) - siliceous aggregate concrete, minimum 5/8-in. cover to reinforcing steel.

F-23 Rating: 45 min. (est.)
6-(p.11) - siliceous aggregate concrete, reinforced; without plaster, endurance approximately 1/2 hr.

F-24 Rating: 45 min. (est.)
6-(pp.7 and 11) - concrete shell of beam and screed approximately 2 1/2 in.; minimum 1/2-in. gypsum and sand plaster.

F-25 Rating: 45 min. (est.)
6-(pp.7 and 11) and 2-(p.4) - approximately 2 1/2 in. thick, plus ceiling; siliceous aggregate concrete, glass wool insulation and wood flooring will probably increase time to failure by temperature rise on unexposed surface.

F-26 Rating: 45 min. (est.)
6-(pp. 7 and 11) - total thickness of concrete, including screed, about 2 1/2 in.; siliceous aggregate, 1/2-in. gypsum and sand plaster ceiling.

F-27 Rating: 45 min. (est.)
6-(pp.7 and 11) - total thickness of concrete, including screed, appears to be a minimum of 2 1/2 in. thick (rating 1/2 hr.); endurance increased by plasterboard ceiling which provides 15 min. protection to battens, 4-(p.40, table 42).

F-28 Rating: 1/2 hr. (est.)
6-(pp.7 and 11) - approximately 2-in. thickness concrete; siliceous aggregate; 1/2-in. gypsum and plaster ceiling; flooring on battens may increase time to failure by temperature rise on unexposed surface.

F-29 Rating: Not available.
Total thickness of concrete and plaster about 2 in., which would achieve a 1/2-hr rating; unless prior load failure occurs; the glass wool insulation, battens and wood flooring will increase time to failure by temperature rise on unexposed surface.

F-30 Rating: 15 min. (est.) - combustible
4-(p.40) - rating reduced to protection period provided by gypsum board ceiling to joists because of lesser depth of joists and absence of subflooring and asbestos paper diaphragm.

F-31 Rating: 15 min. (est.) - combustible
Same as F-30; similar floor failed by surface flaming and collapse at 24 min., 3-(p.129).

F-32 Rating: (a) 30 min. (est.) - combustible
3-(p.128) - 5/8-in. gypsum and sand plaster; rating increased for glass wood insulation.
(b) 45 min. (est.) - combustible
3-(pp. 133 and 134) - 5/8-in. cement. lime or gypsum and sand plaster.

F-33 Rating: (a and b) 20 min. (est.) - combustible
3-(p.128) - similar floor with joists 15 in. on centers failed by flame through and collapse at 27 min.

F-34 Rating: 1 hr. - combustible
1-(p.99) - 1/2-in. plywood probably equivalent to subflooring; ceiling tile probably compensates for lesser thickness of gypsum board.

F-35 Rating: Not available
With tongue-and-groove sub- and finish flooring, rating is 25 or 30 min. (combustible), 2-(pp.4 and 5); 1/2-in. gypsum board will provide 15 min. protection to joists, 4-(p.35).

F-36 Rating: (a and b) 1/2 hr. (est.) - combustible
2-(p.5) - paper pulp board and hardboard may be equivalent to 3/4-in. sub- and finish flooring; floor finish may increase time to failure by temperature rise on the unexposed surface.

F-37 Rating: (a and b) 1/2 hr. (est.) - combustible
Same as F-36; extra thickness of paper pulp board probably compensates for wider spacing of joists.

F-38 Rating: 1/2 hr. (est.) - combustible
2-(p.5) - plywood subfloor and floor probably equivalent to board flooring.

F-39 Rating: (a and b) 1 hr. (est.) - combustible
1-(p.99) - plywood subflooring probably equivalent to board flooring; screws in resilient channels in (b) probably equivalent to nails in wood joists.

F-40 Rating: (a and b) 1 hr. (est.) - combustible
1-(p.99) - plywood subflooring probably equivalent to board flooring; mineral wool batts may increase time to failure by temperature rise on unexposed surface, but not time to load failure; resilient channels in (b) for holding gypsum board will probably not cause a significant change in the endurance.

F-41 Rating: (a and b) 1 hr. (est.) - combustible
1-(p.99) - same as F-39; carpeting may increase time to failure by temperature rise on the unexposed surface.

F-42 Rating: (a and b) 1 hr. (est.) - combustible
1-(p.99) - same as F-39; carpeting on floor and mineral wool in joist spaces may increase time to failure by temperature rise on unexposed surface.

F-43 Rating: 45 min. (est.) - combustible
2-(p.4) - two 1/2-in. layers plywood and 1/2-in. glass fiber board has more fire endurance than 1-in. tongue-and-groove subflooring.

F-44 Rating: 45 min. (est.) - combustible
2-(pp.4 and 5) - 2-in. lesser depth of joists probably compensated by extra thickness of gypsum board ceiling; with 2- by 10-in. joists and nominal 1-in. sub- and finish flooring rating is 1 hr., 1-(p.99).

F-45 Rating: (a) 1 hr. (est.) - combustible
1-(p.99) - lesser depth of joists compensated by fiber glass insulation between joists; 1-in. total plywood flooring probably equivalent to 3/4-in. sub- and finish flooring.
(b) 1/2 hr. (est.) - combustible
2-(p.6) - based on protection provided by gypsum wallboard ceiling to joists; fiberglass insulation will provide some protection to 5/8-in. flooring and probably will increase endurance.

F-46 Rating: (a and b) 45 min. (est.) - combustible
1-(p.99) - rating reduced for lesser depth of joists.
(c) 1/2 hr. (est.) - combustible
2-(p.6) - based on protection provided by gypsum wallboard ceiling to joists.

F-47 Rating: 1/2 hr. (est.) - combustible
2-(pp.4 and 5) - joists 2-in. lesser depth than normal; glass fiber insulation may increase resistance.

F-48 Rating: 45 min. (est.) - combustible
1-(p.99) - rating reduced because of 2-in. lesser than normal depth of joists; 1 1/8-in. plywood flooring probably equivalent to tongue-and-groove sub- and finish flooring; glass fiber insulation may increase resistance.

F-49 Rating: 45 min. (est.) - combustible
1-(p.99) - rating reduced because of 8-in. joists; plywood and perlite concrete flooring probably equivalent to tongue-and-groove sub- and finish flooring.

F-50 Rating: (a, b and c) 45 min. (est.) - combustible
Same as F-49; floor coverings may increase time to failure by temperature rise on the unexposed surface, but endurance with this type of floor usually limited by load failure.

F-51 Rating: (a) 45 min. (est.) - combustible
3-(pp.133 and 134) - 5/8-in. plaster; reference indicates failure by appearance of flame on surface; glass wool insulation may increase endurance, but also may cause the joists, which are 1 in. less than in the referenced structure, to collapse by load failure earlier in the test.
(b) 45 min. (est.) - combustible
Same as (a); sand may increase time to heat penetration, but unless the weight of the sand is considered in the nailing of the metal lath, its weight may cause early failure of the ceiling.

F-52 Rating: 45 min. (est.) - combustible
1-(p.99) - rating reduced because of lesser depth of joists; fiber board in subflooring may contain heat and cause earlier failure of the joists under load; same for mineral wool insulation.

F-53 Rating: 45 min. (est.) - combustible
Same as F-52; plywood and cane fiber board floor probably equivalent to 1-in. tongue-and-groove sub- and finish flooring.

F-54 Rating: not available
The 1/2-in. gypsum wallboard ceiling will give approximately 15 min. protection to combustibles, 2-(p.6); any temperature rise occurring behind the wallboard ceiling will be quickly transmitted to the paper pulpboard subfloor; no fire-retardant treatment indicated for the pulpboard.

F-55 Rating: Not available
Same as F-54; greater thickness of pulpboard will probably require longer time to burn through.

F-56 Rating: (a and b) 3 hrs. (est.)
1-(pp.69 and 70) - perlite plaster equivalent to vermiculite.

F-57 Rating: (a and b) 3 hrs. (est.)
1-(pp.69 and 70) - gypsum and vermiculite or perlite plaster; gypsum and sand plaster ceiling rating is approximately 2 1/2 hrs.

F-58 Rating: 1 hr. (est.) - combustible
1-(pp.64 and 65) - 1 5/8-in. foamed concrete topping on 5/8-in. plywood probably equivalent to 2-in. concrete slab on metal lath.

F-59 Rating: 1 1/2 hrs. (est.)
1-(p.67) - rating reduced for sanded gypsum plaster (instead of perlite) and plain gypsum lath (instead of perforated).

F-60 Rating: 1 1/2 hrs. (est.)
Same as F-59; floor coverings may slightly reduce time to load failure by containing heat within floor structure.

F-61 Rating: 45 min. (est.) - combustible
1-(pp.64 and 65) - rating reduced from 1 hr. because of substitution of plywood for concrete floor (plywood probably does not provide equal stiffening and will retain heat in structure, contributing to load failure of the steel joists).

REFERENCES

1. Fire Resistance Patings, The National Board of Fire Underwriters, New York, N.Y., 1964.

2. Fire Resistance Ratings of Less than One Hour, The National Board of Fire Underwriters, New York, N.Y., 1964.

3. Investigations on Building Fires, Part V, Fire Tests on Structural Elements, National Building Studies, Research Paper No. 12, Department of Scientific and Industrial Research, HMSO, London, England, 1953.

4. Fire Resistance Classification of Building Constructions, Building Materials and Structures Report BMS 92, National Bureau of Standards, Washington, D. C., 1942.

5. Building Materials List, Underwriters' Laboratories, Inc., Chicago, Illinois.

6. Fire Performance Ratings 1965, Supplement No. 2 to the National Building Code of Canada, Associate Committee on the National Building Code, National Research Council, Ottawa, Canada.

7. Fire Resistance of Walls of Gravel Aggregate Concrete Masonry Units, H.D. Foster, E.R. Pinkston and S.H. Ingberg, Building Materials and Structures Report 120, National Bureau of Standards, Washington, D. C., 1951.

8. Architectural Reference Library, United States Gypsum Company, Chicago, Illinois.

APPENDIX B

COMPARISON OF LABORATORY AND FIELD MEASUREMENTS OF THE SOUND INSULATION OF WALL AND FLOOR STRUCTURES

I. INTRODUCTION

The results of early field tests gave birth to the general misconception that the agreement between laboratory and field measurements of airborne sound insulation of nominally identical wall and floor structures is rather poor. It has been stated, as a rule of thumb, that the sound transmission loss values of wall and floor structures measured in field installations may be 6 to 10 dB lower than those derived from laboratory measurements. Unfortunately, many of the early investigations from which this conclusion was drawn were conducted in an indiscriminate manner, under undesirable conditions and often with unorthodox or questionable methodology. Under such circumstances, the information derived from comparisons of laboratory and field measurements is not only doubtful, but may be erroneous and misleading.

Before an investigator can make a meaningful and valid comparison of laboratory and field measurements of the sound insulating performance of a given type of wall or floor structure, he must have a detailed and thorough knowledge of all test conditions and other factors bearing on the accuracy of measurements in both the laboratory and the field installation. Further, he must be sure that the construction of the field specimen is nominally identical in all respects to that tested in the laboratory. Such assurance can only be obtained by personal observation of the construction and installation of the test specimen in both the laboratory and field installations. The investigator should not rely solely on building drawings, since wall and floor structures shown in such drawings are not necessarily identical to those which are eventually erected in the building.

In this connection, it might be useful to review the significance of conducting sound insulation measurements in both laboratory and field installations and briefly summarize the conditions of test and factors which affect the outcome of such measurements.

II. LABORATORY MEASUREMENTS

In laboratory measurements of the sound insulation of wall and floor structures, the test specimen is carefully constructed, installed and properly sealed in a test opening between two massive highly-reverberant chambers, usually of masonry or concrete construction. Such chambers are specially designed and constructed to ensure that the sound being measured is only that which is transmitted directly through the test specimen and that the transmission of sound by any indirect or flanking path around the specimen is negligible. As a result of such special precautions and carefully controlled conditions, the laboratory test provides a measure of the optimum inherent sound insulating capability of a wall or floor structure. The reproducibility of laboratory measurements on different test samples of nominally identical wall or floor structures is within 1 to 3 dB at any given frequency and within equal or better limits in terms of an average or single-figure rating such as the Sound Transmission Class, STC.

Within certain limitations, wall or floor structures tested in the laboratory can be deliberately modified to simulate field conditions and conventional building practices. For example, measurements can be made of the effects on the sound insulating behavior of a test wall due to (a) variations in the quality of workmanship and construction techniques, (b) the installation of pipes or conduits within the wall and (c) specific types of sound leaks, such as caused by the omission of perimeter caulking, poor joint taping and the installation of electrical outlets and plumbing fixtures.

III. FIELD MEASUREMENTS

The primary objective of conducting field measurements usually is to check the performance of wall and floor structures within a building for conformance with specified sound insulation criteria. Such measurements frequently are difficult to perform because in most field installations the conditions of test drastically depart from the closely-controlled ideal conditions found in the laboratory.

The main departures are as follows:

(1) The wall or floor under test in the field becomes an integral part of the building complex because it is structurally coupled to the skeletal frame, adjoining walls and floors or other structural components of the building. As a consequence, the test specimen often is subjected to stresses which result from the support of the dynamic and static loads and the action of shearing forces within the building and which may effect the sound insulating performance of the test specimen.

(2) Flanking sound transmission paths exist in most field installations. Flanking paths for structure-borne noise and vibration are formed by the structural ties of the various walls, floors and building elements. Flanking paths for airborne noise are open corridors, ducts, ceiling plenums, entrance foyers and staircase halls which are common to or connect adjoining dwelling units.

(3) Direct air or sound leaks exist in most buildings, particularly around pipe and duct penetrations, electrical and plumbing outlets and perimeter edges of the wall or floor under test.

(4) Unlike laboratory facilities in which the dimensions of the test chambers and specimens are fixed, wide variations in wall areas, floor spans and room sizes and configurations are common in field installations.

(5) Among some of the other unfavorable conditions commonly found in the field are inadequate diffusion of sound, variable degrees of sound absorption and high unsteady background noise levels in the rooms in which tests are to be conducted.

(6) Test procedures frequently are modified or improvised depending on circumstances and conditions encountered in the field.

All of the above departures tend to reduce the reproducibility and accuracy of field measurements. However, the most serious sources of error associated with field measurements generally are the flanking transmission paths and direct sound leaks which create higher sound pressure levels on the receiving side of the test wall that would be produced by the transmission of sound directly through the wall alone. These higher levels give the erroneous indication that the sound transmission loss of the test wall is lower in value than that obtained in the laboratory. Such low values often are obtained in the field even when construction of the wall structure itself conforms exactly to that tested in the laboratory. Lower sound transmission loss values also occur in the field because walls are not built according to specifications or careless workmanship nullifies their good sound insulating capabilities.

IV. REQUIREMENTS FOR CONDUCTING COMPARATIVE TESTS

Based on the foregoing, it is obvious that better agreement between laboratory and field tests can be achieved if certain requirements and precautionary measures are observed. First and foremost, sound insulation measurements in the field should be made under conditions approaching as closely as possible those found in the laboratory. This implies that:

(a) the construction and installation of the test specimen in the field must conform exactly in every respect to that tested in the laboratory, other than in area or size. This can be determined best by personal observation of the specimen construction particularly in the field,

(b) precautionary measures must be taken in the field to ensure that all sound flanking and leakage paths are minimized for greater accuracy and precision,

(c) measurements should be made in unfurnished and preferably reverberant rooms which are completely enclosed and of moderate size and simple geometric configuration. Because of the difficulties of obtaining accurate results, measurements in areas such as closets, corridors or rooms which are very small, partially enclosed or have unusual designs or configurations should be avoided,

(d) airborne sound transmission loss measurements in both the laboratory and field installations should conform as closely as possible to the "Tentative Recommended Practice for Laboratory Measurements of Airborne Sound Transmission Loss of Building Partitions", ASTM Designation E90-66T of the American Society for Testing and Materials. A method of test dealing with field measurements is currently under development in a subcommittee of the ASTM. Future field tests should be made in accordance with this method after it has been adopted,

(e) measurements of impact sound transmission in both laboratory and field installations should be made in accordance with a method currently in use at the National Bureau of Standards. This method, which is also presently under consideration by the same ASTM subcommittee, is based in part on the use of a standard tapping machine as specified in ISO R140-1960(E), "Field and Laboratory Measurements of Airborne and Impact Sound Transmission," January 1960,

(f) data from field measurements must be normalized to the same reference base as that used for the laboratory data.

V. COMPARISONS OF RECENT LABORATORY AND FIELD MEASUREMENTS

A detailed analysis was made of airborne and impact sound insulation data which were obtained from recent laboratory and field measurements conducted on nominally identical walls and floor-ceiling assemblies. Only those data were used which were obtained under the most favorable laboratory and field conditions and which most closely fulfilled the above requirements. Some of these data were obtained from multiple tests performed on nominally identical specimens in both laboratory and field installations. Such tests gave a reasonably accurate indication of the reproducibility of laboratory and field results, as well as a more reliable determination of the sound insulating merits of the various test specimens involved.

Since both wall and floor-ceiling structures were involved in this investigation, separate comparisons of the laboratory and field test results were made for each type of structure. In the case of wall structures, comparisons were made only of the airborne sound transmission loss measurements. With regard to floor-ceiling structures, laboratory and field measurements were made of both airborne sound transmission loss and impact sound transmission. Separate comparisons were conducted for each type of measurement.

As a matter of convenience, the conclusions of the various laboratory and field test comparisons are reported in the order mentioned above.

VI. CONCLUSIONS

A WALL STRUCTURES: AIRBORNE SOUND INSULATION

1. When the conditions of test outlined in Section IV are met as closely as practicable, the agreement between the results of laboratory and field tests is generally as good as the reproducibility of laboratory test data on two individual walls of nominally identical construction. The sound transmission loss values obtained from field measurements generally agree within 1 to 3 dB of those derived from laboratory measurements, at any discrete frequency band. In terms of a single-figure rating, such as the Sound Transmission Class, STC, the agreement between laboratory and field data is within one or two points.

2. If several different types of wall structures are tested in the field, the rank ordering of the structures in terms of their airborne sound insulating merits is found to be identical to the rank ordering of the same wall structures tested in the laboratory.

3. On occasions, walls tested in the field will register sound transmission loss values which exceed laboratory values by 1 or 2 dB. These higher values occur when the field specimen is substantially larger than that tested in the laboratory. For a given type of construction, a large wall tends to be less stiff and thus may provide more sound insulation than a small wall.

4. Both load-bearing and nonload-bearing walls with good airborne sound insulating capabilities can be constructed and installed in the field at nominal cost and in full conformance with established building construction disciplines and codes. However, in order to achieve optimum performance it is imperative that the workmanship be carefully supervised.

A word of caution is offered at this point, so that the naive individual might not make the basic assumption that the field measurements of existing wall or floor constructions are always found to be in close agreement with laboratory measurements. This is not the case at all! In fact, field measurements on existing wall or floor structures constructed with typical or normal workmanship would be as much as 8 to 10 dB lower than those obtained from laboratory measurements.

Close agreement between laboratory and field measurements is possible only when the test specimens are of identical construction and the same isolating techniques used in the laboratory installation are used in the field.

B FLOOR-CEILING STRUCTURES: AIRBORNE SOUND INSULATION

Virtually the same conclusions as above can be drawn regarding the agreement between the results of laboratory and field airborne sound insulation measurements on floor-ceiling structures of nominally identical construction. This applies to all types of floor-ceiling structures including those which utilize floating floor systems and/or resiliently hung ceiling assemblies.

C FLOOR-CEILING STRUCTURES: IMPACT SOUND INSULATION

Unfortunately, in this investigation, it was not possible to determine the quantitative differences between the results of laboratory and field measurements of impact sound insulation, because of the lack of sufficient body of authentic and authoritative data. The scarcity of data is due primarily to the fact that a strong interest in impact testing did not develop until just recently. As a consequence, many of the new floor-ceiling specimens tested in the laboratory have not as yet been used in the field, to any great extent. Further, the wide selections of floor surfacing and covering materials lessen the probability of finding identical floor-ceiling specimens on which to make laboratory and field comparisons. Unlike measurements of airborne sound insulation which are not seriously influenced by minor variations of mass or edge restraints of the test specimen, impact sound insulation is strongly dependent on the resilient characteristics of the floor surfacing material, the construction of the structural floor and the degree of its vibrational isolation from the building structure.

In laboratory measurements of impact sound transmission, the floor-ceiling specimen is structurally isolated from the receiving room to ensure that the impact sound being measured is only that which is transmitted directly through the test specimen and that the leakage of sound or sound transmission by any indirect path is negligible. Thus, the laboratory test provides a measure of the optimum inherent impact sound insulating capabilities of a floor-ceiling structure.

In the field, the floor-ceiling assembly is an integral part of the building complex which is structurally bonded to load-bearing walls and other supporting structures of the building. Such rigid ties form numerous flanking paths for impact noise. As a consequence, a substantial amount of impact sound energy may reach a receiving room by flanking transmission through the walls enclosing it. In buildings of wood frame construction, the total impact noise radiation from the walls of the receiving room often may be as great or perhaps even exceed that from the floor-ceiling specimen under test. As a result, the impact sound insulation of a floor-ceiling specimen tested in the field may appear to be substantially lower than that obtained for the same type specimen tested in the laboratory. This is particularly true in the case of floor structures with resiliently hung ceilings. The flanking paths generally by-pass the suspended ceiling and thus render it ineffectual.

The sound insulation values of floors tested in the field generally will be lower than those obtained from laboratory tests, since the desired vibrational isolation of the floor from the building can not be achieved to the same degree as it is in the laboratory. Such isolation is difficult to achieve in practice because floor structures require support, and as a consequence the vibrational isolation is rendered less effective at the points of support. However, some floor-ceiling constructions have been developed which improve the acoustical decoupling and preserve the structural support requirements. One such construction consists of a structural support floor on which a floating floor is erected and from which a gypsum board ceiling is suspended by resilient hangers. This construction used in conjunction with support walls employing resiliently mounted surfaces generally provides the best impact sound insulation. It is estimated that the agreement between laboratory and field tests for such construction would be within 1 or 2 points.

APPENDIX C

A SUMMARY OF NOISE SOURCES

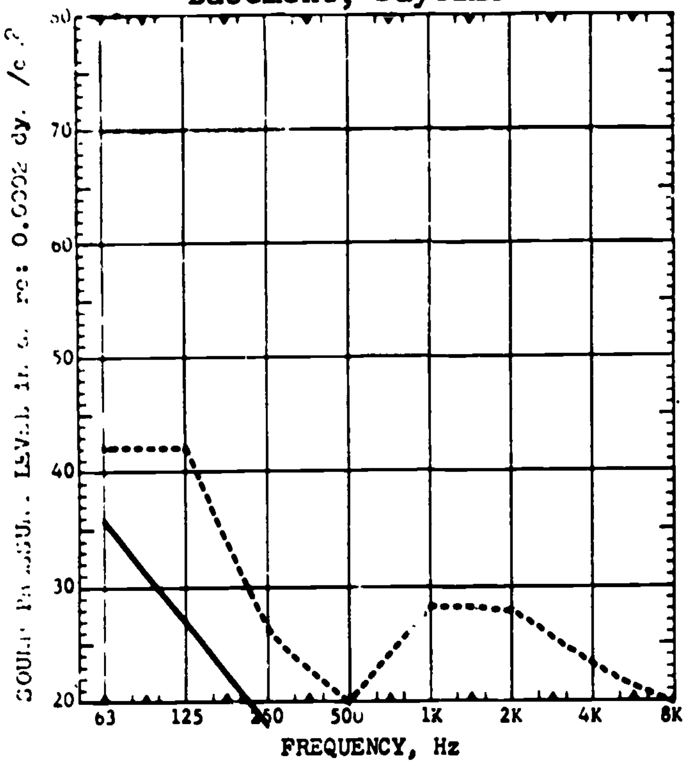
In order to obtain a better understanding of the character of the noise produced by various appliances and other sources, an extensive survey of acoustical literature was made for information concerning the intensity and frequency distribution of the sounds produced by such sources of noise.

The following pages contain graphical representations of the noise intensity as a function of frequency of some of the more common noise sources found in and around the home. Some of the data were obtained from laboratory measurements where the acoustical environment was known or could easily be determined. However, the largest portion of the data was obtained in actual installations where the acoustical environment was unknown. For this reason, the information is presented as obtained from the literature with no attempt to normalize to a reference reverberation time or reference space absorption. The sound pressure levels should therefore be interpreted as the measured levels of some sources in their particular environments; i.e., the same sources in different installations could well produce greater or lesser noise levels as the case might be.

A numbered bibliography of references used in this survey of noise sources appears at the end of this section. Information contained in each graph was obtained from those references identified by number in the caption of each graph.

Indoor Ambient Noise Levels
Average Single Family Home
(in octave bands)

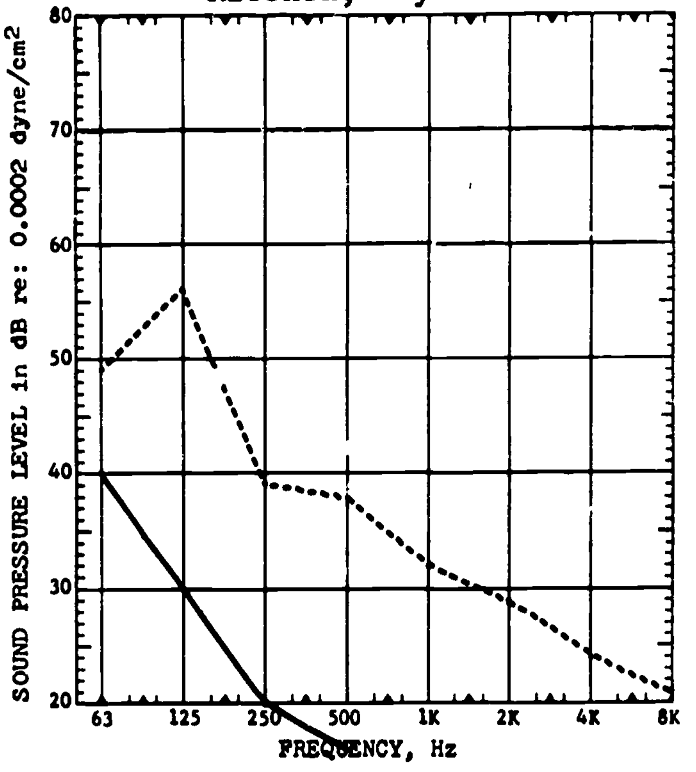
Basement, Daytime



Ref. #1

——w/o heater pilot & water heater.
·······with " " " " "

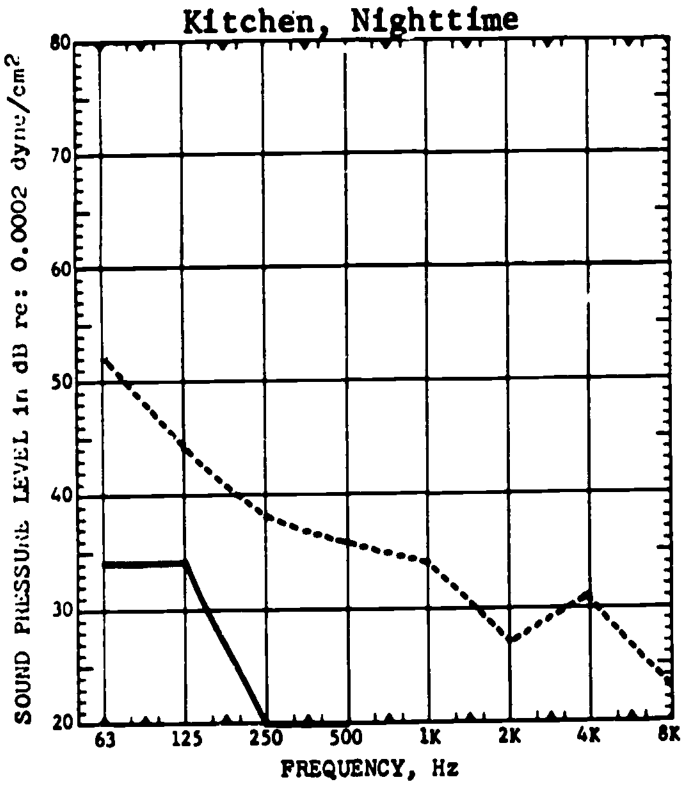
Kitchen, Daytime



Ref. #1

——w/o refrigerator.
·······with "

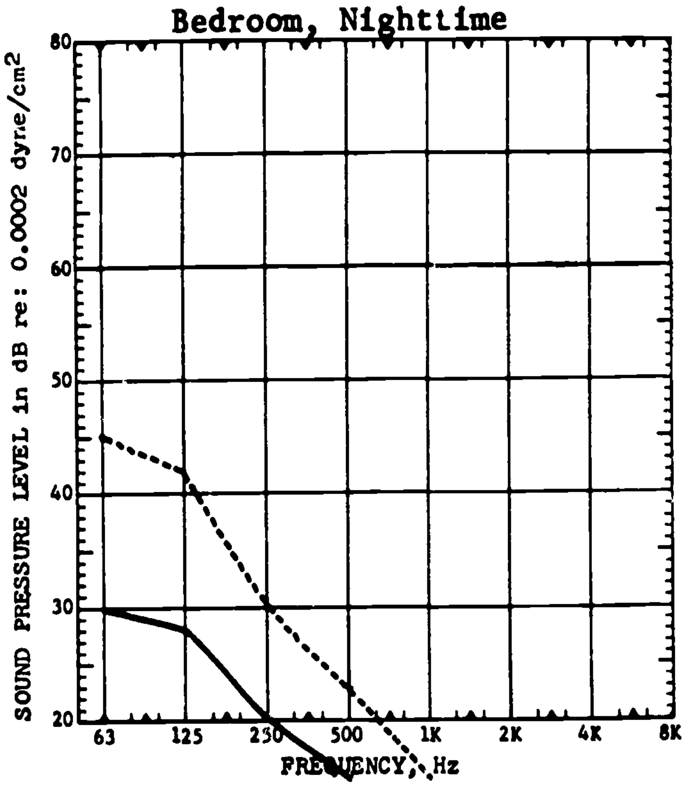
Kitchen, Nighttime



Ref. #1

——w/o heating & refrigerator.
·······with " " "

Bedroom, Nighttime

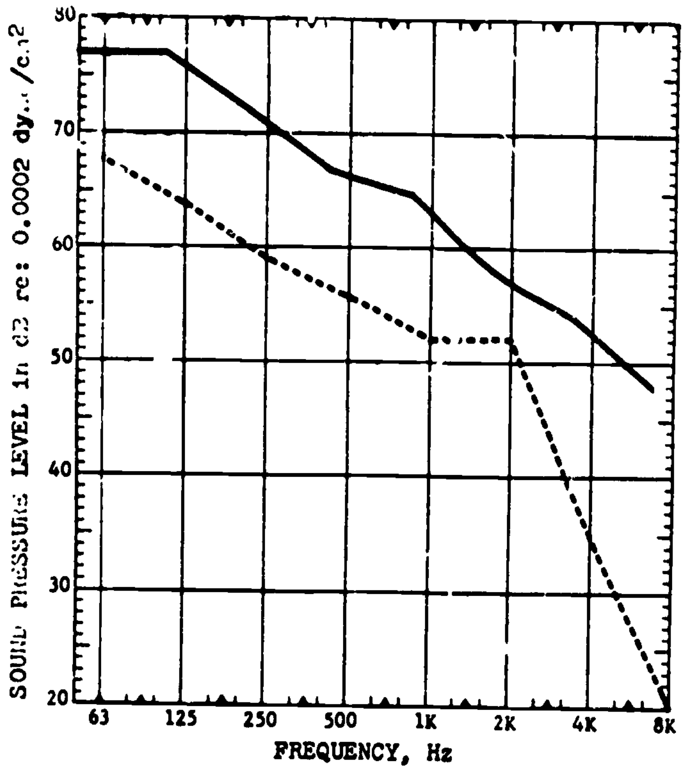


Ref. #1

——w/o heating.
·······with "

Outdoor Ambient Noise Levels
(in octave bands)

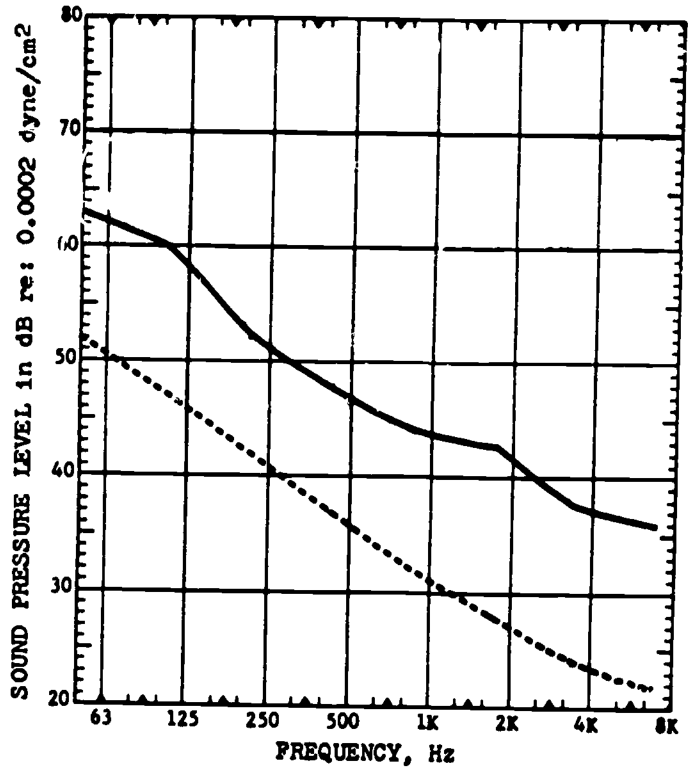
Noisy Residential Area



—— Ref. #2
Daytime, near industrial area.

········ Ref. #1
Nighttime, near traffic.

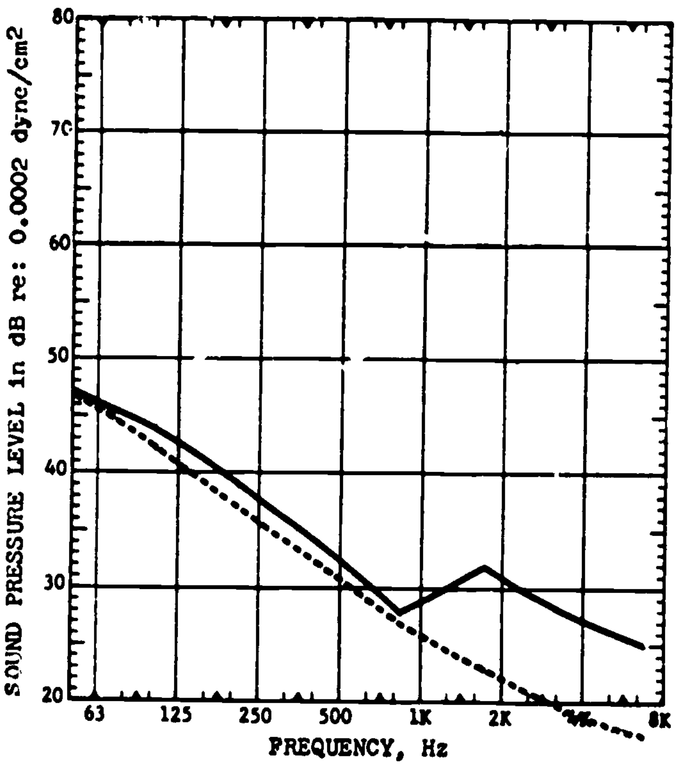
Average Residential Area



—— Ref. #1
Daytime.

······· Ref. #3
Nighttime Urban, no traffic (Est.)

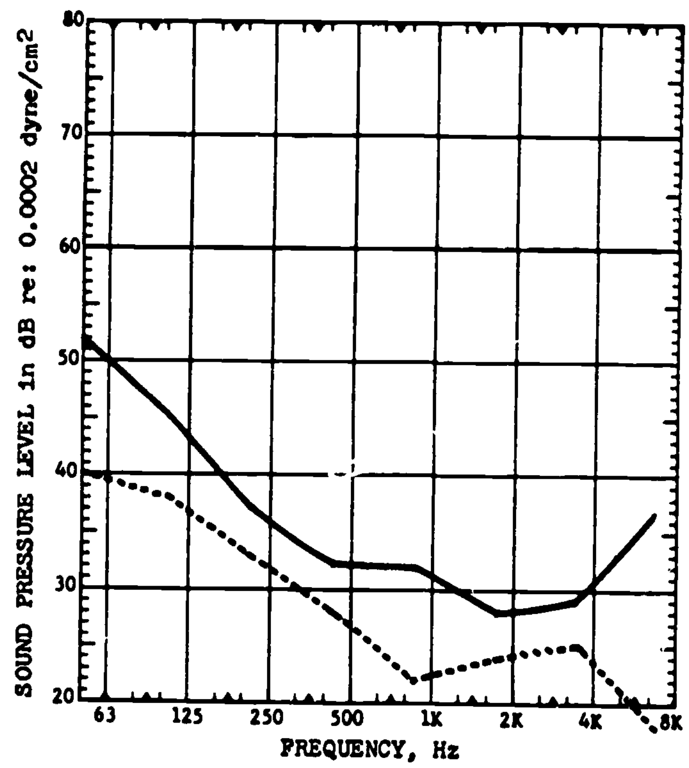
Quiet Residential Area



—— Ref. #4
Daytime.

······· Ref. #3
Nighttime Suburban, no traffic (Est.)

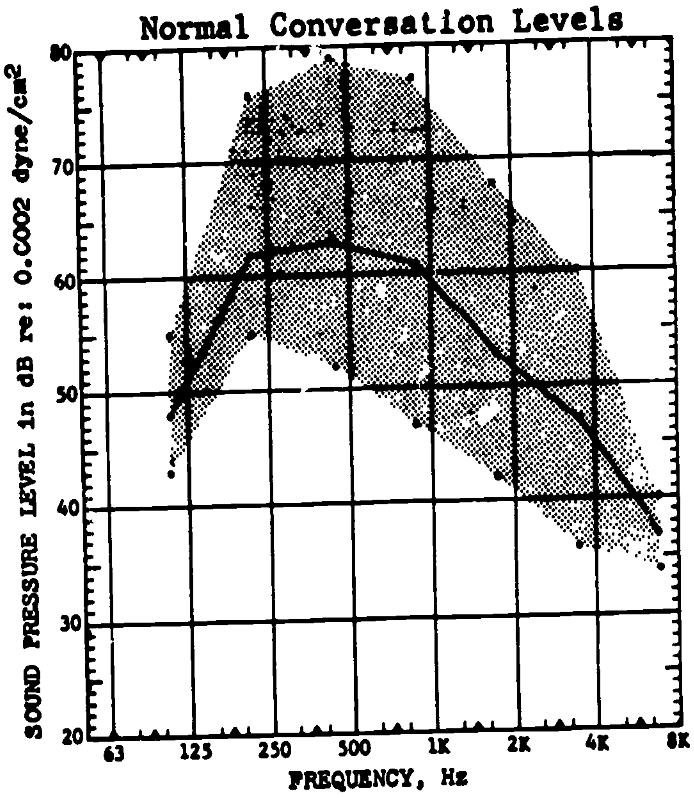
Rural Area



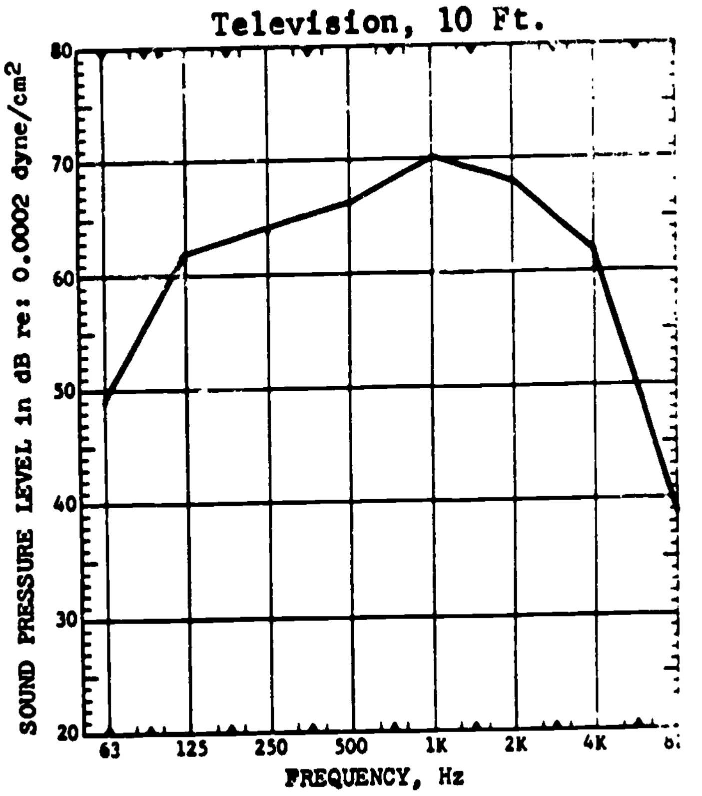
—— Ref. #1
Near Highway, Daytime.

······· Ref. #4
No Highway noise, Daytime.

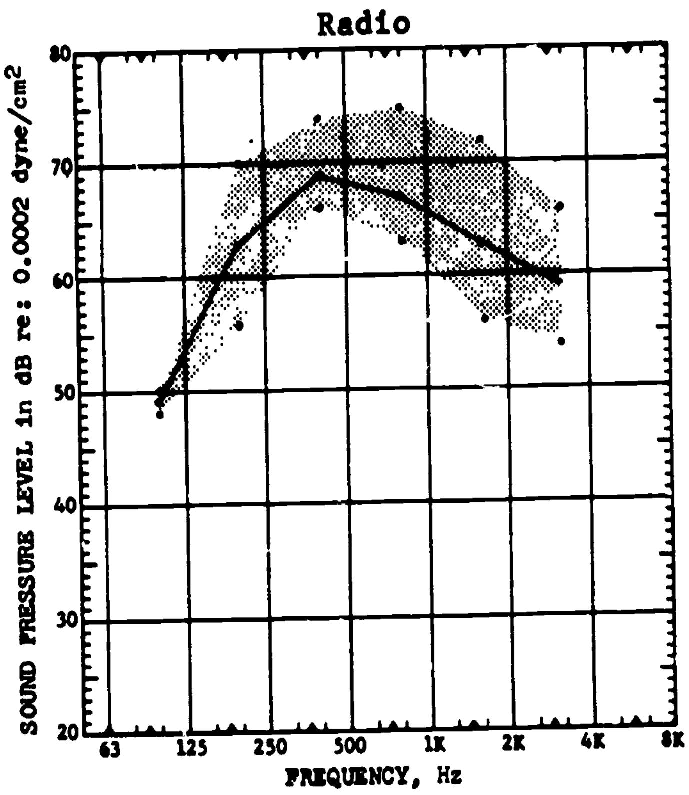
Speech and Music Noise Levels
(in octave bands)



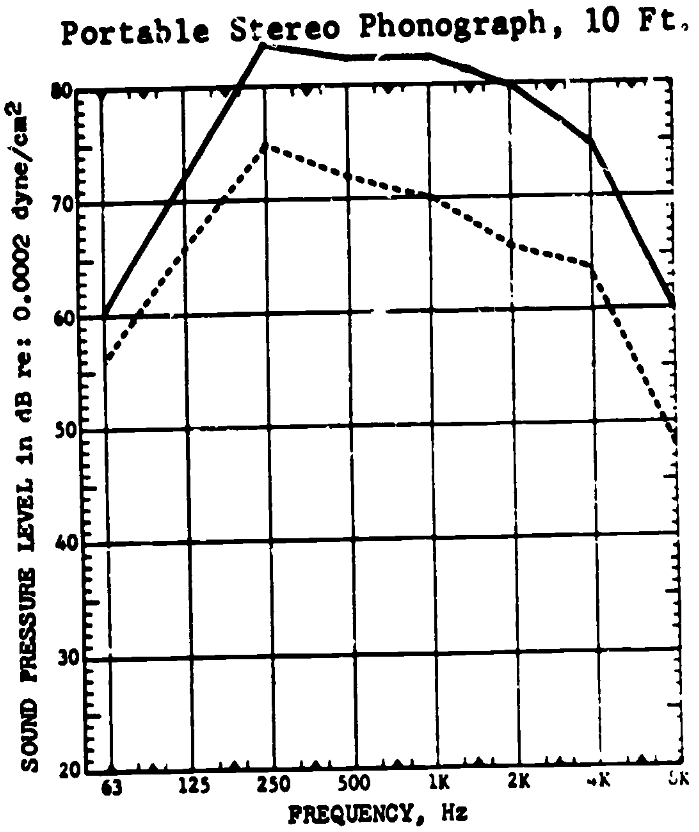
——Refs. #1, #12 and #14
Average of 4 measurements
Spread of measurements



Ref. #1
——Peak Levels



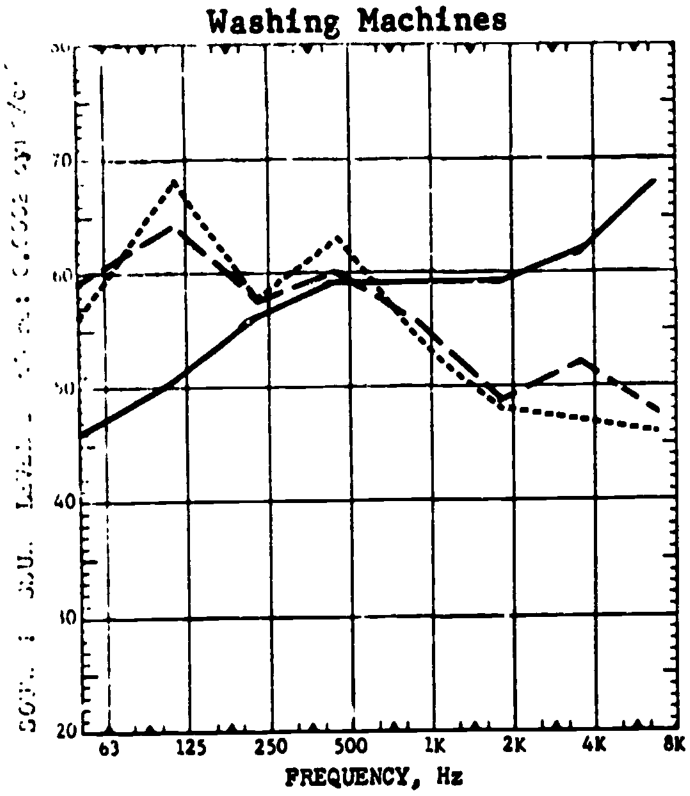
——Refs. #1, #12 and #15
Average of 3 measurements
Spread of measurements



Ref. #1
——Teenager Listening Levels
---------Adult Listening Levels

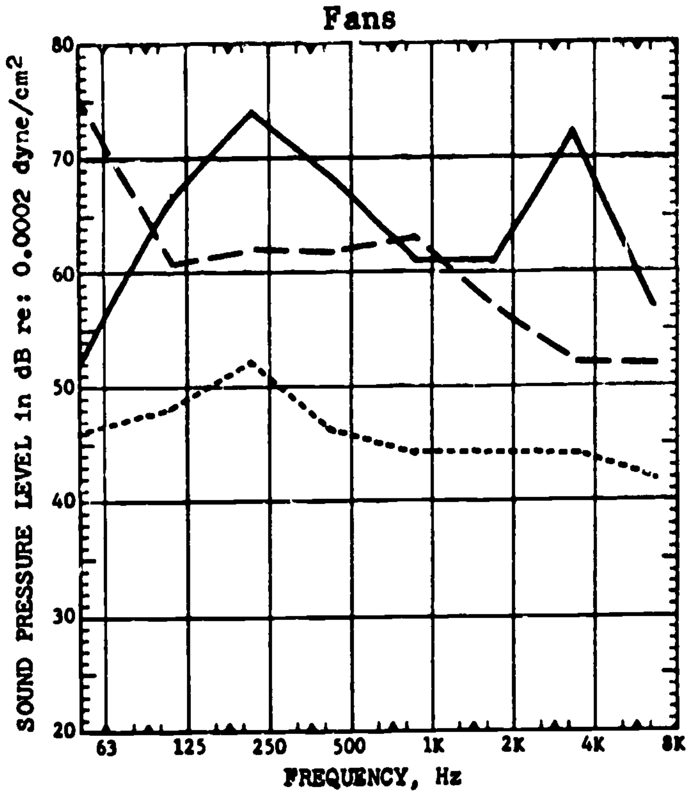
Household Appliance Noise Levels
(in octave bands)

Washing Machines



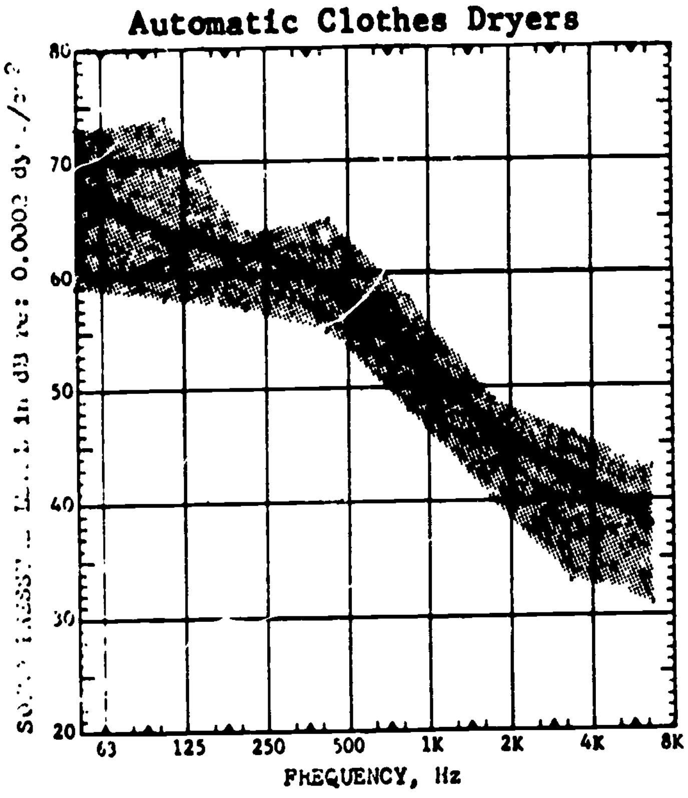
Ref. #1
Average of 2 measurements.
——Filling
--------Washing
— — —Rinsing

Fans



——Ref. #4, Stove Hood Exhaust.
--------Ref. #1, Kitchen Wall Exhaust.
— — —Ref. #1, 20-in. Window Fan on High Speed.

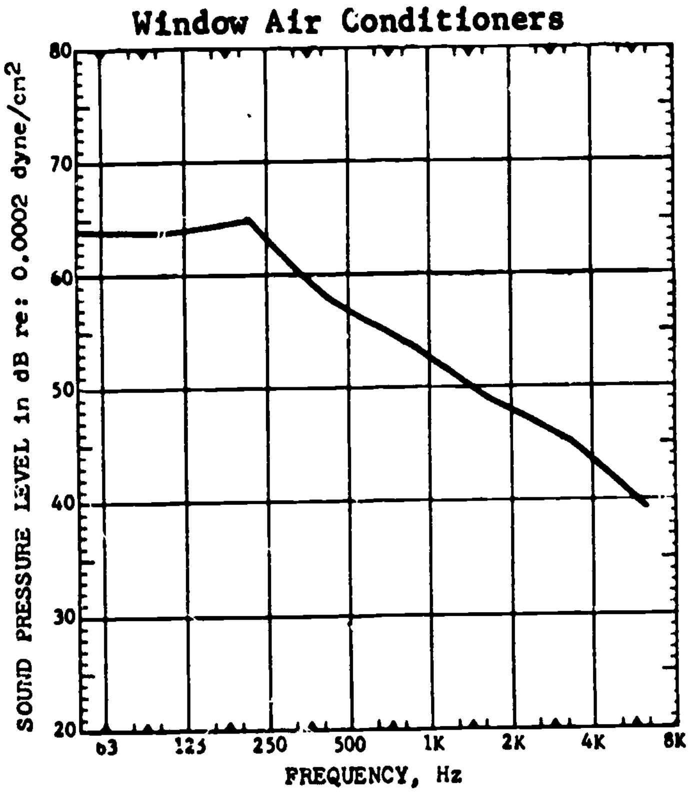
Automatic Clothes Dryers



——Refs. #1, #4 and #11.
Average of 4 measurements.

Spread of measurements

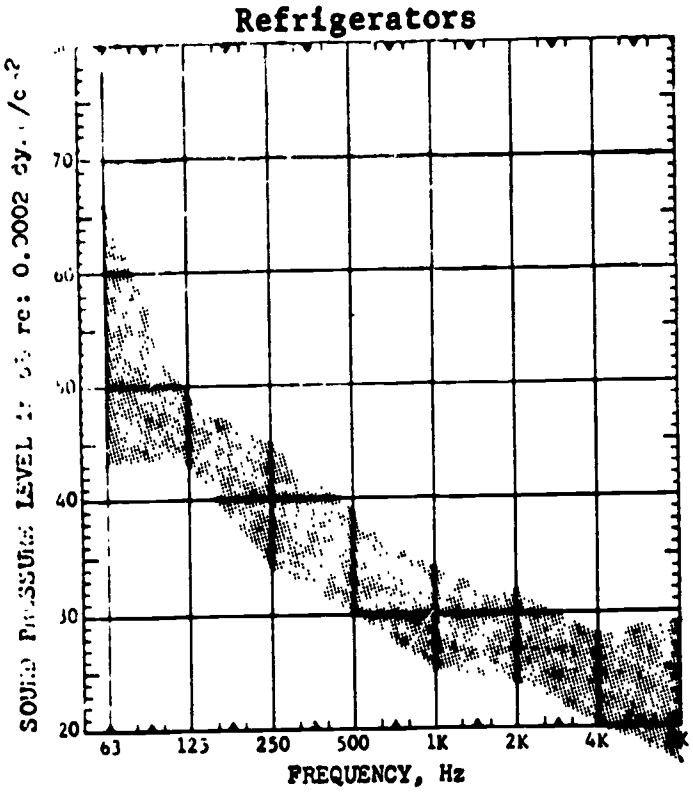
Window Air Conditioners



Refs. #1, #4 and #12.
——Average of 3 measurements.

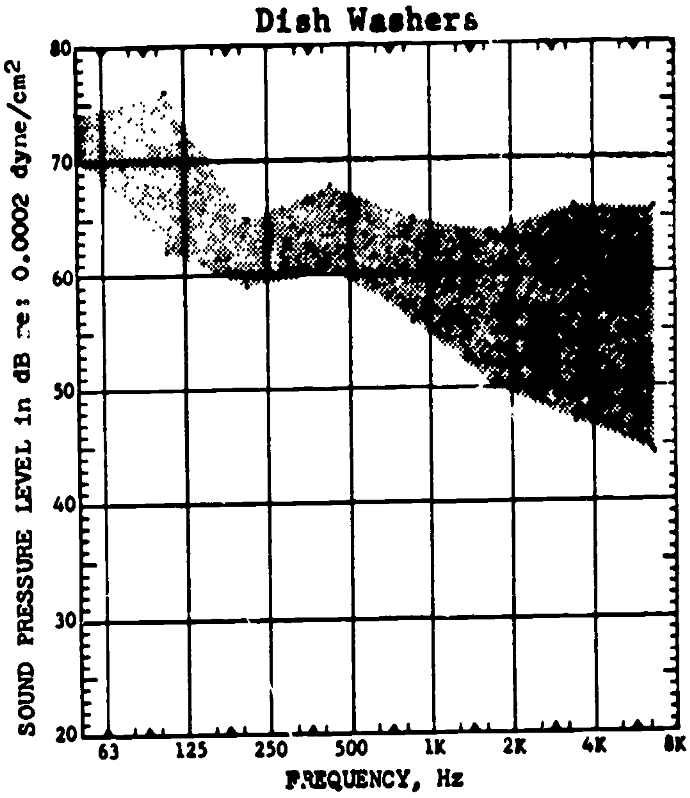
Household Appliance Noise Levels
(in octave bands)

Refrigerators



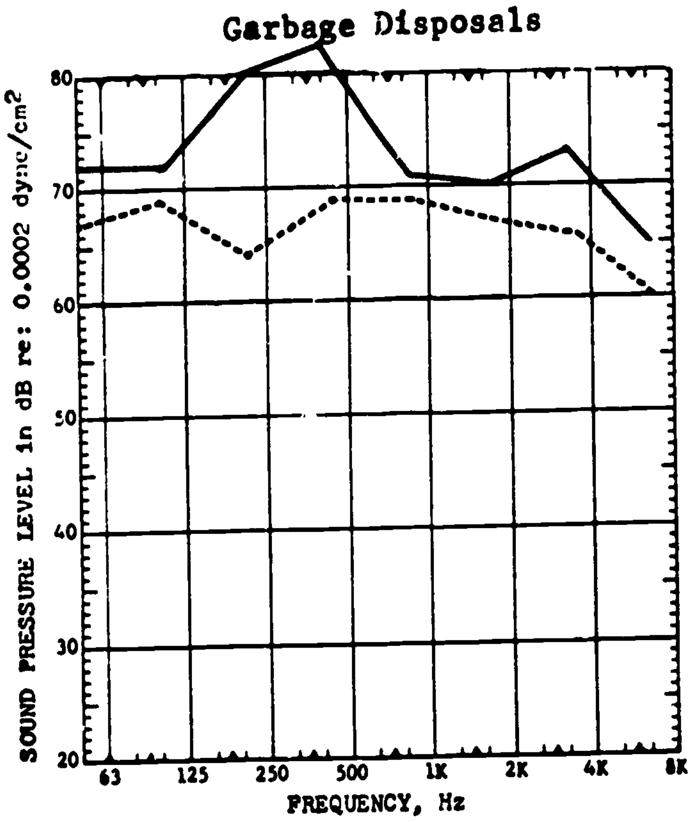
Ref. #13
Range of measurements on 6 different refrigerators.

Dish Washers



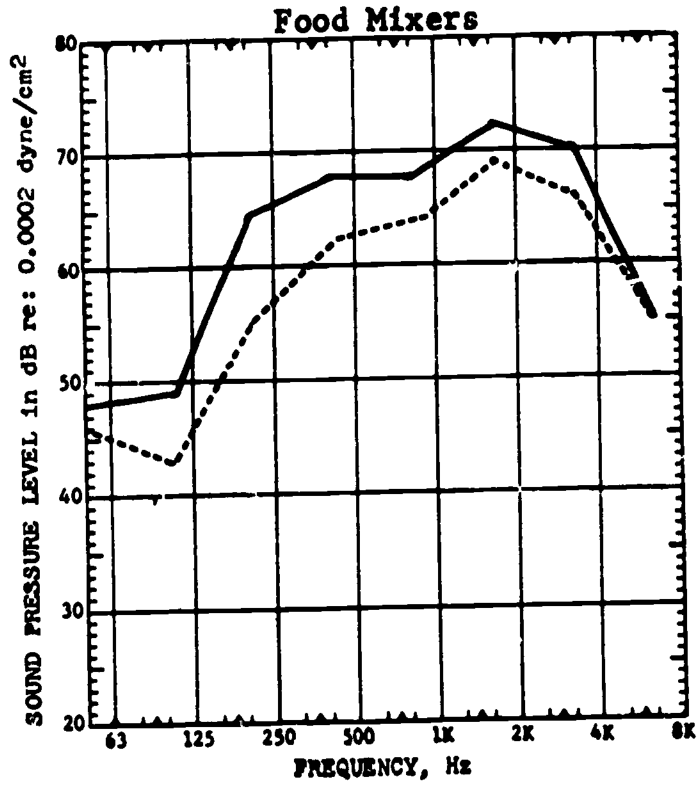
Refs. #4 and #11
Range of measurements.

Garbage Disposals



Ref. #4
——— Grinding Bones.
------- Running Freely.

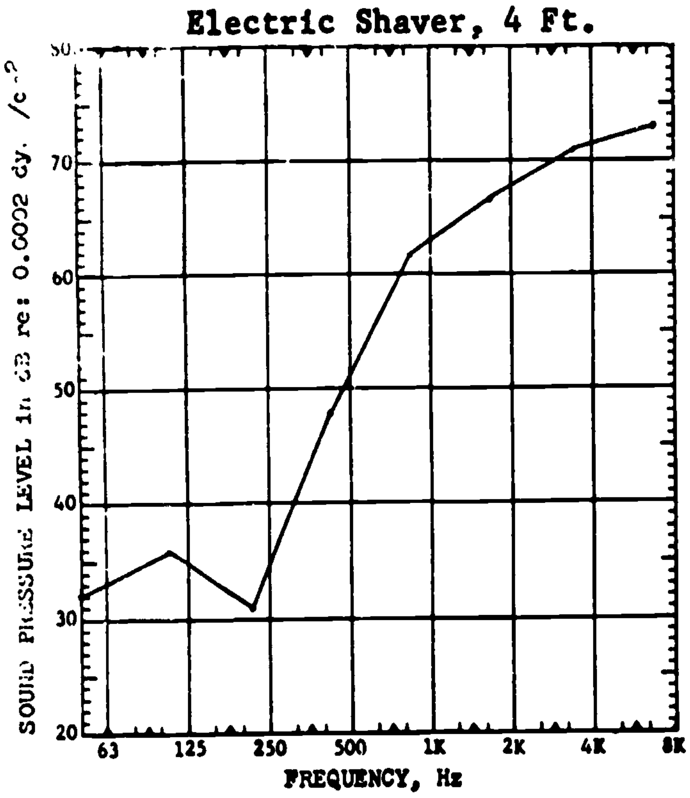
Food Mixers



Ref. #4
——— On Tile.
------- On Pad.

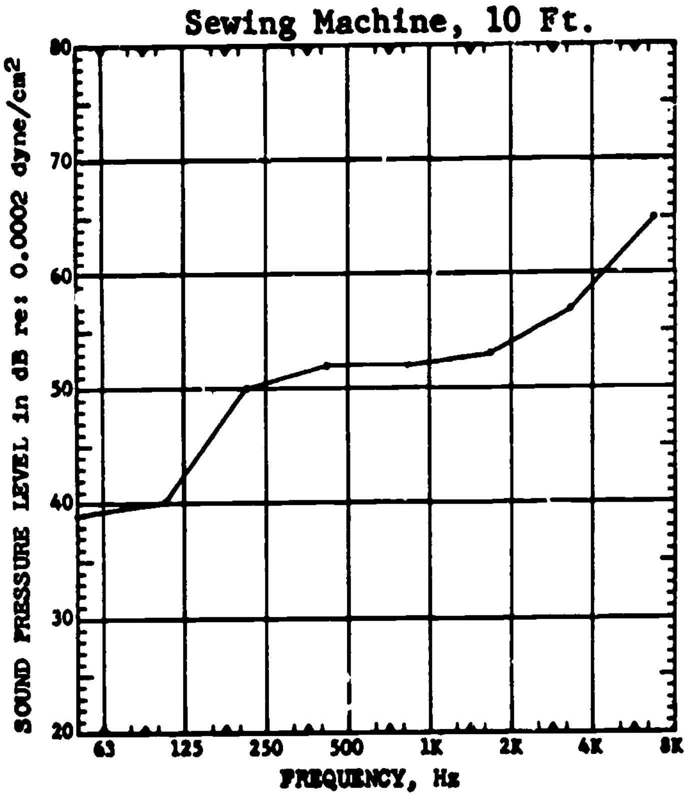
Household Appliance Noise Levels
(in octave bands)

Electric Shaver, 4 Ft.



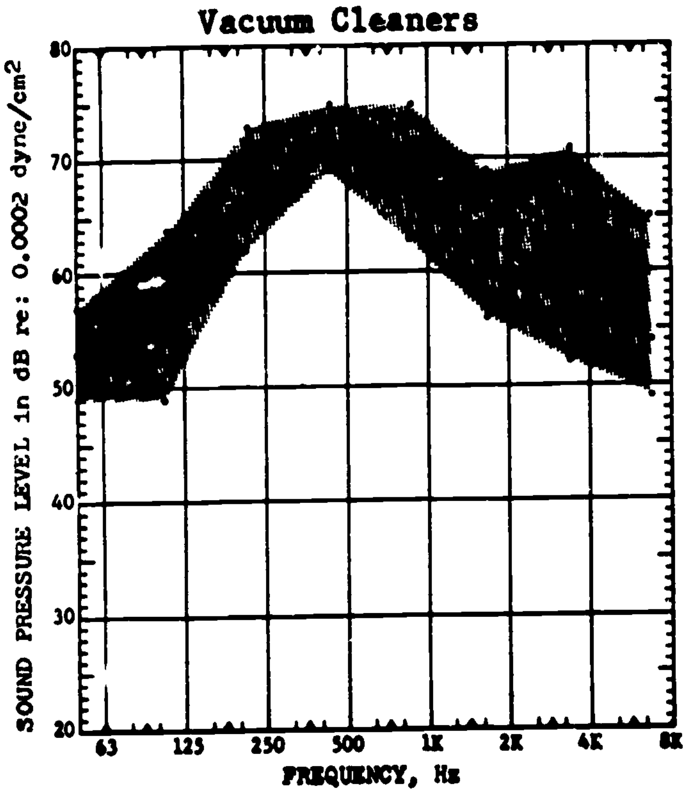
——Ref. #1

Sewing Machine, 10 Ft.



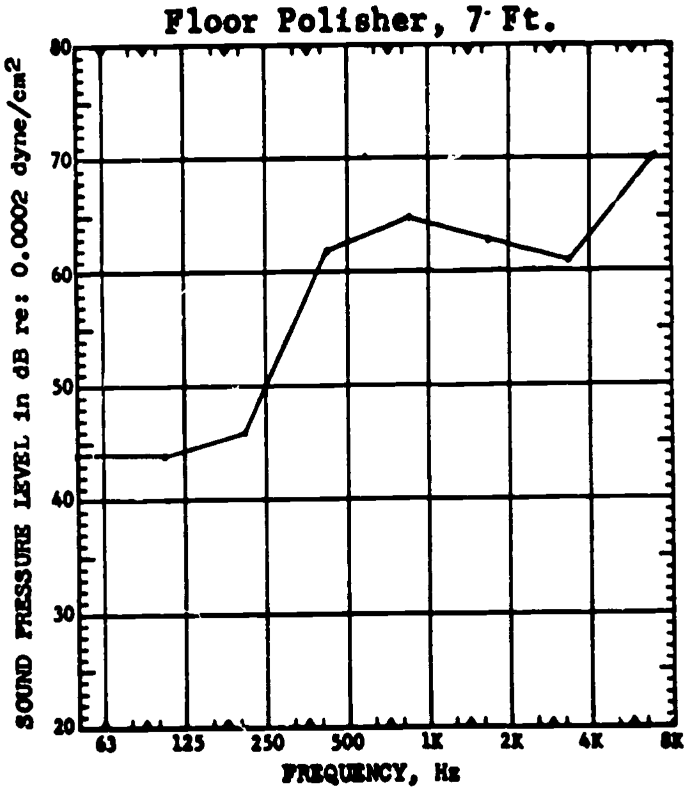
——Ref. #1

Vacuum Cleaners



——Refs. #1, #4, #11 and #12.
Average of 6 measurements.
Spread of measurements.

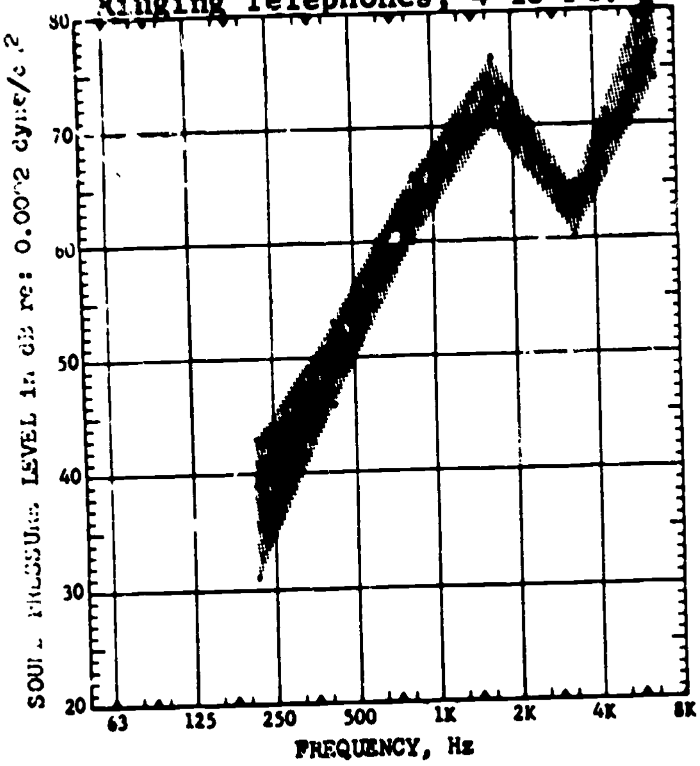
Floor Polisher, 7 Ft.



——Ref. #1

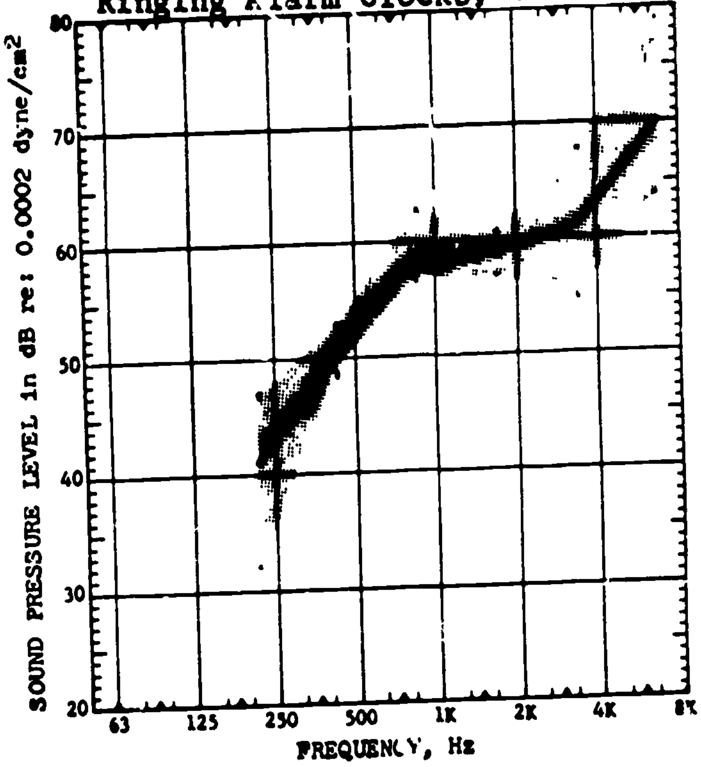
Miscellaneous Household Noise Levels
(in octave bands)

Ringing Telephones, 4-13 Ft.



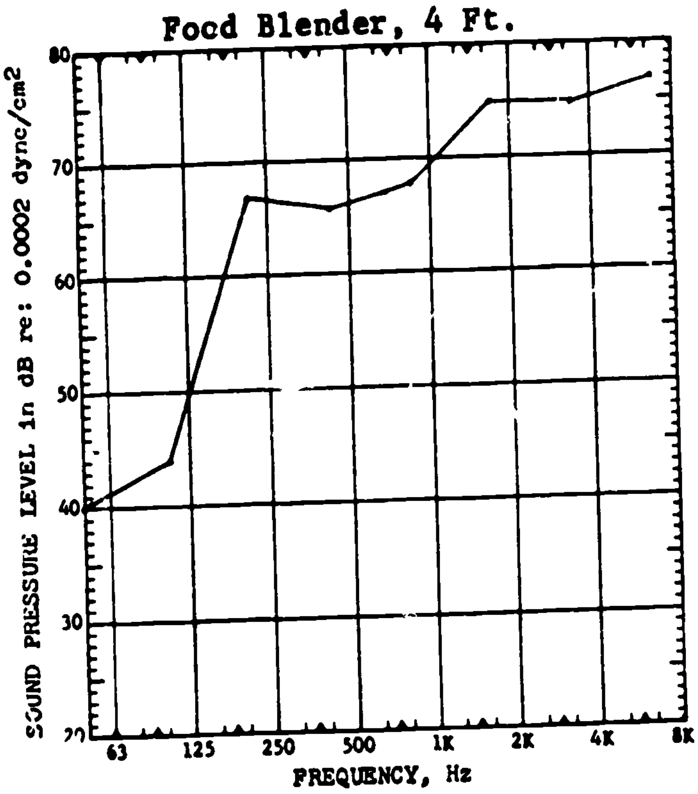
——Ref. #1
Average of 3 measurements.
Spread of measurements.

Ringing Alarm Clocks, 4-9 Ft.



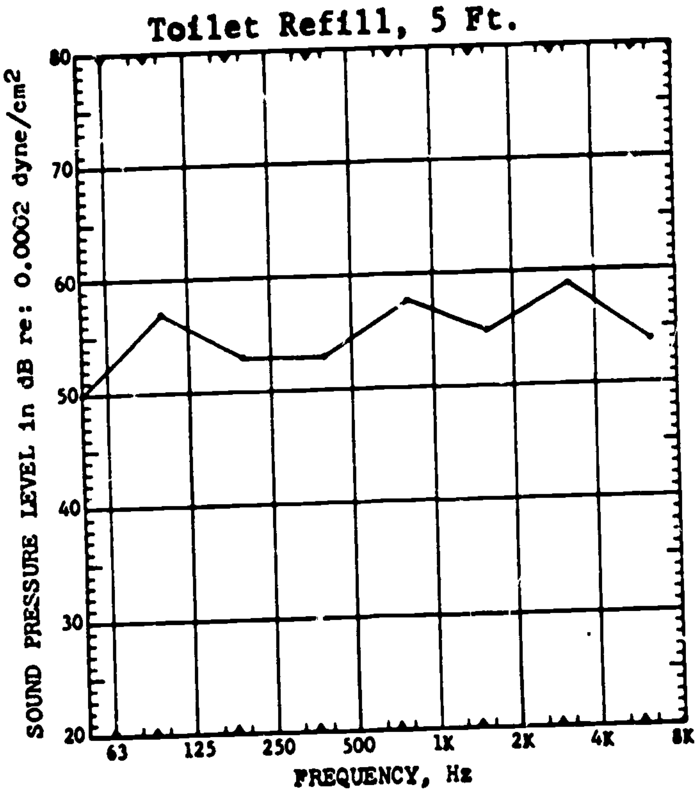
——Ref. #1
Average of 3 measurements.
Spread of measurements

Food Blender, 4 Ft.



——Ref. #1

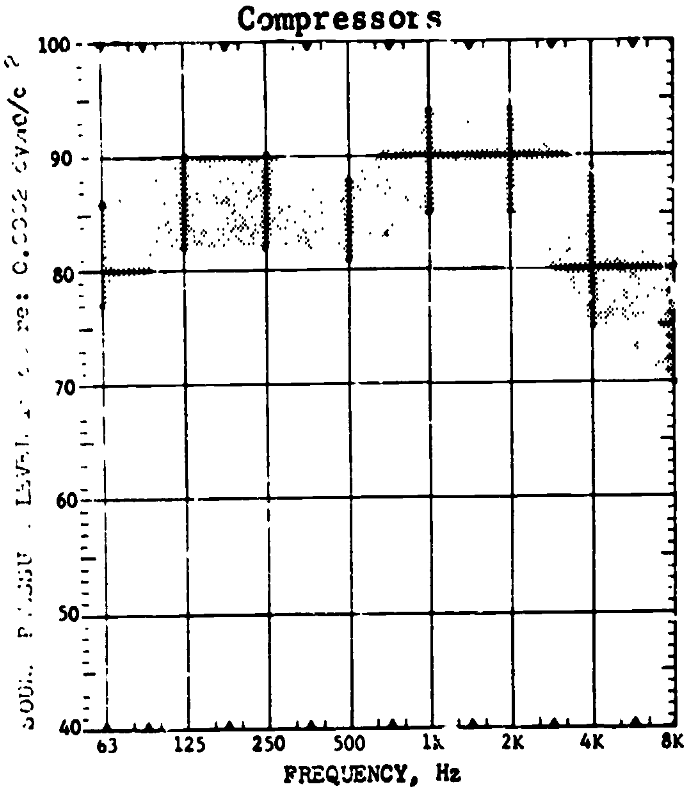
Toilet Refill, 5 Ft.



——Ref. #1

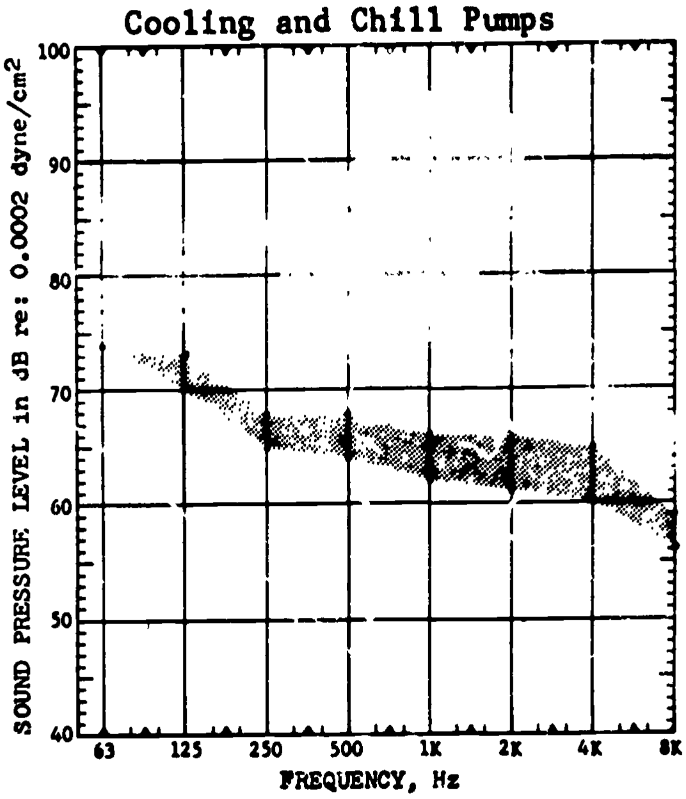
Equipment Room Noise
(in octave bands)

Compressors



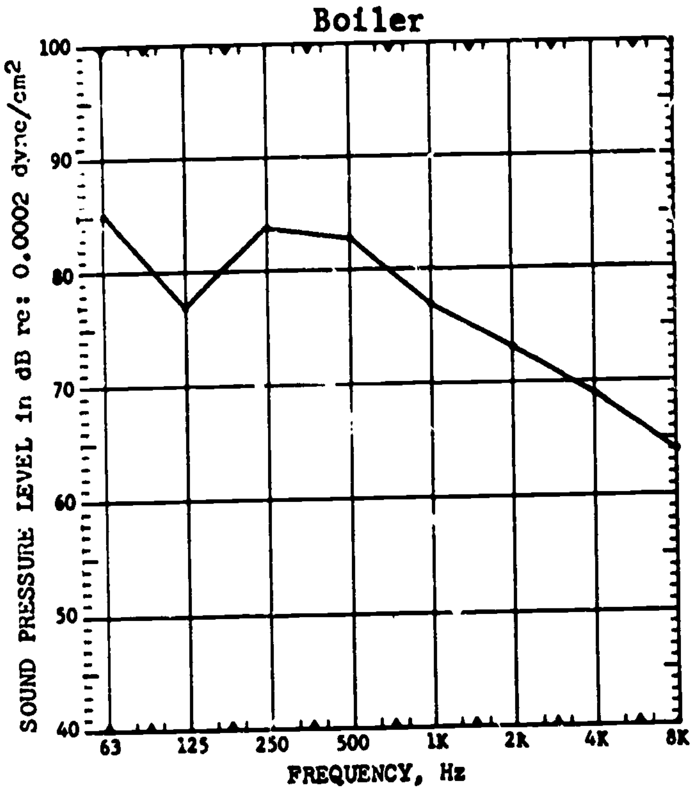
Ref. #1
Range of measurements.

Cooling and Chill Pumps



Ref. #1
Range of measurements.

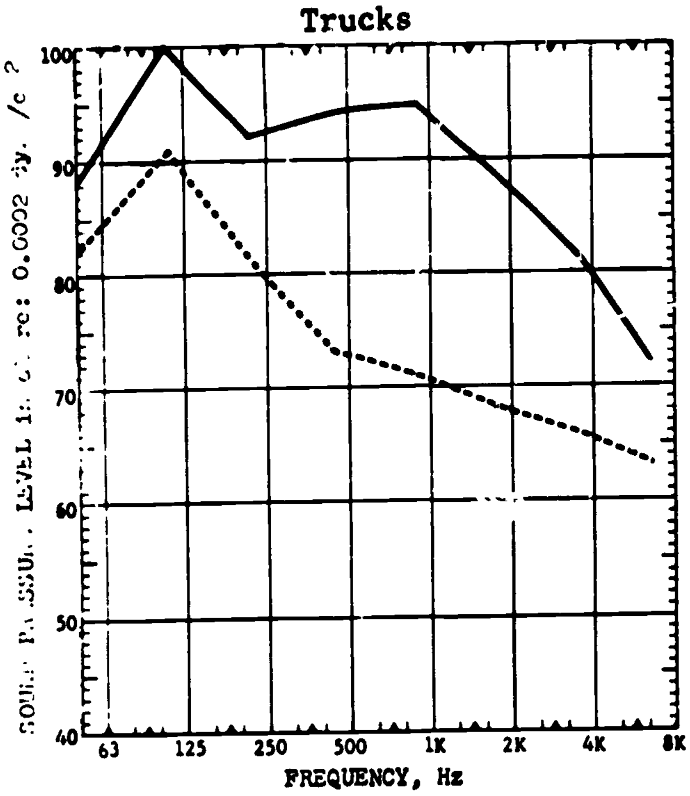
Boiler



Ref. #1
——Steam Capacity of 2000 lb/hr.

Motor Vehicle Noise Levels
(in octave bands)

Trucks

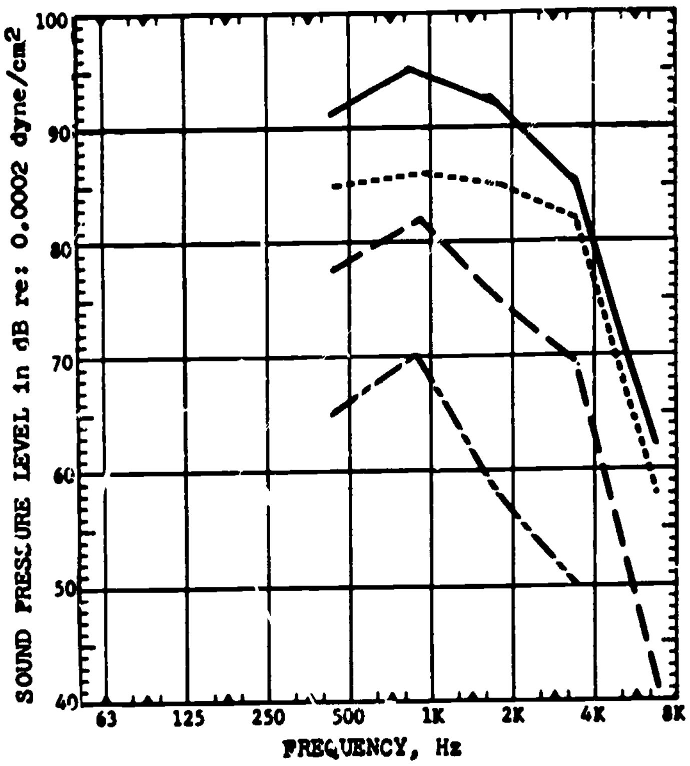


Ref. #5

——Diesel Powered.

·······Gasoline Powered.

Automobile Horns



Ref. #6

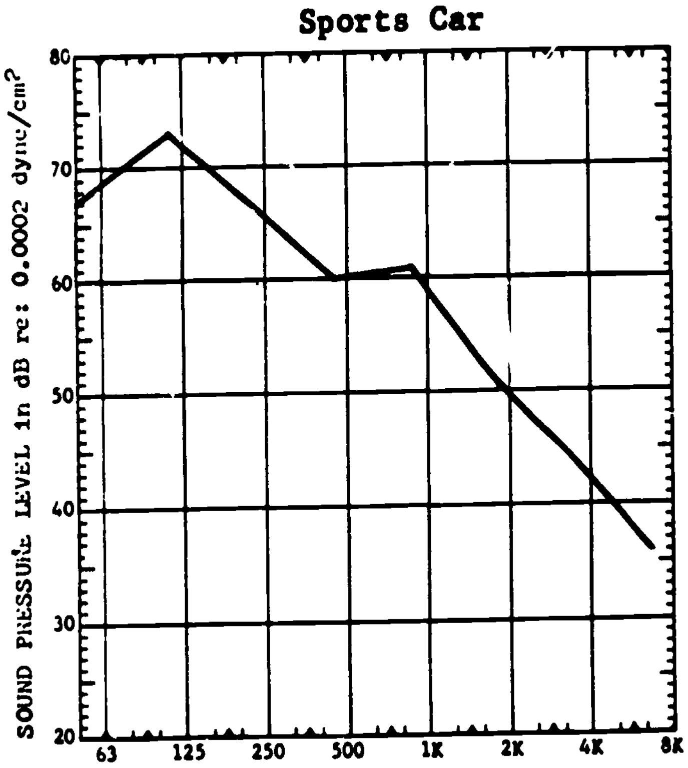
——12 Ft. from horns.

·······50 Ft. from horns.

— — -100 Ft. from horns.

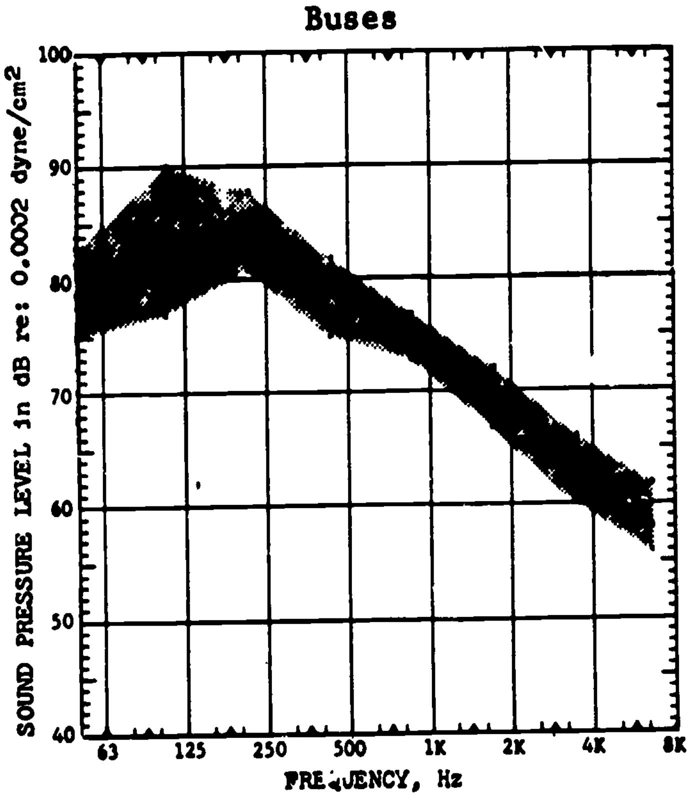
-·—-300 Ft. from horns.

Sports Car



——Ref. #5

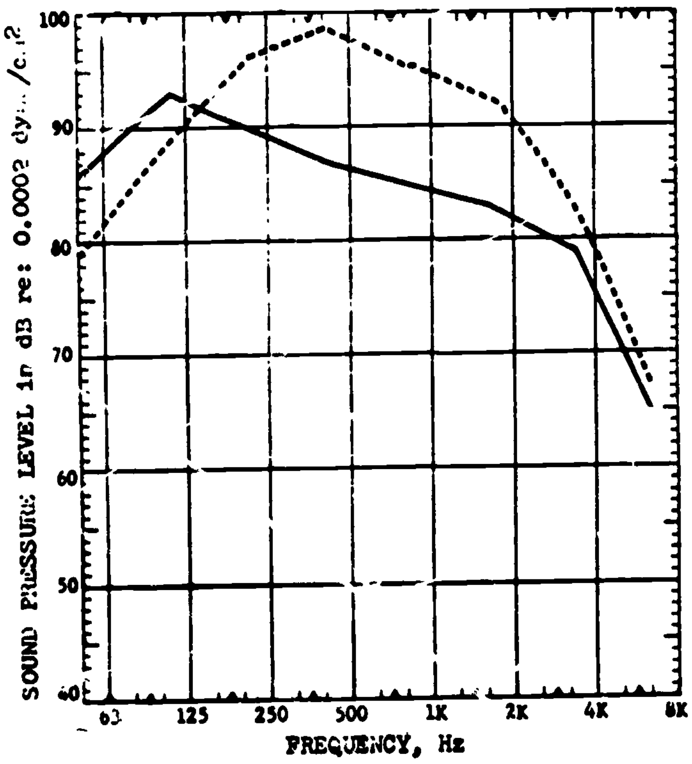
Buses



——Refs. #5 and #7
Average of 3 measurements.

Spread of measurements.

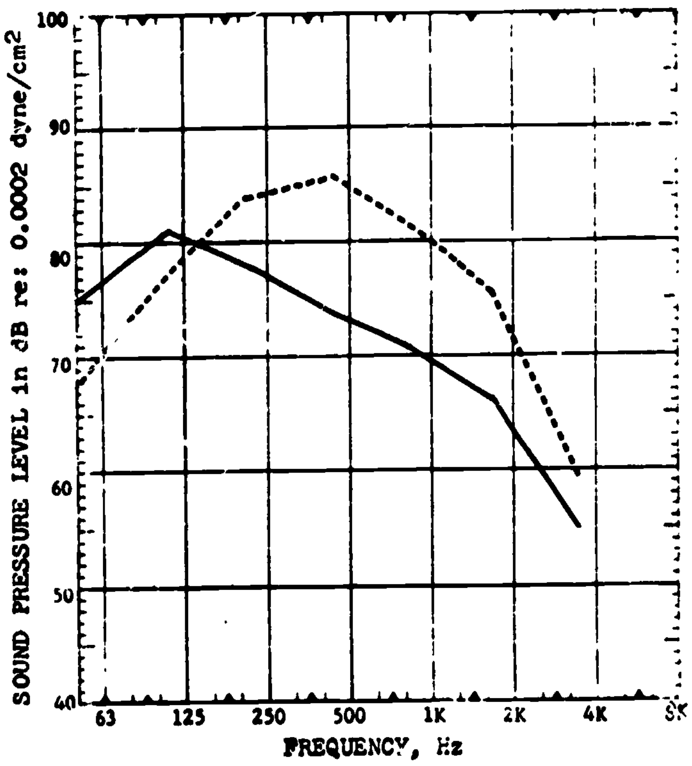
Airplane Noise Levels
(in octave bands)



Ref. #16

——— Propeller Aircraft
.... Jet Aircraft

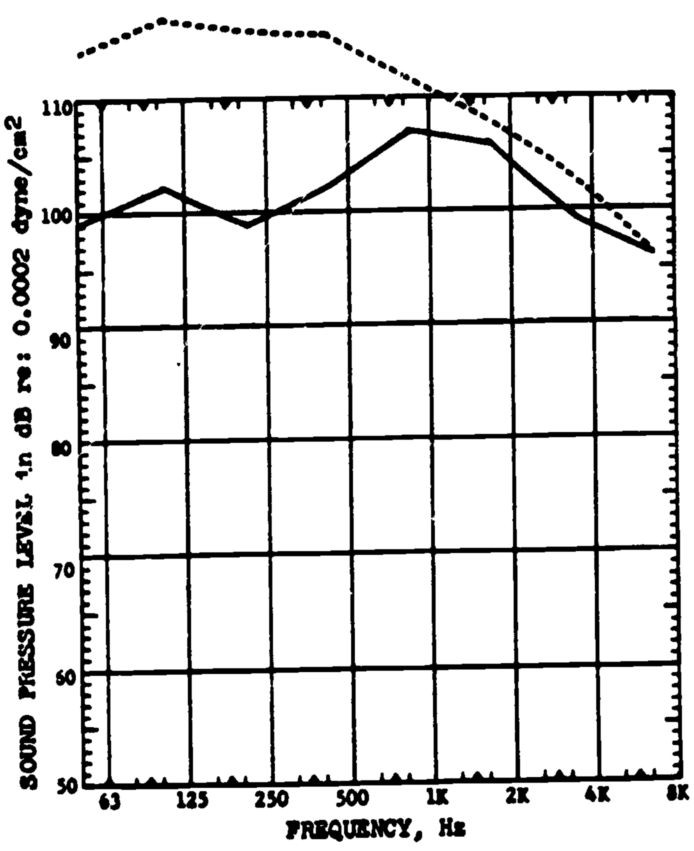
Measurements made at slant distances of 1500 ft on both <u>sides</u> of aircraft during take off.



Ref. #16

——— Propeller Aircraft
.... Jet Aircraft

Measurements made at slant distances of 1 mile on both <u>sides</u> of aircraft during take off.



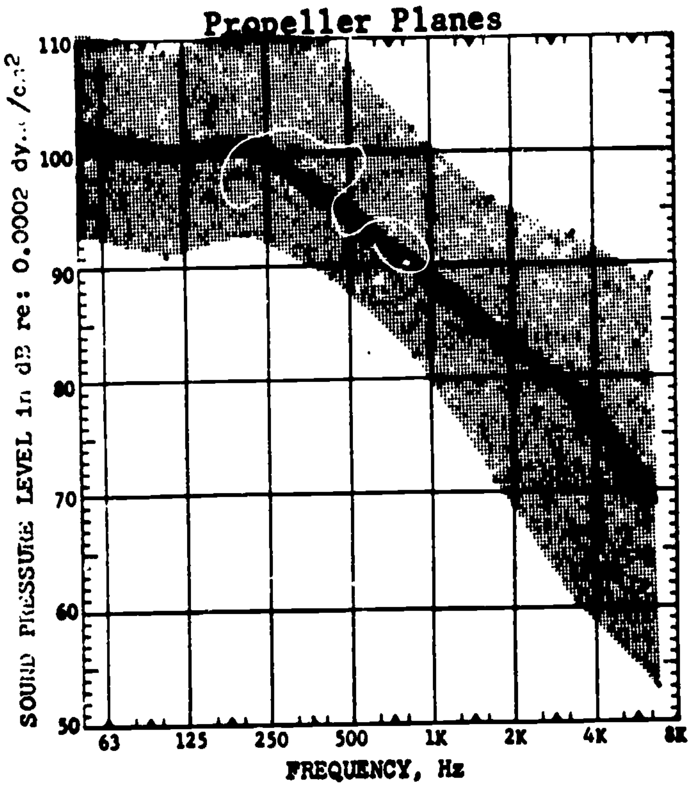
Ref. #17

Jet measured at a distance of 200 ft.
——— in front of jet, azimuth 0°-45°
.... in back of jet, azimuth 120°-160°

As seen in the graph on the left, the noise output from a jet is greater from behind than in front. Measurements made in front of both types of aircraft may tend to favor the jet as less noisy, as shown on page C-12. The jet would have appeared to be noisier if similar measurements were made behind the take off point. In the comparisons illustrated in the above graphs, it appears that the jet is noisier.

Airplane and Train Noise Levels
(in octave bands)

Propeller Planes

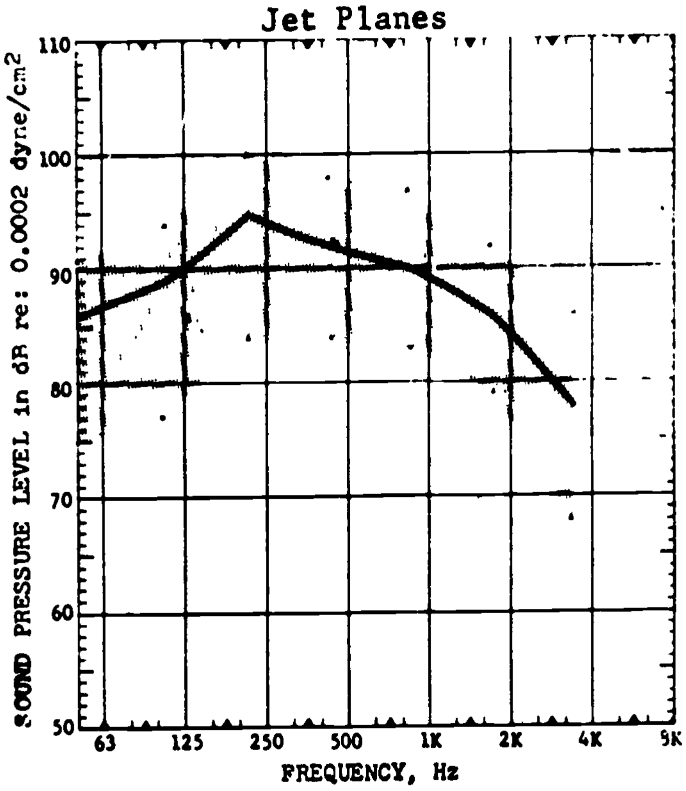


——Refs. #8 and #9
Average of 30 measurements, 2 to 2.5 miles in <u>front</u> of take off point.*

Spread of measurements.

* See page C-11

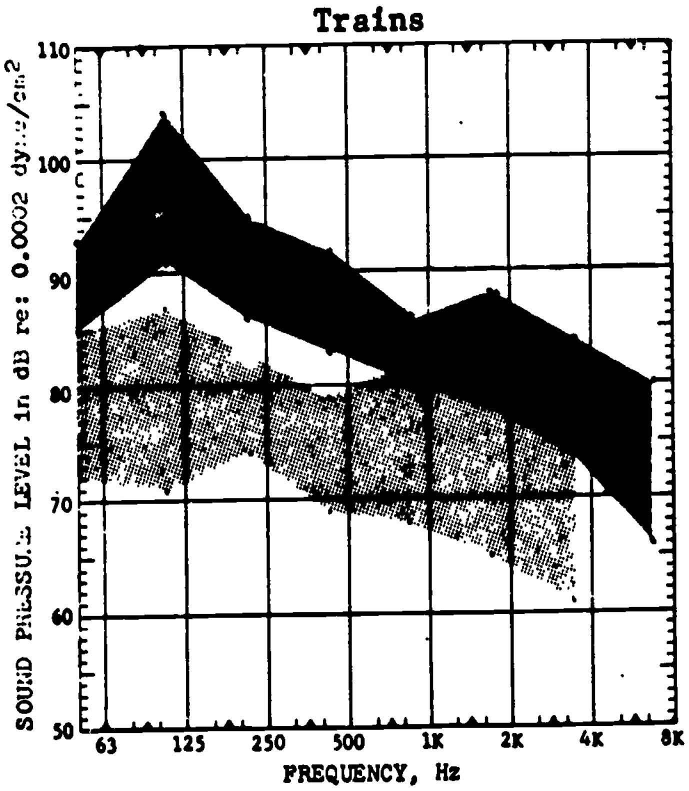
Jet Planes



——Refs. #8 and #9
Average of 18 measurements, 2 to 3 miles in <u>front</u> of take off point.*

Spread of measurements.

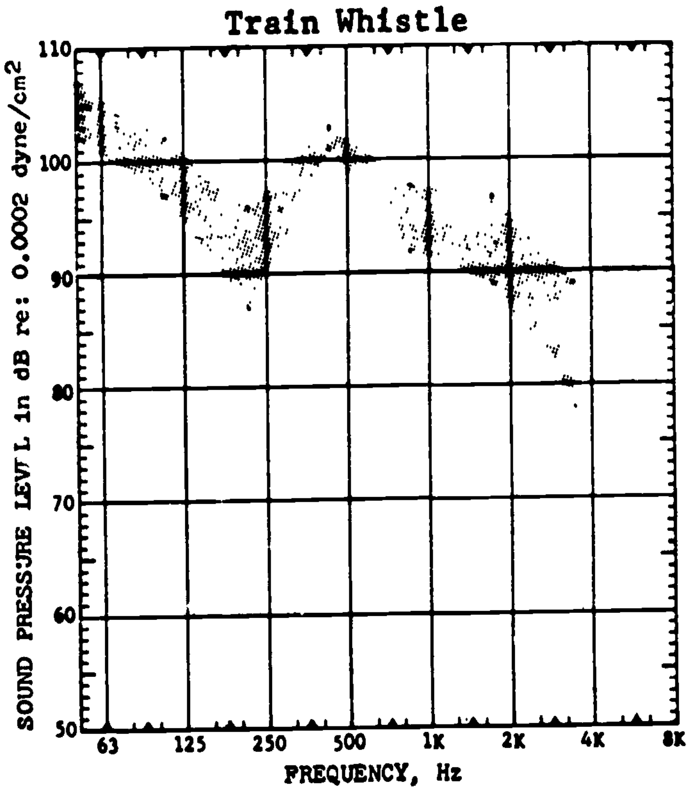
Trains



Ref. #10

Coasting at 100 Ft.
Pulling Hard at 100 Ft.

Train Whistle



Ref. #10

Whistle at 100 Ft.

REFERENCES

1. National Bureau of Standards: Unpublished Data.

2. Goodfriend, L.S., "Noise in the Community", Noise Control, Vol. 4, No. 2, (March 1958), pp. 22-28.

3. Seelbach, Jr., H., and Oran, F.M., "What to Do about Cooling-Tower Noise", Sound, Vol. 2, No. 5, (September-October 1963), pp. 32-41.

4. Mikeska, E.E., "Noise in the Modern Home", Noise Control, Vol. 4, No. 3, (May 1958), pp. 38-41.

5. Veneklasen, P.S., "City Noise - Los Angeles", Noise Control, Vol. 2, No. 4, (July 1956), pp. 14-19.

6. Callaway, D.B., "Spectra and Loudnesses of Modern Automobile Horns", The Journal of the Acoustical Society of America, Vol. 23, No. 1, (January 1951), pp. 55-58.

7. Bonvallet, G.L., "Levels and Spectra of Transportation Vehicle Noise", The Journal of the Acoustical Society of America, Vol. 22, No. 2, (March 1950),pp. 201-205.

8. Miller, L.N., and Beranek, L.L., "Comparison of the Take-Off Noise Characteristics of the Caravelle Jet Airliner and of Conventional Propeller-Driven Airliners", The Journal of the Acoustical Society of America, Vol. 29, No. 11, (November 1957), pp. 1169-1179.

9. Gibbs, R.M., and Howell, H.H., "Noise Characteristics for the Boeing 707", Noise Control, Vol. 5, No. 1, (January 1959), pp. 13-17.

10. Embleton, T.F.W., and Thiessen, G.J., "Train Noises and Use of Adjacent Land", Sound, Vol. 1, No. 1, (January-February 1962), pp. 10-16.

11. Miller, L.N. (L.L. Beranek, ed.), Noise Reduction, (New York: McGraw-Hill Book Company, 1960).

12. Northwood, T.D., "Sound Insulation and the Apartment Dweller", The Journal of the Acoustical Society of America, Vol. 36, No. 4, (April 1964), pp. 725-728.

13. Sabine, H.J., "Measurement and Reduction of Refrigerator Noise", A paper presented at a symposium on Domestic Refrigerator and Freezer Engineering, ASHRAE 71st Annual Meeting, (June 29-July 1, 1964).

14. Parkin, P.H., and Humphreys, H.R., Acoustics, Noise and Buildings, (New York: Frederick A. Praeger, 1958).

15. van den Eijk, J., "My Neighbor's Radio", Instituut voor Gezondheidstechniek T.N.O., Stuttgard, 1959.

16. Eldred, Ken, Comments on "Noise Characteristics of the Caravelle Jet Airliner", Noise Control, Vol. 4, No. 3, (May 1958), pp. 46-8.

17. Hoover, R.M. and Miller, L.N., "Noise Characteristics of Some Jet Ground Operations", Noise Control, Vol. 5, No. 2, (March 1959), pp. 28-31.

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