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BY

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Summary of a seminar presented at the
1966 Annual Convention of the National
House Builders Association in Montreal
January 11, 1966

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PREFACE

Lack of effective noise control is cited as a major source of tenant complaint in multi-family dwellings and an important factor in the high rate of turnover in some rental properties. This, combined with the current trend to multi-family housing, has led to increased emphasis by builders on the control of noise in new construction and correspondingly a need for reliable technical information on the subject.

To meet this need the Division of Building Research, working through the Research Committee and the Manufacturers' Council of the National House Builders Association, presented a seminar on "Noise Control in Residential Construction" at the NHBA annual meeting in Montreal in January 1966. The Division's contributions, which were presented by T. D. Northwood, Building Physics Section, and H. B. Dickens and A. T. Hansen, Housing Section, form the subject matter of this paper.

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R. F. Legget,
Director.

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by

T. D. Northwood, H. B. Dickens, and A. T. Hansen

A tenant may be attracted to a new apartment building by the splendid lobby, the sauna bath or the swimming pool, but whether he stays or not will probably depend on less obvious amenities. One of the most important is adequate protection from noise. Even the occupant of a single-family dwelling may yearn for a quiet refuge from the prattle of his children or of their transistor radio.

Recognizing the importance of sound insulation, the National House Builders Association invited the Division of Building Research to present a seminar on this subject at the NHBA Annual Meeting in Montreal in January 1966. The substance of that presentation is recorded here. The papers consider, step by step, the properties of typical sounds and how they are transmitted within buildings, the acoustical requirements for adequate protection of the occupants, and the practical methods of design and construction that will meet these requirements. A bibliography of other relevant publications has been included at the end of this report.

SOUND AND NOISE

Before considering actual construction details, it will be a useful preliminary to establish the vocabulary used in describing sound waves and in evaluating noise control problems.

A sound wave reaches the ear as a minute fluctuation in air pressure which can be represented graphically as shown in Figure 1. One complete fluctuation of the wave is a cycle, and the number of cycles per second is the frequency or pitch of the sound. The movement of a sound wave through air can be compared with a ripple on the surface of water; the distance from peak to peak is known as the wavelength.

The simple fluctuation shown in Figure 1 represents a single frequency. Most sounds contain many frequencies and their graphs look more like those shown in Figure 2, but the individual frequency components can be dealt with one at a time in acoustical calculations. The relative importance of the various frequencies in some typical sounds are depicted in sound spectra, as illustrated in Figure 3. Note that most of the power in speech is around 400 cycles per second. The intelligibility of speech depends mainly, however, on a slightly higher frequency band. Footsteps have a somewhat similar spectrum, although for a wood joist floor there would be more low frequency energy than for the concrete floor illustrated here.

The wavelength corresponding to each frequency is shown at the top of Figure 3, and it will be seen that the wavelengths of interest range from 2 in. to about 10 ft. Generally the efficiency of a source in radiating sound depends on its size relative to a wavelength. Thus, a vibrating body only a few inches in diameter will not radiate much low frequency sound. But if it is attached to a large radiating surface it will then produce much more low frequency sound.

A sound becomes a noise when it interferes with one's own activities. If it is too loud, it makes it difficult to converse with people, or listen to music, or sleep. Even when it is not very loud, it will intrude if it conveys any kind of message. Speech that is intelligible, or nearly so, is certainly the worst offender. Footsteps are annoying because of their sharp impulsive quality, and the directional effects associated with them. One of the classic examples is the sound of one shoe dropping; the message it conveys is that there will probably be a second one.

Hearing - The Decibel Scale

Figure 4 indicates the range of frequencies and sound levels that can be heard. The decibel scale is useful in this context because it corresponds closely to the way variations in intensity or loudness are perceived. The ear recognizes percentage changes rather than absolute differences in pressure. The minimum change perceived under laboratory conditions is about 1 dB which corresponds to a 10 per cent change in sound pressure. In actual situations 2 or 3 dB is a very small change; 10 dB is a substantial change.

The zero on the sound level scale is arbitrarily set to about the minimum one can hear in a very quiet laboratory environment. More typically, even in quiet situations, there is usually a background level of noise amounting to at least 10 or 15 dB, more often 30 to 40 dB. Conversational speech averages about 70 dB. A successful cocktail party can approach 85 dB but this is still below the threshold of pain which is around 130 dB.

Sound in Buildings

The sound level in a room depends not only on the power of the source, but also on the amount of sound absorption in the room. Absorption may be provided by furnishings, such as carpets, drapes and furniture, or by acoustical material. This is a good point at which to consider how much one can accomplish by absorption treatment in the source room itself. To achieve a 10 dB reduction in sound level, the absorption must be multiplied by a factor of 10. Perhaps this can be done in a kitchen or bathroom or a particularly bare playroom, but in a reasonably furnished bedroom or living room, it will be difficult even to double the absorption which would reduce the noise by only 3 dB. Another problem with this approach to noise control is the fact that some types of noise sources adapt themselves to their surroundings. For example, the noise level produced by a radio or TV set is determined by the listener and the volume control rather than by the amount of absorption in a room.

Sound Barriers

The most effective means of controlling the propagation of sound in a building is to erect walls and floors that act as good barriers to sound. The first requirement of a barrier is that it be impermeable. A wall built of porous block, for example, is not very effective because the sound actually travels through the pores of the material, unless they are sealed at some point in the path by plaster or heavy paint. The next desirable virtue is weight: the sound transmission loss of a single wall increases by roughly 5 dB when the weight is doubled. The top curve in Figure 5 illustrates what one can achieve with a 9-in. brick wall. This is about the practical limit that can be achieved by weight alone.

Another approach is to use a multiplicity of walls with a minimum of coupling between them. A typical stud wall consists essentially of two walls, but they are connected to some extent by a stud framework and also by the air confined between them. Consideration will be given later to the effects of these two types of coupling on the performance of stud walls.

In addition to weight and impermeability, the other factor of importance in a wall is its flexural stiffness. Unfortunately, stiffness is not usually a virtue. In the case of thin panels or lightweight masonry, stiffness is responsible for what is known as a "coincidence dip" in the transmission loss curve. The performance of a lightweight masonry wall shown in Figure 5 exemplifies this with a bad mid-frequency slump in performance. Similarly, the plaster layers of the stud wall show a very characteristic coincidence dip in the high frequency range.

Sound Transmission Class

Another point to observe in Figure 5 is that the transmission loss varies markedly over the frequency range. Clearly, there is a problem in comparing the insulation performances to be expected from these three walls. In the old days it was customary to take a simple average of measurements made at certain standard frequencies. This may be rather misleading, however, if the transmission loss varies irregularly as indicated by the broken curve. The average of the transmission loss measurements for the lightweight masonry wall appears good because of the satisfactory performance at very high frequencies, but this says nothing about its poor performance in the important middle frequency range. The other difficulty about averages is that about 57 kinds of averages have been used, by various people at various times. One must, therefore, be cautious in interpreting average figures in trade literature.

Acoustical experts now rely on a new type of rating which provides a more reliable figure of merit for the common sound insulation applications -- Sound Transmission Class (STC). The classification procedure involves comparing the actual transmission loss curve with a set of STC contours similar to the one shown in Figure 5. In effect, the procedure is to consider only the low parts of the transmission loss curve relative to this contour.

Impact Sound

So far the discussion has been related primarily to airborne sounds, that is, sounds, such as voices, that travel through the air before they impinge on the boundaries of a room. Another equally important category is impact sounds such as footsteps, which originate as vibrations in the structure itself.

The assessment of impact sounds is not as cut and dried as one would like, but there is an international standard test, and several rating schemes similar to the STC system. The Impact Noise Rating (INR) developed by the U.S. Federal Housing Administration, which is now widely used in the United States, will be referred to later in comparisons of different floor constructions.

How Much Sound Insulation is Needed?

In principle at least one can control the sounds produced in one's own dwelling, so this discussion will concentrate on party walls and floors in multiple dwellings. Ideally, the amount of sound insulation should at least equal the difference in noise spectra between the noisy apartment and the quiet one. Then the noise that penetrates to the quiet side will not be heard. On the noisy side typical noises will be TV, voices, and so on. In the most critical cases the background level on the quiet side will consist of a random collection of noises transmitted from outdoors and from distant parts of the building. Incidentally, a Swedish survey showed that if a building fronts on a busy thoroughfare, the people who overlook the street complain about traffic noise but not about their neighbours; but the people at the back of the building complain about the neighbours.

For typical noises and background conditions, about two-thirds of the tenants will be satisfied most of the time if an insulation of STC 50 is provided between critical areas such as bedrooms or living rooms. This, by the way, will still be inadequate for separating, say, kitchens from bedrooms. In Residential Standards* the minimum requirement is STC 45, but about half the occupants of such a building will sometimes find it inadequate; for less than STC 45, the percentage and degree of dissatisfaction increases very rapidly. At the upper extreme, the practical maximum that can be achieved in a wall is about STC 55, and this requires great care in construction details.

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* Residential Standards, Supplement No. 5 to the National Building Code of Canada 1965, NRC 8251.

There is considerably less information available about impact noise, but it appears that a recommended value of the Impact Noise Rating would be zero or better. An INR of -10 should be regarded as the rock-bottom minimum, about equivalent to the airborne requirement of STC 45.

SITING AND LAYOUT OF BUILDING

The location and interior layout of a building can greatly influence the noise problem and it is important to begin noise control at the planning stage.

Flexibility in site layout is often limited but where outdoor noise levels are high the following can assist in reducing their effect:

1. Locate the building as far from noise source as possible. The noise level drops about 6 dB each time the distance is doubled.

2. Take advantage of hills, highway cuts or other buildings to provide sound barriers. Note that trees or shrubs are of little value as barriers though they may provide some absorption of sound.

3. Locate noncritical areas such as corridors, kitchens, bathrooms, elevators and service spaces on the noisy side and critical areas such as bedrooms and living spaces on the quiet side.

4. Keep windows away from the noisy side of a building wherever possible.

Windows

Windows are the weakest part of exterior walls in terms of sound control. Their effectiveness is directly related to the over-all air tightness of the installation. This is the reason why fixed windows are better for sound control than openable windows. Fixed single glazing is about as good acoustically as openable double glazing (Figure 6). Most fixed double glazing is in the range of STC 30 to 35 and this increases as the space between the panes is increased. For a relatively high degree of sound control (an STC of over 40) it is necessary to provide two panes of glass separated by at least an 8-in. space - not a very practical situation in most cases. There is a fundamental difference in this regard between heat and noise control. For thermal insulation there is little advantage in an air space larger than 3/4 in.

In summary:

1. Keep windows on noisy side of buildings to a minimum
2. Use sealed units wherever possible
3. Make sure that movable windows are well weatherstripped to reduce air leakage.

Control of Indoor Noise

Much can be done with the interior layout of buildings to control noise in the more critical areas.

In apartment buildings the stacking of identical units on successive floors one above the other so that kitchens are over kitchens and bathrooms are over bathrooms can aid considerably in noise control. These are not only noisy areas but frequently have hard surface floors which tend to increase the problem of impact sound transmission which is a source of frequent complaints in existing apartments. Such problems are costly to control by construction methods.

The floor problem can be minimized between units in apartment buildings by placing each apartment unit on two floors with the bedrooms of each on the lower level below their own living areas. This could still result in some impact noise problems within the unit itself but at least confines the problem to one occupancy where the occupants can exercise some degree of control.

For all apartments, except perhaps the small efficiency type, the layout of each floor can usually be planned so that quiet areas in one apartment are separated from adjacent apartments by buffer zones such as closets, stairways, halls and kitchens. If this is done the STC 45 party wall may be adequate. Where this arrangement is not possible the best alternative is to place quiet areas such as bedrooms adjacent to similar areas in the next apartment and to provide an STC 50 party wall between. The worst arrangement is to place noisy areas of one unit next to quiet areas of the neighbouring unit (for example, kitchens next to the neighbours' bedroom). In this case even an STC 50 wall would probably be inadequate.

An example of a poorly planned unit is shown in Figure 7. In this layout the bedroom, which should be a quiet area, is next to the elevator and also adjacent to the neighbour's kitchen. The choicest areas which are buffered from the neighbouring noise are occupied by the bathroom and kitchen which are noncritical rooms. In contrast Figure 8 shows a well-planned layout with the noncritical areas such as kitchen and bathroom acting as buffers against unwanted noise.

The plumbing fixtures serving kitchen and bathrooms are particularly troublesome sources of noise. The problem can be minimized by placing kitchens and bathrooms of adjacent units back-to-back and one above the other with the services in a wall away from the critical rooms. Methods of handling the special noise problems arising from mechanical and electrical services will be discussed later. It is particularly important in planning, however, to locate furnaces, pumps, compressors, fans, and laundry equipment away from quiet areas such as bedrooms. In high-rise apartments the location of elevators and incinerator chutes should be given careful consideration. Elevators are a special problem since they may cause noise or vibration throughout the entire building.

The planning principles used in the control of noise between apartments can also be effective in controlling noise within a single occupancy. This is illustrated in Figure 9. Note that:

1. The noisy areas, bathrooms, stairs, kitchens and back entrances, are grouped and the bathrooms are back to back.

2. The common bathroom partition or the bathroom-kitchen partition allows the plumbing stack to be isolated from the quiet areas.

3. Sleeping and living areas are separated, with the bedroom on the lower left being the quietest room.

4. Clothes closets are arranged to act as sound barriers.

5. Sleeping areas are separated from living areas by an extra door in the hallway.

With care in planning the partitions within a dwelling plus one or two extra doors will serve as sound barriers to divide the dwelling into zones of acoustical privacy. The typical stud partition is a fairly adequate noise barrier within a dwelling (but not between dwellings) provided it is not made ineffective by heating ducts, openings around electrical fixtures, or by poorly fitting doors.

Open Planning

The trend to open planning in house layout is a trend away from acoustical privacy. For the control of noise there is no substitute for a wall or a door. As a minimum the open plan should be modified by separating off one quiet zone such as the bedroom area from the remainder of the house (Figure 9). Within the open plan one can temper noise problems by suitable space arrangement and by a judicious use of acoustical materials. Transmitted noise levels will not usually be reduced by more than 5 or 10 dB by this means, but at least the sharp edge can be taken off sounds such as the clatter of dishes. The kitchen, in fact, is a good place to consider the application of acoustical material. Another useful area is a hallway or foyer separating noisy from critical zones. This is especially helpful if a direct line of sight to the noise source is avoided.

Doors

Doors are generally the weak link in the control of sound between rooms and consequently they determine the degree of sound privacy that can be achieved. A typical door may have an STC 15 to 20 compared with STC 30 to 35 for a standard stud partition with drywall. Where doors are used in a wall there is no advantage in increasing the STC of the partition. The situation could be improved by using a heavier (solid core) door and providing gasketing to control air leakage although this would be of reduced value where the door must be undercut to allow for return air flow in heating or ventilating systems.

A gasket installed between the door and jamb can also assist by softening the impact when the door is slammed. This is a particularly useful treatment for doors to apartments from common halls. Wherever possible doors to such halls should be offset so that noise is not radiated directly across from one door to another. The use of carpets on the floor and acoustic tile on the ceiling will aid in sound control within the corridor and make it a useful buffer zone between apartments.

SOUND TRANSMISSION THROUGH WALLS

The effectiveness of a single layer wall, such as unit masonry, concrete or solid gypsum, in resisting sound depends mainly on its weight. Other things being equal, doubling the weight increases the transmission loss by about 5 dB. One must, however, consider also the stiffness of a wall which is responsible for a drop in transmission loss in a certain frequency range. Thickening a wall, thereby increasing both weight and stiffness, therefore will not necessarily improve it if the stiffness effect is brought into a more critical frequency range.

A masonry wall of given weight per square foot will provide better performance if it is constructed as a cavity wall rather than as a single homogeneous layer. Then the system becomes two massive layers coupled together only by the compressibility of the confined air space. The improvement due to the air space may be spoiled, however, if the two layers are connected by a large number of rigid ties. Ties should be used as sparingly as possible and should be relatively flexible. Coupling through the air space may be substantially reduced by introducing absorptive material such as mineral wool.

The typical frame wall is another example of a cavity wall, and all the above considerations apply. The overall performance depends on the weights of the surface layers and the coupling through the air space or through the studs, whichever is the more important. Usually the three factors are not independent, and it is difficult to present a simple analysis. Generally, increasing the mass of the surface layers reduces air-space transmission, but increasing their stiffness increases stud transmission; mineral wool in the space reduces air transmission; resilient connectors or separate studs reduce stud transmission. The overall performance may depend in a complicated way on each factor.

In walls with a positive break in the sound travel path, such as with staggered studs, the sound resistance can be improved by installing a sound absorbing material such as mineral wool in the space. Sound resistance is improved because the transmission from one side of the wall to the other is through the air space and not through the structure itself.

Thus, the factors that affect the sound transmission of a wall are the mass of the wall, the stiffness, the continuity of the sound transmission path through the wall, and in some cases the sound absorption within the space.

Some Typical Constructions

The significance of these factors can be better appreciated by an examination of the constructions shown in Figure 10. To simplify comparison, $\frac{1}{2}$-in. gypsum wallboard has been assumed throughout. The STC values given in this figure are typical numbers only and can vary with individual tests.

The simplest wall with wood studs at 16 in. centres and 1/2" plasterboard on each side has the lowest rating - STC 33. When this wall is constructed with staggered studs on a 6 in. plate STC 40 is achieved. Here the increased air volume (and reduced air coupling) is helpful. When mineral wool is introduced the distinctions between stud systems become more obvious. Thus, with studs at 16 in. centres the improvement is only from STC 33 to 36, whereas with staggered studs the improvement is from STC 40 to 48. This effect is even more pronounced with thicker surfaces since in these cases the degree of stud coupling becomes more important. Stud coupling can also be reduced by using fewer studs (wood studs at 24 in. centres), or more flexible ones (steel channels) or by interposing soft or resilient links between stud and plasterboard. Doubling the weight of the surfaces (lath and plaster or double layers of plasterboard) improves the performance by about 3 dB.

Residential Standards require walls between occupancies to have an STC 45 and also to provide a 1-hr fire resistance. Wood-frame walls meeting these requirements are shown in Figure 11.

The diagram on the right shows the most commonly used arrangement of staggered studs. In this case lath and plaster finish provides the required sound and fire rating without the addition of insulation. The wall with 5/8-in. drywall requires insulation in the cavity to satisfy the requirement of STC 45. This applies also to the diagram on the left which shows resilient clips or channels. Lath and plaster finish will give an STC 45 without insulation whereas the wall with 5/8-in. wallboard requires insulation to obtain this value.

An STC 45 wall has been criticized as being too low and not providing as high a standard of sound resistance as many people would desire. An STC 50 wall would provide a significant increase in occupant satisfaction and can be obtained with a relatively modest increase in cost.

Two examples of wood-frame walls which give STC 50 and also provide a 1-hr fire rating are shown in Figure 12. Again these involve a staggered stud wall and a wall using resilient mountings.

The differences between these walls and those in Figure 11 are that $\frac{1}{2}$-in. lath is used instead of 3/8-in. lath for the plastered wall and two layers of 3/8-in. gypsum board are used in place of a single layer of 5/8-in. board for the drywall. In both cases insulation is required between the studs.

Turning now to masonry walls, constructions providing STC 45 and a 1-hr fire rating are illustrated in Figure 13. These include walls constructed from 8-in. dense concrete block or 4-in. block with plaster on both sides.

If lightweight blocks are used, 8-in. blocks must have the surfaces sealed by painting both sides or by applying a coat of plaster on at least one side. Otherwise there is sound leakage through the pores, and the wall will not meet the STC 45 requirement. Alternatively, the application of a separate wall finish over furring will provide the necessary seal.

Masonry constructions providing STC 50 are illustrated in Figure 14. The top diagram illustrates a cavity wall which utilizes both mass as well as discontinuity of the sound travel path to reduce sound transmission. In the case of solid masonry with the plaster or drywall finish attached by resilient fasteners the concrete block need only be 6 in. thick if made with dense aggregate and 8 in. thick when cinder aggregate is used. If resilient fasteners are not used and the finish is applied over furring an 8-in. dense aggregate block will provide an STC 50 rating.

SOUND TRANSMISSION THROUGH FLOORS

The principles described for walls also apply to floors as far as airborne sound is concerned. As has been explained the factors that determine airborne sound resistance are weight, stiffness, breaks in sound travel paths, and sound absorption within the space.

Transmission of impact sound through floors is an additional problem and results when the floor is set in vibration through direct mechanical contact. This noise is transmitted through the floor structure and radiated to the room below. This type of noise can lead to more complaints than airborne sound. In this country there are as yet no established building regulations governing impact noise transmission although the Residential Standards do provide a guide for rating the impact noise resistance of a number of floor constructions.

The most effective method of reducing impact noise transmission is by the use of a soft floor covering such as a carpet and pad. Cork tile is also of value but is less effective than a carpet. Other so-called resilient floor coverings such as vinyl, linoleum, or rubber tile are of little value in controlling impact noise. Another method of control is to provide a floating floor surface. This can be done by separating the finish floor from the floor structure by means of a resilient layer such as fibreboard. Similarly the ceiling may be suspended by the use of resilient clips which partially isolate the ceiling from the floor structure. Alternatively, the ceiling may be supported by a set of joists separate from those supporting the floor. This provides in effect a situation much like the staggered stud arrangement. With such constructions some further reduction in impact noise transmission can be achieved by placing a sound absorbing layer of mineral wool insulation within the joist space.

Some Typical Constructions

The various methods used in reducing impact noise transmission are illustrated in Figure 15. Again, for ease of comparison, a ceiling finish of $\frac{1}{2}$-in. gypsum board is used throughout. The finish floor consists of $\frac{1}{2}$-in. hardwood on a $\frac{3}{4}$-in. subfloor.

As indicated in the upper left diagram of Figure 15 a simple wood joist floor system has an impact noise rating or INR of -18. As explained previously, an INR of less than -10 is considered poor, a rating between -10 to zero is only fair, and a rating of zero or over is good. The STC of this particular system is 32. If the ceiling finish in this construction was omitted, as in the case of an unfinished basement, the STC would be reduced to 25 and the INR to -28.

By providing a floating floor as shown in the lower left diagram (Figure 15) the STC is raised from 32 to 46 and the INR increased from -18 to about -9. The floating floor is formed by placing a layer of fibreboard over the subfloor, gluing strapping to the fibreboard and installing another sub-floor and finish floor on this strapping. About the same improvement in STC and in INR can be achieved by providing a resilient mounting for the ceiling or by staggering the joists as indicated in the diagrams on the right (Figure 15).

Batt-type insulation within the joist space would improve the performance of all these systems to some extent with respect to both airborne and impact noise. The most noticeable effect would be achieved with the suspended ceiling and staggered joist systems. Adding a carpet and pad to any of these constructions would also considerably improve the impact rating.

When separating dwelling units by sound-resistant floors, fire aspects also should be considered. Figure 16 illustrates some typical wood floor systems that provide a 1-hr fire separation and also give STC 45. These provide a fair INR rating of between -10 and zero.

As can be seen these diagrams are quite similar to those in Figure 15 except that 5/8-in. fire-resistant gypsum board or lath and plaster have been used for the ceiling finish. The lath and plaster will have superior sound resistance to the 5/8-in. wallboard.

As mentioned previously, STC 45 is a minimum standard and it is often desirable to provide STC 50 to achieve a higher percentage of occupant satisfaction. In the case of floors, however, occupant satisfaction also depends on good impact resistance, and this will require a construction having an INR of zero or greater.

Figure 17 illustrates two floor constructions that provide STC 50 or better and at the same time provide good impact noise resistance. In these constructions a floating floor is combined with a suspended ceiling or staggered joists to achieve the desired result. In addition, insulation has been added between the joists to improve performance.

Turning to noncombustible construction, Figure 18 illustrates three common constructions of this type which will provide STC 45 with a fair resistance to impact noise. With the simple concrete slab floor it is necessary to install some type of soft floor covering on the slab (upper diagram) or provide a resilient layer between the slab and the finish floor (middle diagram) to achieve a fair impact rating. A carpet combined with a resilient pad directly on the slab would provide good impact resistance.

The lower diagram in Figure 18 illustrates another noncombustible floor using bar joists. Here again, to achieve a fair resistance to impact noise, either a soft surface must be provided or a resilient layer provided between the floor finish and the slab. The 5/8-in. fire-resistant gypsum board on the ceiling will provide a construction having a 1-hr fire resistance.

Figure 19 shows three floors that will provide good impact noise resistance and STC 50 or over. The slab (upper diagram) has been increased to a 5-in. thickness compared with 3 in. in Figure 18. A carpet and pad would still be necessary to obtain a good impact rating. Alternatively, the finish floor can be supported on furring strips cemented to the slab as shown in the middle diagram. The finish in this case could be tile over $\frac{1}{4}$-in. underlay supported by a subfloor.

The lower diagram indicates a bar joist system in which the ceiling finish is supported on resilient clips to obtain a good impact rating. In addition, mineral wool must be installed in the joist space when a drywall ceiling is used. The addition of a carpet and pad would further improve the impact rating.

In summary, the methods of achieving control of noise transmission through floors include providing a resilient layer between the finish floor and the floor structure, suspending the ceiling on resilient clips or channels, or using staggered joists. These measures will not only reduce airborne noise transmission but will improve impact performance as well. The provision of a carpet and pad adds little to the resistance to airborne noise but is very effective in improving the impact performance.

NOISE IN MECHANICAL SYSTEMS

Methods of noise control in plumbing and heating systems are less well established than the methods for control of airborne and impact sound through building elements. Some general guidelines can be laid down, however, and these will be illustrated with examples from known trouble areas.

Noise from mechanical systems may be either vibration or impact noise, or airborne noise. The noise may arise within the mechanical equipment such as fans, motors, and pumps, or be generated by the flow of air in ducts or the flow of water in pipes. In addition, the ducts themselves may act as a channel to transmit noise from one room to another.

Equipment Noise

Equipment noise may be reduced in the following ways:

1. Locate the equipment as far away as possible from the quiet areas

2. Confine the noise by surrounding the equipment with sound-resistive construction or by providing buffer zones such as corridors, stairwells or storage rooms.

3. Line equipment enclosures with sound-absorbent materials. Such treatment is not a substitute for sound-resistive construction but will help by reducing the noise level.

4. Look for "quiet" equipment and appliances. In the case of equipment this may mean a quieter operating pump, or a motor that has been specifically designed to control vibration. Some appliances such as dishwashers and garbage disposal units are marketed under so-called "regular" or "quiet" models.

In addition, some water closets operate at a lower noise level than others. To provide a basis for selection, noise level ratings should be obtained if available so that the performance of the different models can be compared.

5. Isolate the equipment from the structure by supporting on resilient pads.

6. Use flexible connectors between the equipment and connecting ducts or pipes.

These last two principles are illustrated in Figure 20. The upper figure shows a pump on resilient pads and connected to the circulating system by a length of flexible hose. The lower figure shows an electrical appliance supported on resilient pads and wired with flexible cable to prevent direct transmission of vibration to the structure.

Noise in Piping

Noise problems also arise from water flow through piping. The turbulence of the flow creates whistling or gurgling sounds and causes pipe vibration. Contraction and expansion of pipes due to temperature changes may cause creaking at the supports.

Three significant factors that affect noise in plumbing systems are the water pressure, water velocity, and the number of valves and fittings. For good noise control the static water pressure in the system should not exceed 35 to 45 psi. If it is more, a pressure-regulating valve should be installed. Increasing the diameter of the supply piping will also reduce the velocity but this is less effective than reducing the pressure to control noise in pipes.

Owing to water turbulence, valves and fittings can produce considerably more noise than straight runs of pipe. Tests on $\frac{1}{2}$-in. steel pipe have shown that valves can produce noise levels varying from 20 to 30 dB depending on the type of valve and whether or not it is fully open. Similar noise levels arise with meters and other fittings that create some discontinuity of flow within the line. Globe valves are preferred if it is necessary to control the rate of flow but if valves are to remain fully open most of the time a gate valve is quieter. In general the fittings in the system should be kept few in number by designing the layout with a minimum of bends.

Piping must be isolated from the building structure to control the transmission of noise originating in the system. When pipes are rigidly attached to a large surface by hangers, clips or straps, the whole surface will radiate sound and generate noise throughout the structure. A layer of resilient material between the support and the pipe will greatly reduce transmission of noise in this way. The number of pipe supports should be kept to a minimum and the straps or hangers attached to the most massive structural element available. It is better, for example, to fasten to masonry walls than to floor joists. It is most important to avoid fastening to light panel surfaces which will readily amplify the sound.

A frequent source of noise is the flow of waste water from a water closet or bathtub. As a first step in the control of this problem the drain piping should be kept away from walls of quiet areas such as bedrooms. Secondly, wherever the pipe passes through or is attached to the building structure, resilient material should be used to prevent direct contact (Figure 21). A resilient mounting should be used to support the pipe at the end of a long vertical run as indicated in the bottom diagram of Figure 21. This is of particular importance in multi-storey buildings where the use of resilient supports for plumbing stacks will do much to reduce impact sound transmission.

Resilient material at the supports will also permit hot water piping to move without binding due to expansion and contraction. Temperature differences of 100°F may occur in these lines causing copper piping to expand or contract as much as 1 in. in an 80-ft run. To allow for this movement, swing arm offsets or loops should be provided in all long straight runs of piping. Insulating the pipe will help to maintain a more even temperature in the pipe, thus minimizing expansion and contraction.

Another problem with piping is water hammer. This occurs when water is turned on and off quickly, producing a shock wave in the system which causes the pipe to vibrate.

High pressure, high velocity, and quick closing valves combine to produce the worst water hammer conditions. The problem can be particularly severe in equipment, such as automatic washers, that use electrical means of shut-off. Water hammer can be controlled by installing air cushions to act as shock absorbers in the system (Figure 22). These may eventually lose their effectiveness as the air in them becomes absorbed in the water. The system must then be drained to let air back in. Special air chambers are available with a diaphragm to prevent their becoming water-logged.

In summary, noise in piping systems can be controlled by:

1. Reducing water pressure
2. Increasing the size of piping
3. Minimizing the use of fittings, particularly quick-closing valves
4. Isolating pipes and fixtures from the structure with resilient pads
5. Keeping drain pipes away from walls of quiet areas
6. Providing air cushions to control water hammer
7. Making provision for movement due to expansion and contraction

Noise in Ducts

Duct work can also give rise to noise problems. A metal duct acts like a speaking tube on a ship and readily transfers sound from one area to another. This can lead to annoying noise problems through the short-circuiting of sound barriers between apartments and through the transfer of equipment noise throughout the living space. Sound does not only enter or leave a metal duct through an opening or grille but can also enter through the thin metal sides (Figure 23).

This is why ducts through sound barriers should be kept to a minimum and duct layout through noisy areas such as service or maintenance rooms should be avoided if possible. Such measures will help to reduce noise pick-up by the ducts.

Fibrous linings inside the ducts will reduce sound transmission within a duct system. A 6-ft length next to each wall or ceiling outlet is generally sufficient. This can be of particular value in common duct exhausts from kitchens or bathrooms of apartments which provide an easy path for noise transmission. Note, however, that insulation on the outside of a duct does not help in controlling airborne transmission through the duct.

When noise is caused by air flow, streamlining the ductwork using smooth curve bends or turning vanes in elbow or "T" fittings will reduce the noise level by reducing turbulence.

Figure 24 illustrates the use of flexible collars to prevent transfer of equipment vibration to the ductwork. Note that there is no attachment to the structure between the flexible connection and the equipment. The supporting hangers should not be placed between the flexible collar and the equipment it is supposed to isolate.

One of the biggest obstacles to successful noise control still remains - poor construction practice. It is not enough to merely specify proper noise control methods - supervision must be provided to ensure good workmanship and control of construction details. Even minor variations from specified methods can nullify the value of sound conditioning by permitting ducts, pipes, or conduits to short-circuit construction separations.

CONSTRUCTION PRACTICES THAT DECREASE SOUND RESISTANCE

The STC and INR ratings for walls and floors that were mentioned earlier were determined in a laboratory under somewhat artificial conditions in that the specimens were carefully constructed and no extraneous transmission paths were involved. Such values may be obtained in the field, but only when equal care is taken and there are no leakage or flanking transmission problems. Some departure from the tested construction may be inevitable, but in many instances there is an unnecessary reduction in performance because of poor construction practice.

For example, Figure 13 illustrated an 8-in. masonry wall with a rating of STC 45. This wall, when tested in the laboratory, had full head and bed joints. Full mortar joints are not generally achieved in the field, however. Such a wall in practice would probably not be in the 45 class because of sound leakage through these joints. In order to obtain the 45 class rating it may be necessary to plaster at least one side of the wall to seal the surface or, alternatively, fur the wall and add a separate finish.

Details that deserve special consideration are wall-to-floor connections. Both the acoustic and fire aspects should be considered. Figure 25 shows a wrong way and a right way to handle this situation.

The left-hand diagram in Figure 25 is wrong in several respects. First, the space is left open at the ends of the joists; this allows free passage of airborne sound. Second, because the joists are nailed together, impact noise is readily transmitted from one floor system to another. In addition, of course, the detail is poor from the point of view of fire resistance as there is nothing to stop fire from spreading across the dividing wall. The right-hand diagram in Figure 25 shows good practice. Not only does the blocking provide effective fire stopping but it is good acoustically as well. The double blocking will reduce the airborne sound transmission and the path of impact sound transmission is broken from one side of the party wall to the other. Another good feature is the break in the subfloor at the wall. This is also essential to reduce impact noise transmission.

Figure 26 shows the situation where the floor joists run parallel to the party wall. This detail not only provides good fire stopping but provides resistance to impact noise transmission and to airborne noise. Here again the subfloor is broken at the wall and there is no continuous path for impact noise transmission.

When installing a floating floor over wood joists more often than not the floor is fastened so that the nails penetrate through the resilient layer and into the framing or subfloor below. This has the effect of short-circuiting the resilient layer and some of its effectiveness is lost. It would be much better acoustically if the strapping on top of the resilient layer were cemented in place and if the nails used for the finish flooring were short enough that they do not penetrate through the resilient layer.

When floating floors are used the floating portion should not be in contact with the perimeter walls of the room. In fact there should be about a $\frac{1}{2}$-in. gap left between the floating floor and the walls. This space is then covered with a moulding. This applies as well if the floated floor is concrete over a resilient layer.

In the case of walls, problems may arise where the wall finish is cut for the installation of other equipment. For example, installing recessed medicine cabinets in party walls results in only a light gauge metal separation between one side of the wall and the other. Surface mounted cabinets should be used rather than penetrate the finish of any wall designed for sound resistance. Installing receptacles or switches back-to-back can also be a source of noise transfer through the wall. These should be placed as wide apart as possible on the opposite sides of the wall - at the very least they should not occur in the same stud space.

Bathtubs are usually installed with no wall finish behind the tub. This provides an easy sound transfer path, particularly where bathrooms are back to back. The wall finish should be applied down to the floor before the tub is installed. This would probably mean that an additional layer of wallboard would have to be installed after the tub is placed. Since it occurs adjacent to a loud noise source resulting from filling the tub or taking a shower, special construction is justified.

Sealing any gap around a pipe, duct, or electrical wiring that penetrates a sound barrier is essential. These gaps can greatly decrease the effectiveness of the barrier. Not only is it desirable from an acoustic standpoint but it is also important for fire protection. If a wall with a 50 STC rating had the equivalent of 1 sq in. of hole through it, the wall would transmit roughly the same sound as a class 40 wall with no openings.

Other faults sometimes noticed are in connection with the installation of equipment or piping. It does little good, for example, to go to the expense of providing carefully installed resilient pads beneath equipment if the piping from the equipment is then rigidly attached to the floor slab above. If resilient mountings are used make sure they are not bridged by mortar droppings or spilled concrete.

In summary, pay particular attention to wall-floor intersection details. Break the structural continuity of floors insofar as practicable across a supporting wall intended to provide sound resistance. Do not build a floating floor so that the floating portion is in contact with the walls. Break the subfloor at the dividing sound wall.

It should be remembered that every time a hole is made in a wall designed as a sound barrier the effectiveness of that wall is reduced. Where holes must be made, for example, for outlet boxes, they should be offset from one another on opposite sides of the wall.

Lastly - make a conscientious attempt to plug all cracks in sound barrier walls. Caulk around pipes and ducts or any other opening to reduce airborne noise transfer.

* * * * * *

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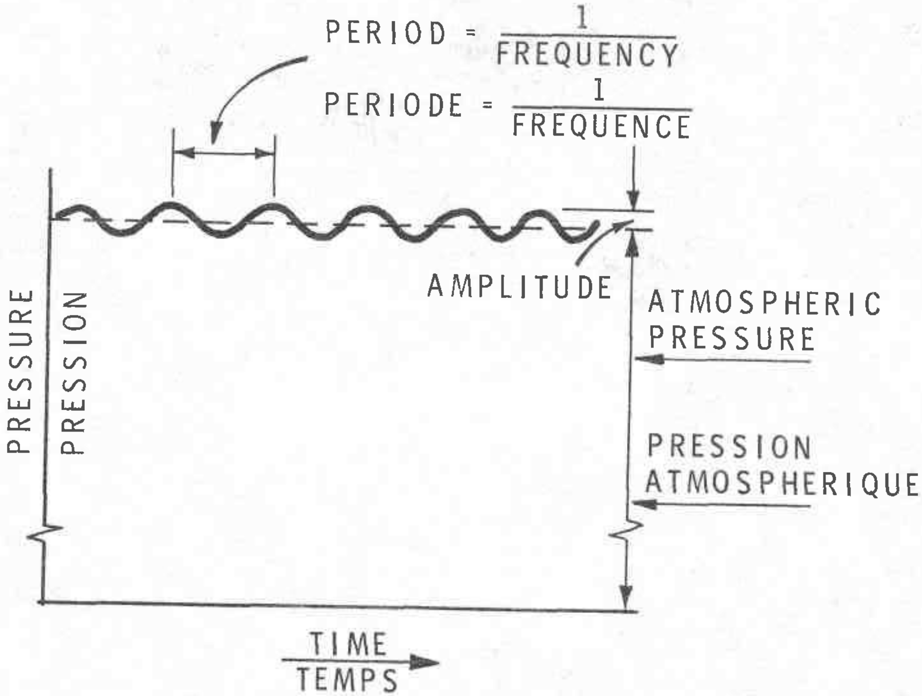


FIGURE 1
SIMPLE SOUND WAVE

ONDE SONORE SIMPLE

BR 3577-1

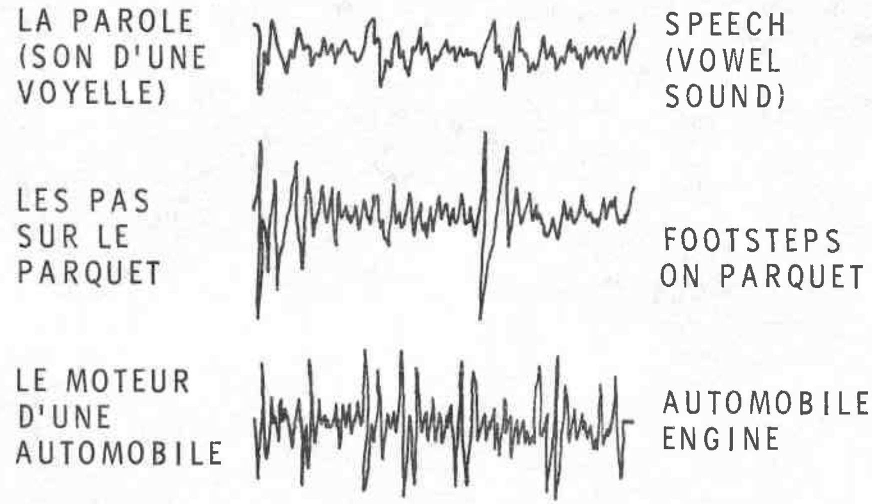


FIGURE 2

SOUND WAVES FROM SEVERAL COMMON SOURCES

ONDES SONORES PROVENANT DE PLUSIEURS SOURCES COMMUNES

BR 3577-2

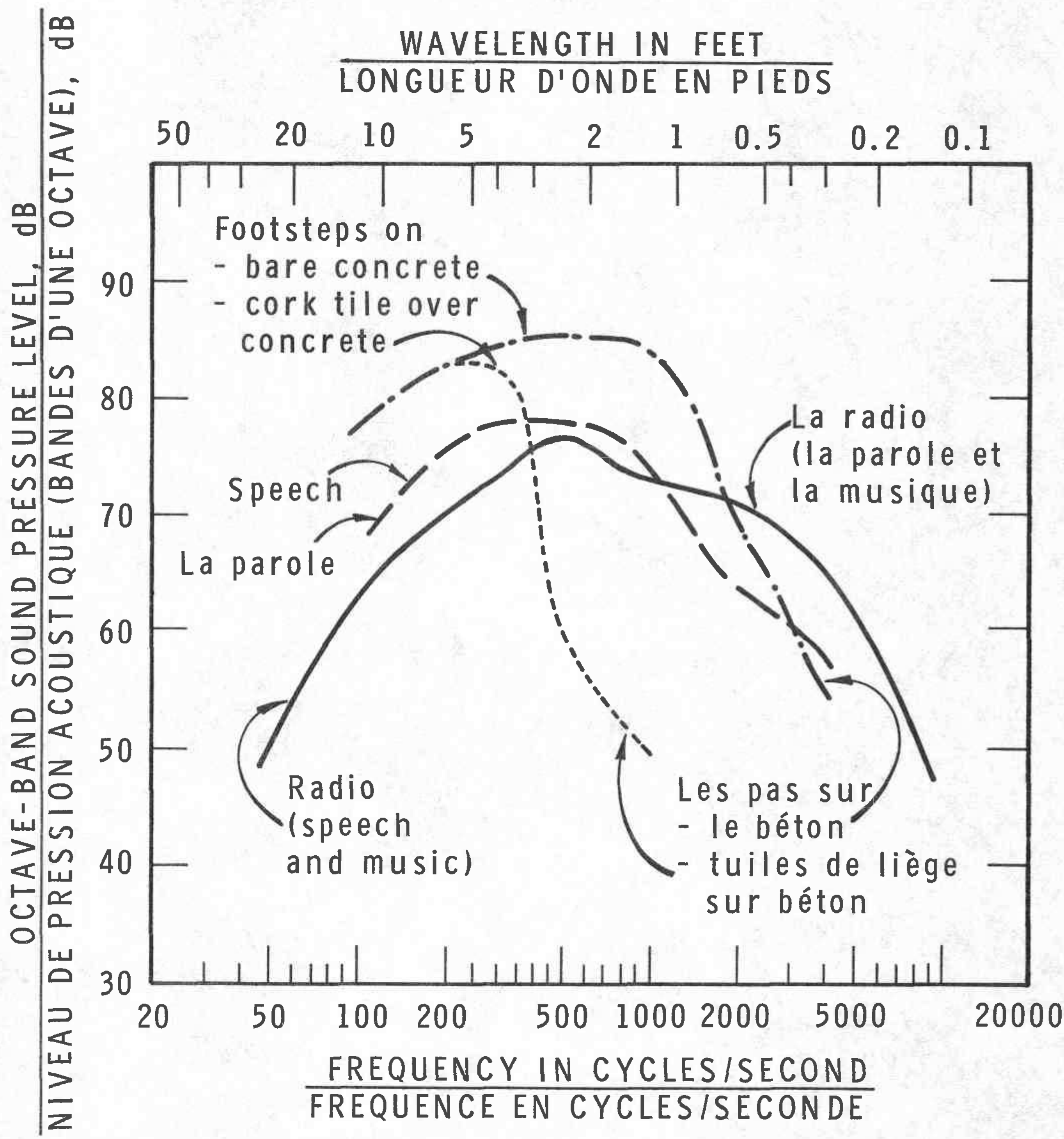


FIGURE 3

FREQUENCY RANGE OF TYPICAL SOUNDS

INTERVALLE DES FREQUENCES DES SONS TYPIQUES

BR 3577-3

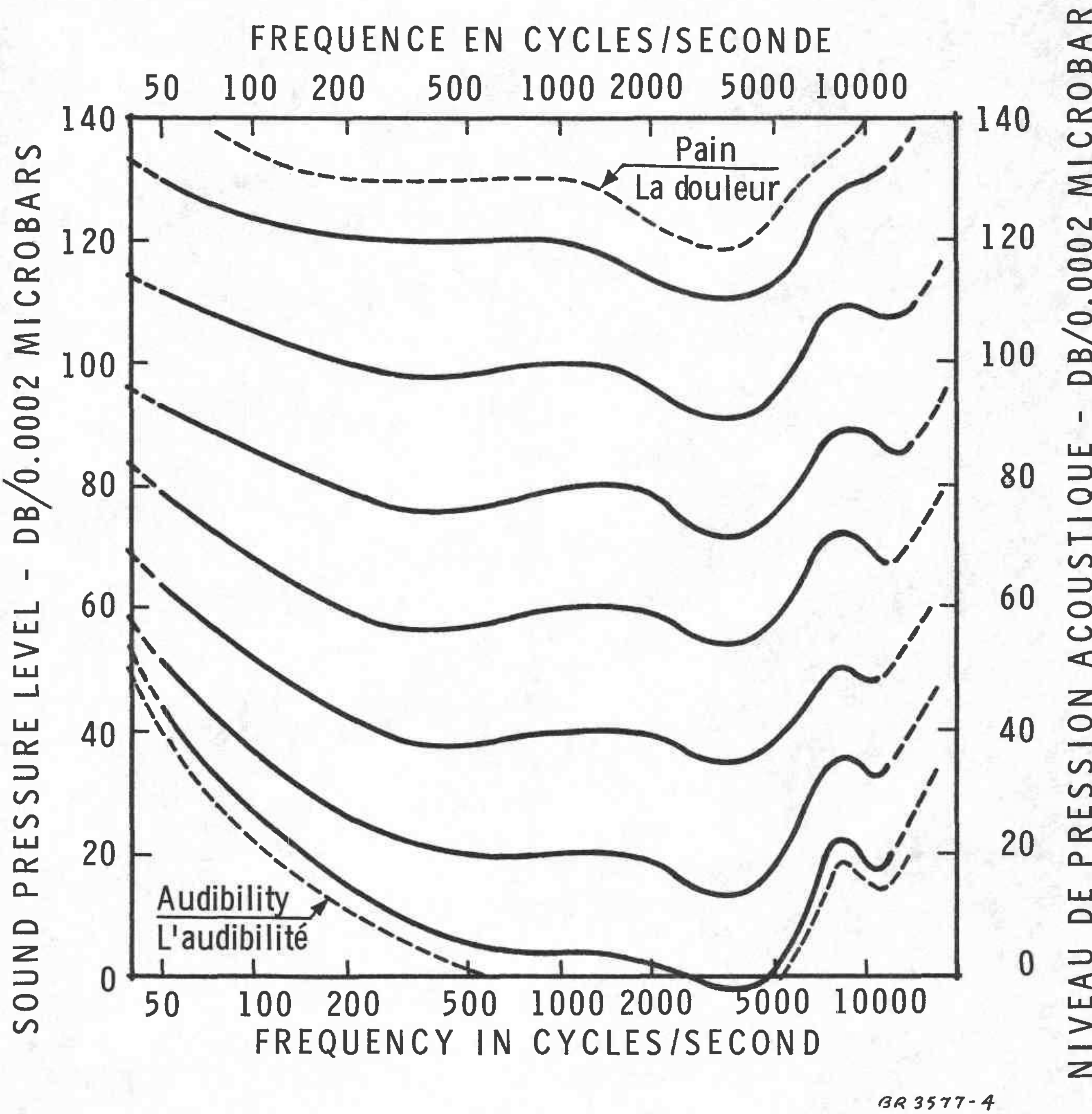


FIGURE 4

APPARENT LOUDNESS OF DIFFERENT SOUND INTENSITIES

SONORITE APPARENTE DE DIVERSES INTENSITES DE SON

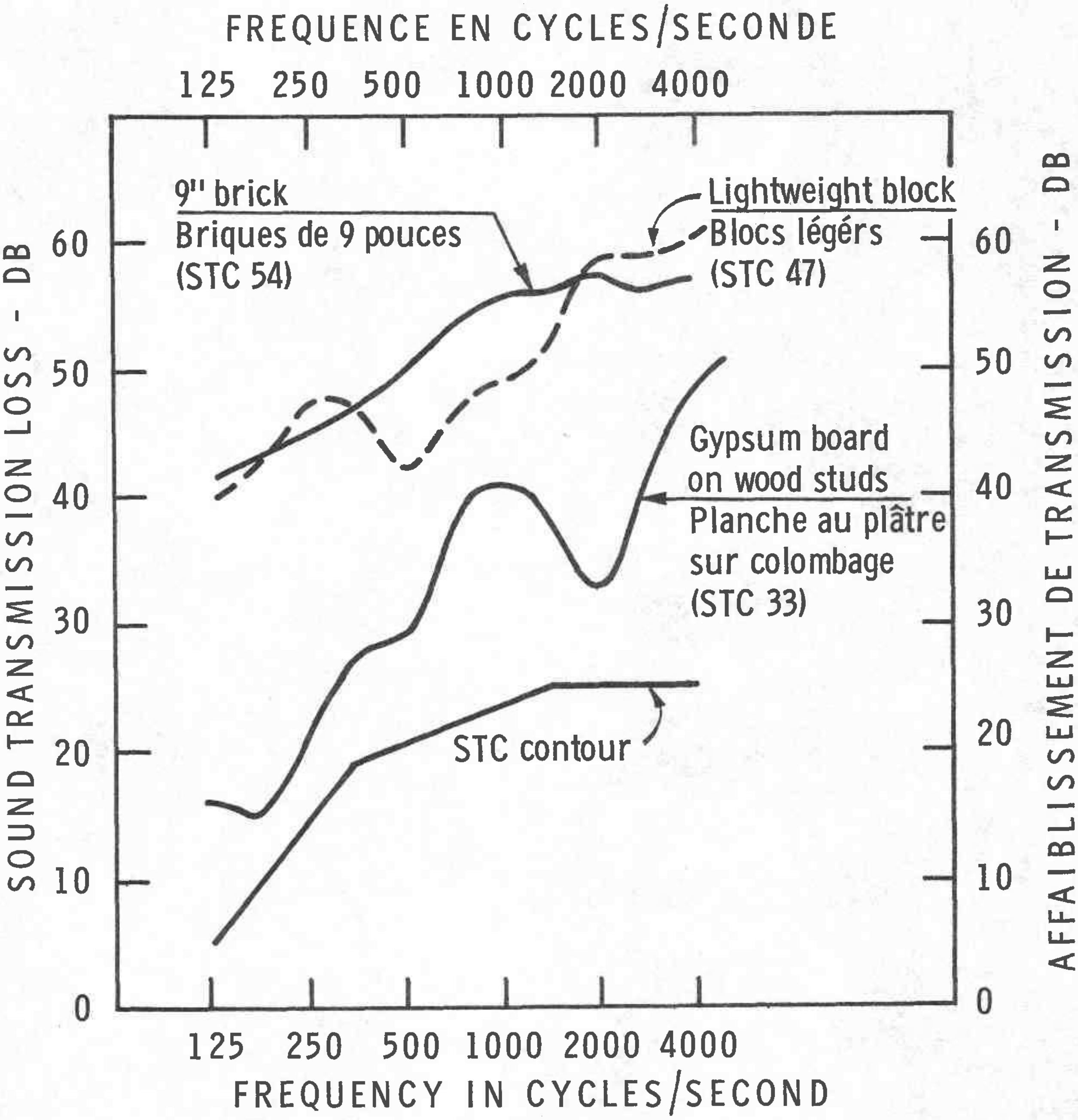


FIGURE 5

SOUND TRANSMISSION LOSS OF WALLS AT VARIOUS SOUND FREQUENCIES

AFFAIBLISSEMENT DE TRANSMISSION DU SON DES MURS A DIVERSES FREQUENCES DE SON

BR 3577-5

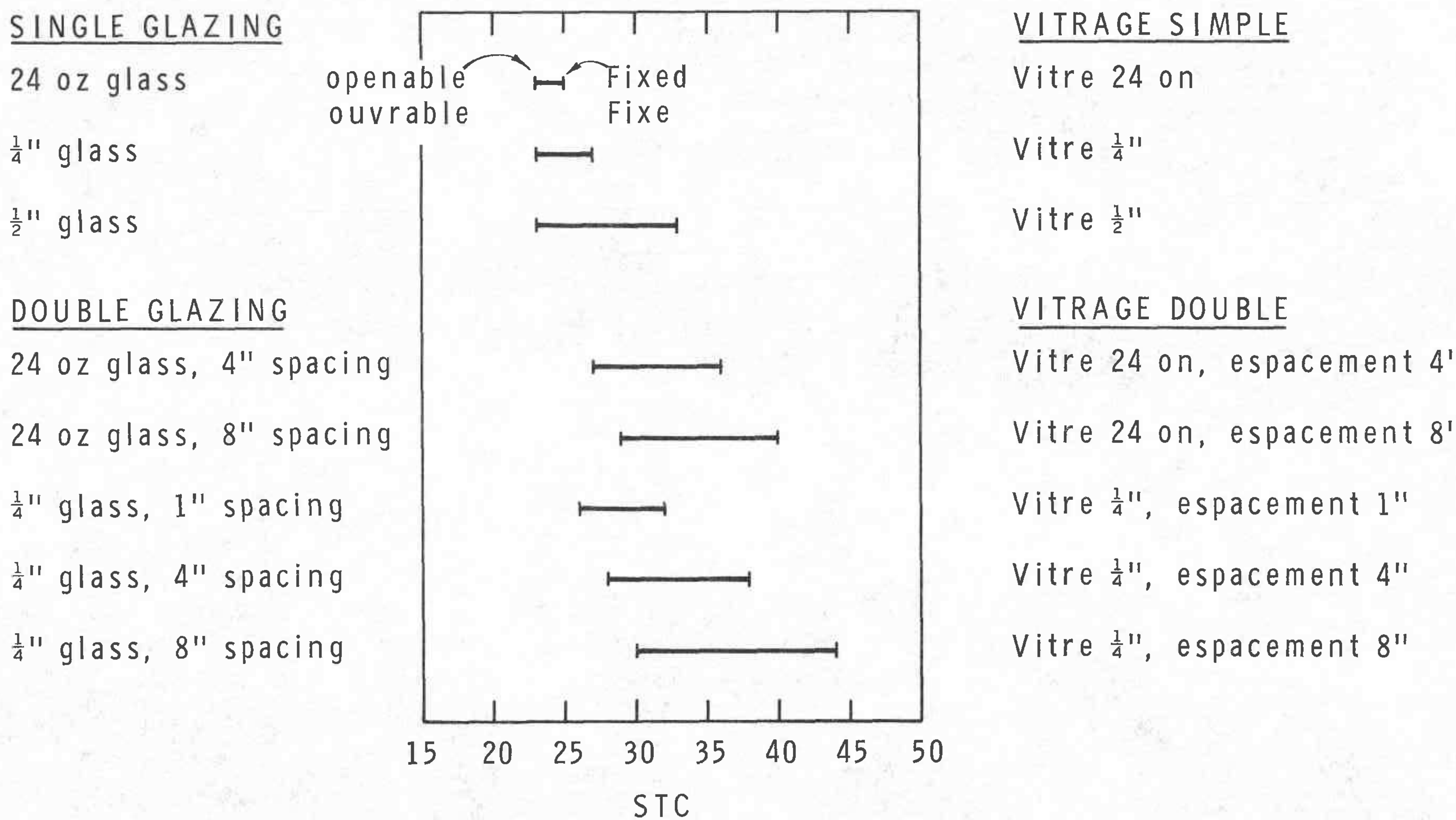


FIGURE 6

SOUND INSULATION OF WINDOWS

ISOLATION PHONIQUE DES FENETRES

BR 3577-7

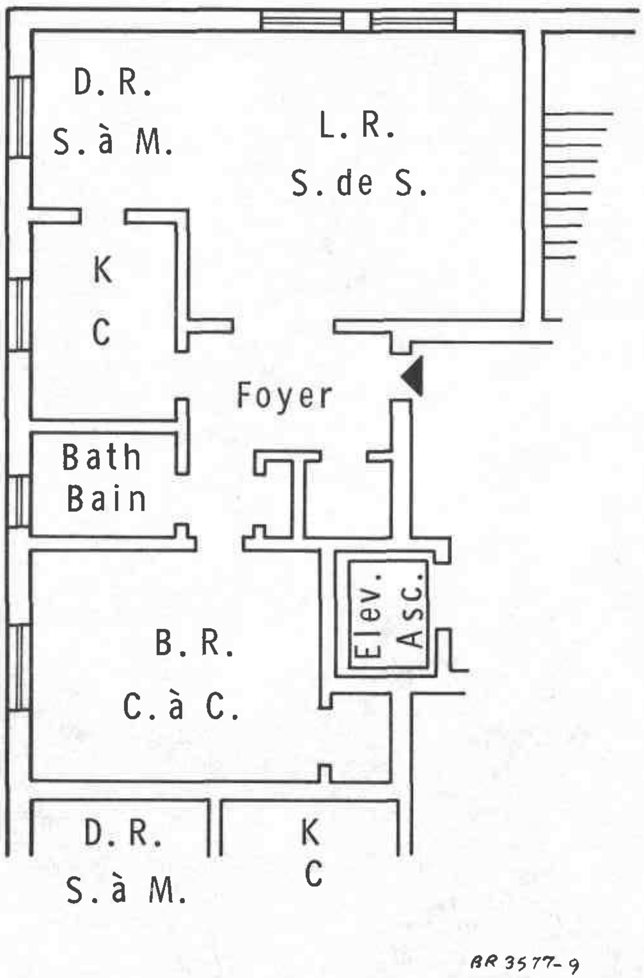


FIGURE 7
POORLY PLANNED APARTMENT

APPARTEMENT MAL PLANIFIE

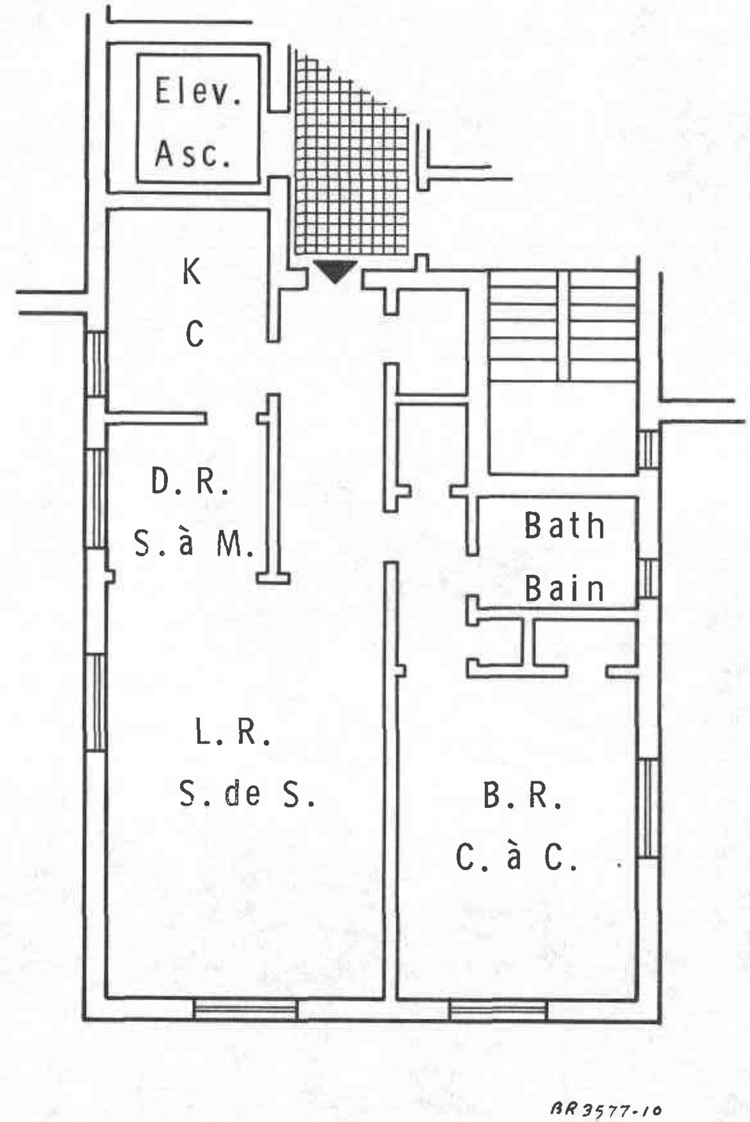


FIGURE 8
WELL PLANNED APARTMENT

APPARTEMENT BIEN PLANIFIE

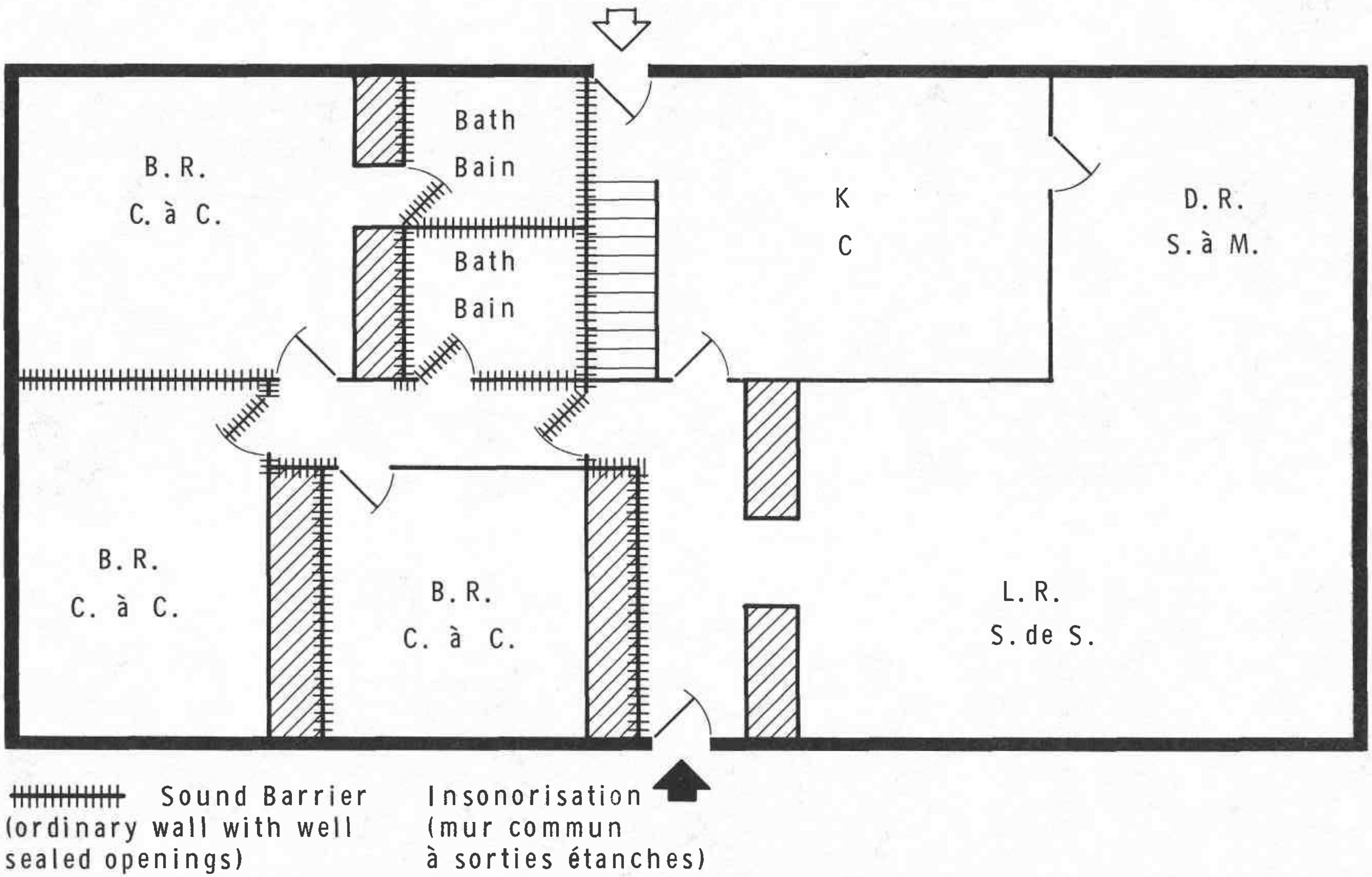


FIGURE 9

SOUND BARRIERS IN A SINGLE FAMILY HOUSE

ISOLEMENT ACOUSTIQUE DANS UNE MAISON UNIFAMILIALE

BR 3577-11

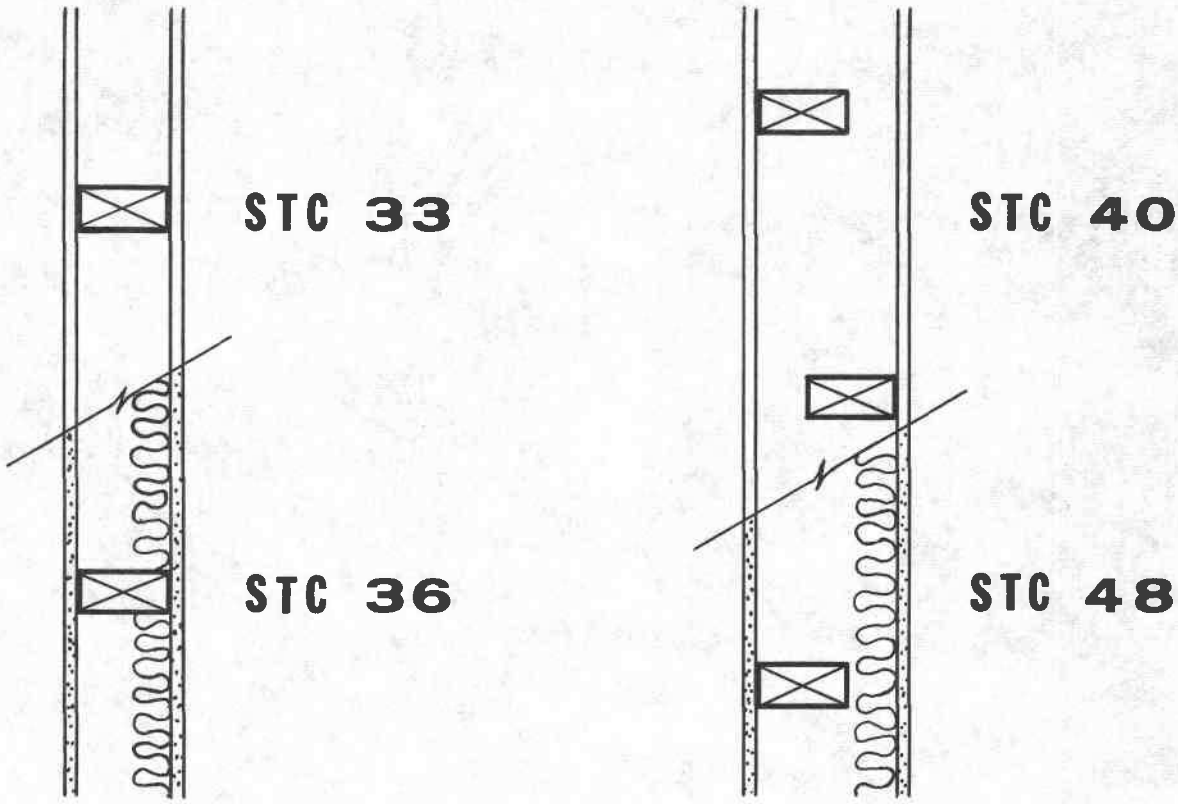
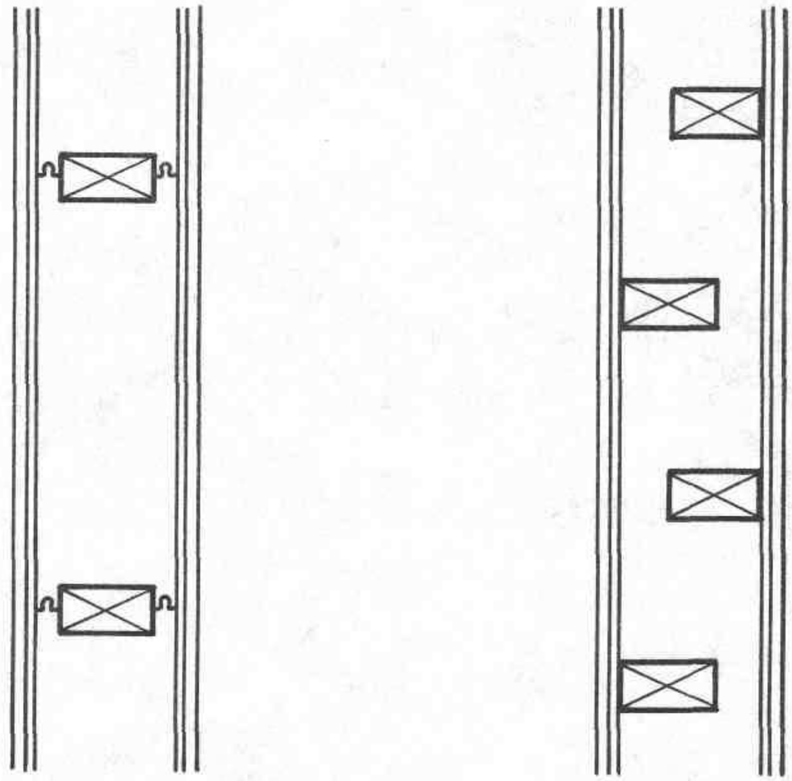


FIGURE 10

SOUND TRANSMISSION CLASS FOR SOME COMMON FRAME WALLS

CATEGORIES DE TRANSMISSION DU SON DES MURS COMMUNS A PANS DE BOIS

BR 3577-13



$\frac{1}{2}$" PLASTER ON $\frac{3}{8}$" LATH OR $\frac{5}{8}$" GYP. BOARD (PLUS MINERAL WOOL)

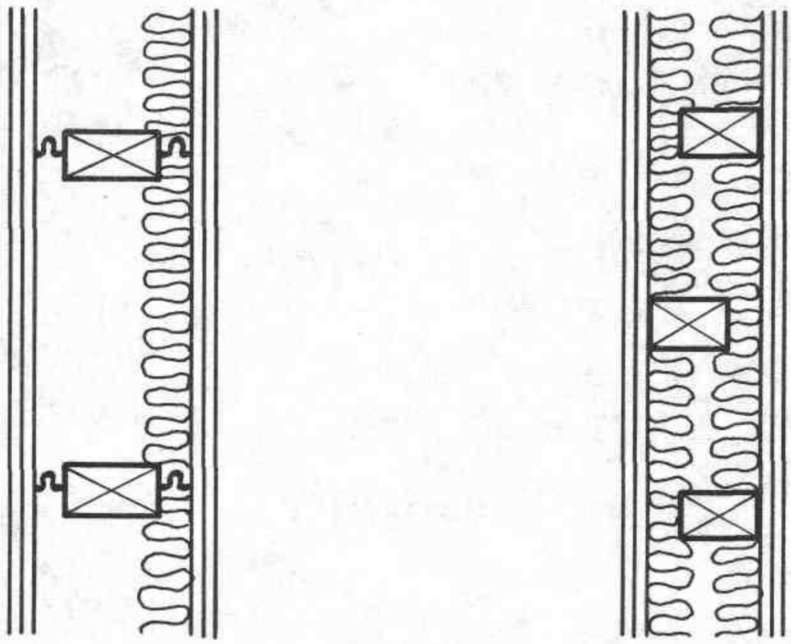
ENDUIT DE $\frac{1}{2}$" ET LATTE AU PLATRE DE $\frac{3}{8}$" OU PANNEAU AU PLATRE DE $\frac{5}{8}$" (AVEC LAINE MINERALE)

FIGURE 11

WOOD FRAME WALLS PROVIDING AN STC 45 OR MORE

MURS A PANS DE BOIS ACCORDANT UN CTS 45 OU PLUS

BR 3577-14



½" PLASTER ON ½" GYP. LATH
OR 2 LAYERS ⅜" BOARD BOTH
SIDES

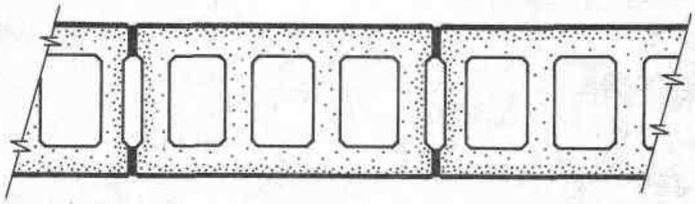
ENDUIT DE ½" ET LATTE DE PLATRE DE ½"
OU 2 RANGS DE PANNEAU DE PLATRE DE ⅜"

FIGURE 12

WOOD FRAME WALLS PROVIDING AN
STC 50 OR MORE

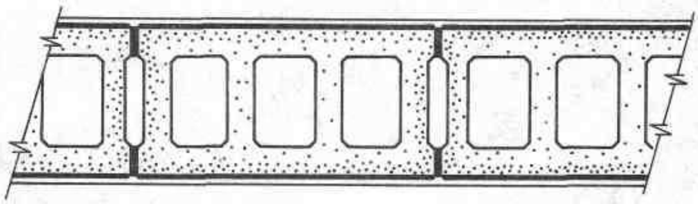
MURS A PANS DE BOIS ACCORDANT
UN CTS 50 OU PLUS

BR 3577-15



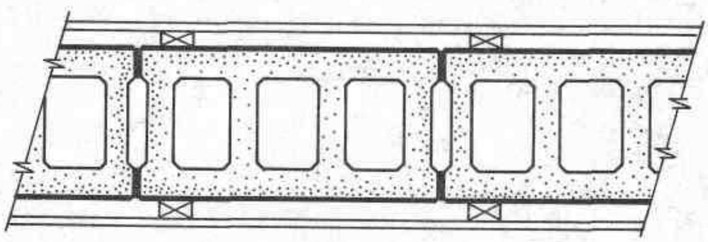
8" DENSE AGGREGATE BLOCK

BLOCS DE 8" EN BETON ORDINAIRE



8" LIGHT WEIGHT BLOCK
PAINTED BOTH SIDES

BLOCS DE 8" EN BETON
LEGER PEINTS SUR LES
2 FACES



8" LIGHT WEIGHT BLOCK

BLOCKS DE 8" EN BETON LEGER

WALL FINISH ON FURRING

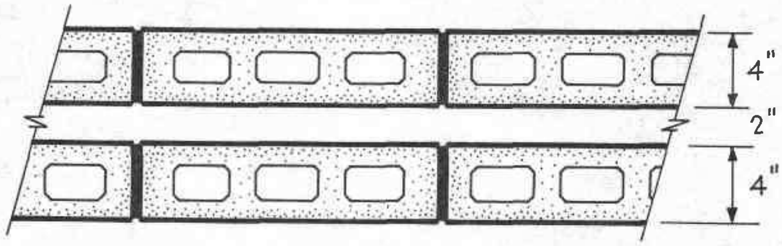
FINI INTERIEUR DE MUR
SUR LAMBOURDES

FIGURE 13

MASONRY WALLS PROVIDING AN
STC 45 OR MORE

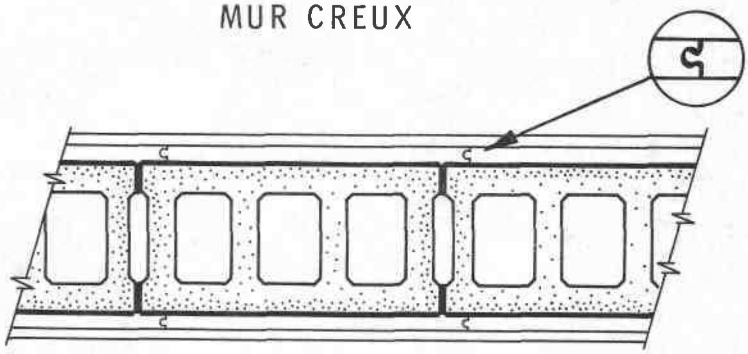
MURS DE MACONNERIE ACCORDANT
UN CTS 45 OU PLUS

BR 3577-16



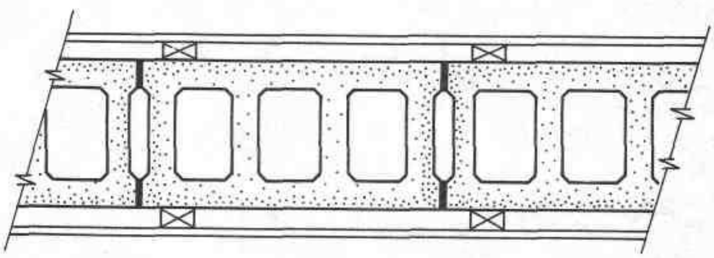
CAVITY WALL

MUR CREUX



6" DENSE BLOCK
RESILIENT MOUNTING
½" GYPSUM BOARD
OR LATH AND PLASTER

BLOCS DE 6" EN
BETON ORDINAIRE
ATTACHES ELASTIQUES
PANNEAU AU PLATRE DE ½"
OU ENDUIT ET LATTE



8" DENSE BLOCK
FURRING
½" GYPSUM BOARD
OR LATH AND PLASTER

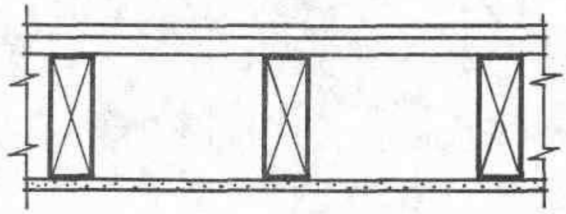
BLOCS DE 8" EN
BETON ORDINAIRE
LAMBOURDES
PANNEAU AU PLATRE DE ½"
OU ENDUIT ET LATTE

FIGURE 14

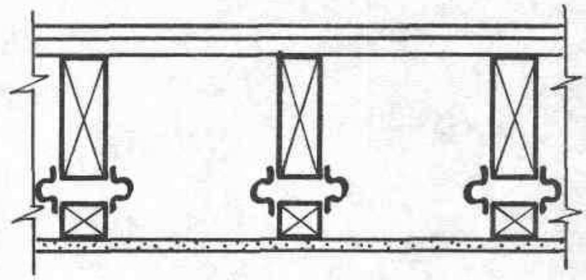
MASONRY WALLS PROVIDING AN
STC 50 OR MORE

MURS DE MACONNERIE ACCORDANT
UN CTS 50 OU PLUS

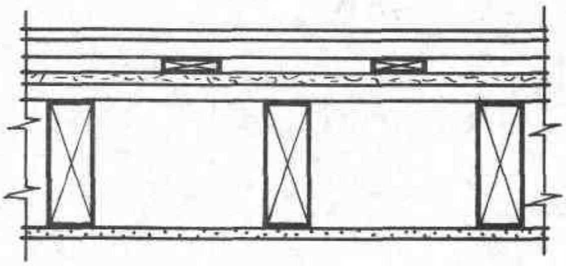
BR 3577-17



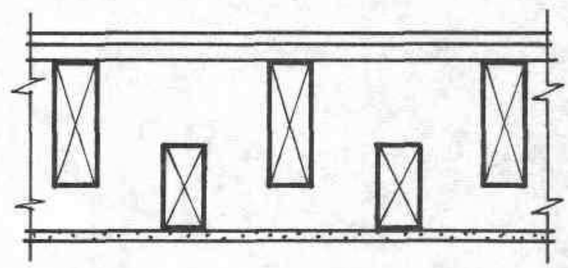
STC 32
INR -18



STC 45
INR -10



STC 46
INR -9



STC 47
INR -8

FIGURE 15

SOUND TRANSMISSION CLASS FOR SOME COMMON WOOD FRAME FLOORS

CATEGORIES DE TRANSMISSION DU SON DE QUELQUES PLANCHERS ORDINAIRES A PANS DE BOIS

BR 3577-18

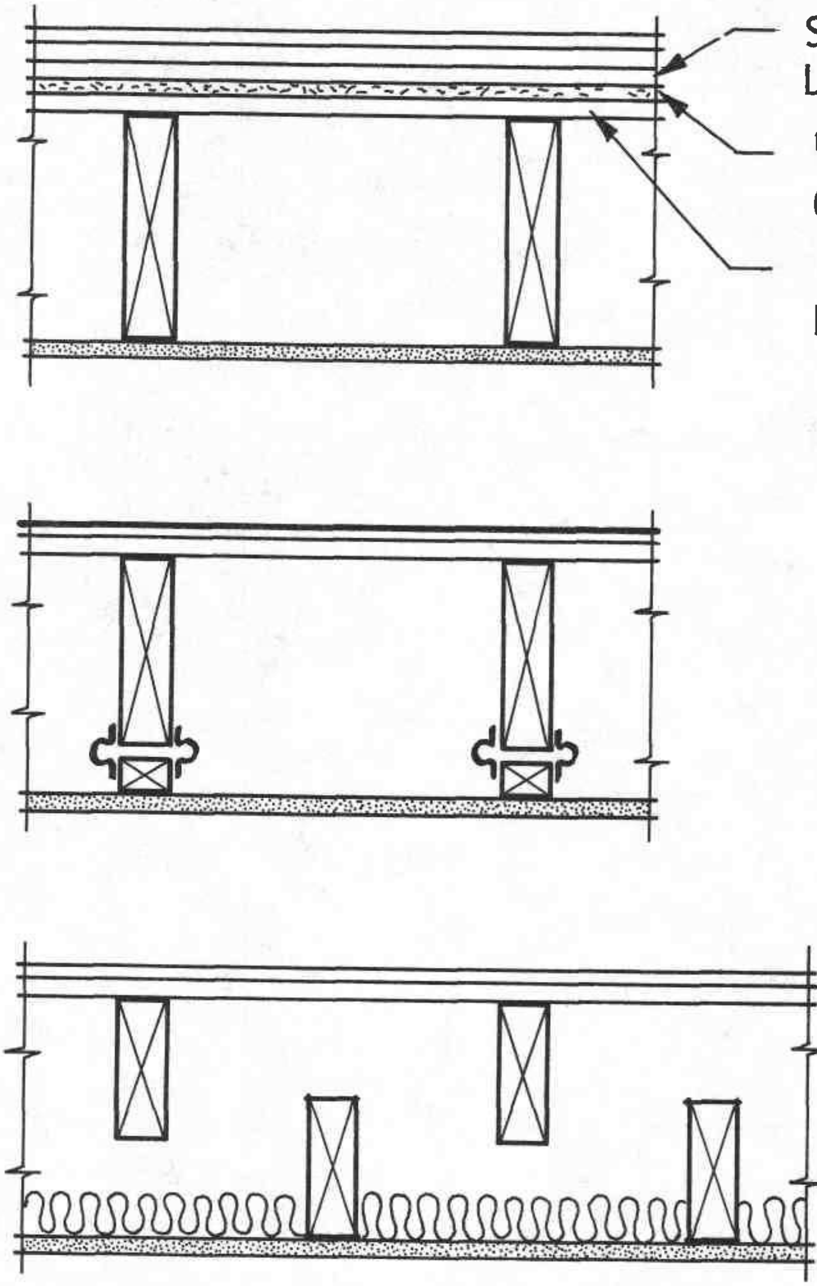
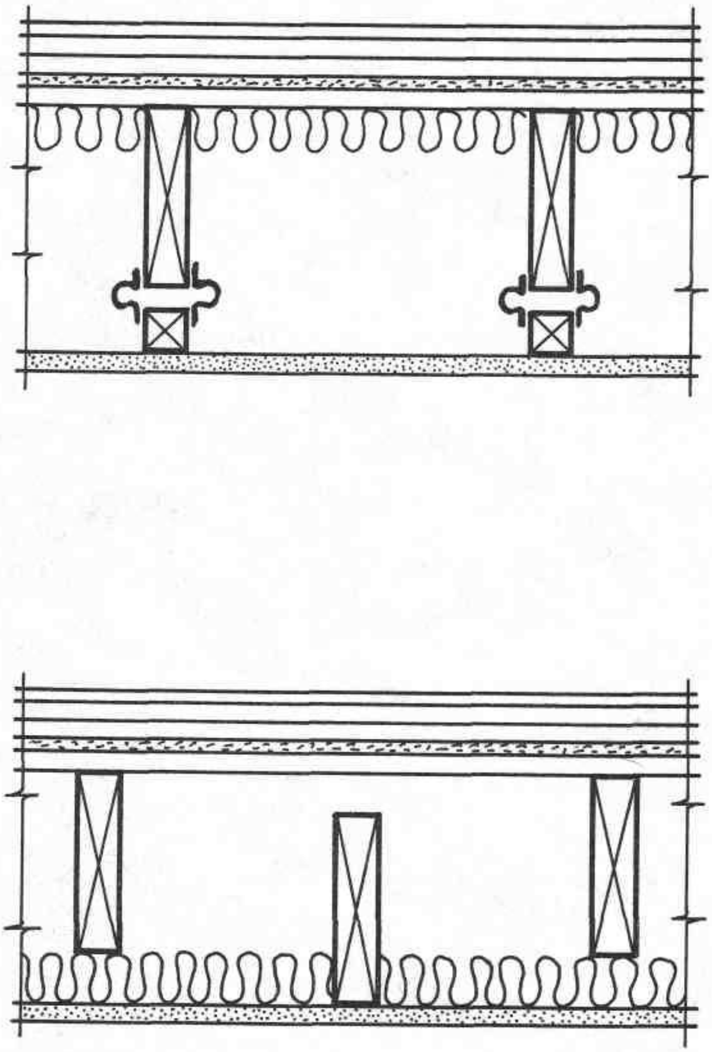


FIGURE 16

WOOD FRAME FLOORS PROVIDING AN STC 45 OR MORE

PLANCHERS A PANS DE BOIS ACCORDANT UN CTS 45 OU PLUS



½" FINISH FLOOR
LUMBER SUBFLOOR
STRAPPING
½" FIBREBOARD
LUMBER SUBFLOOR

PARQUET DE ½"
FAUX PLANCHER
LAMBOURDES
CARTON-FIBRE ½"
FAUX PLANCHER

5/8" GYP. BD. OR LATH & PLASTER CEILING

PANNEAU AU PLATRE DE 5/8" OU LATTE ET ENDUIT

FIGURE 17

WOOD FRAME FLOORS PROVIDING AN STC 50 OR MORE

PLANCHERS A PANS DE BOIS ACCORDANT UN CTS 50 OU PLUS

BR 3577-20

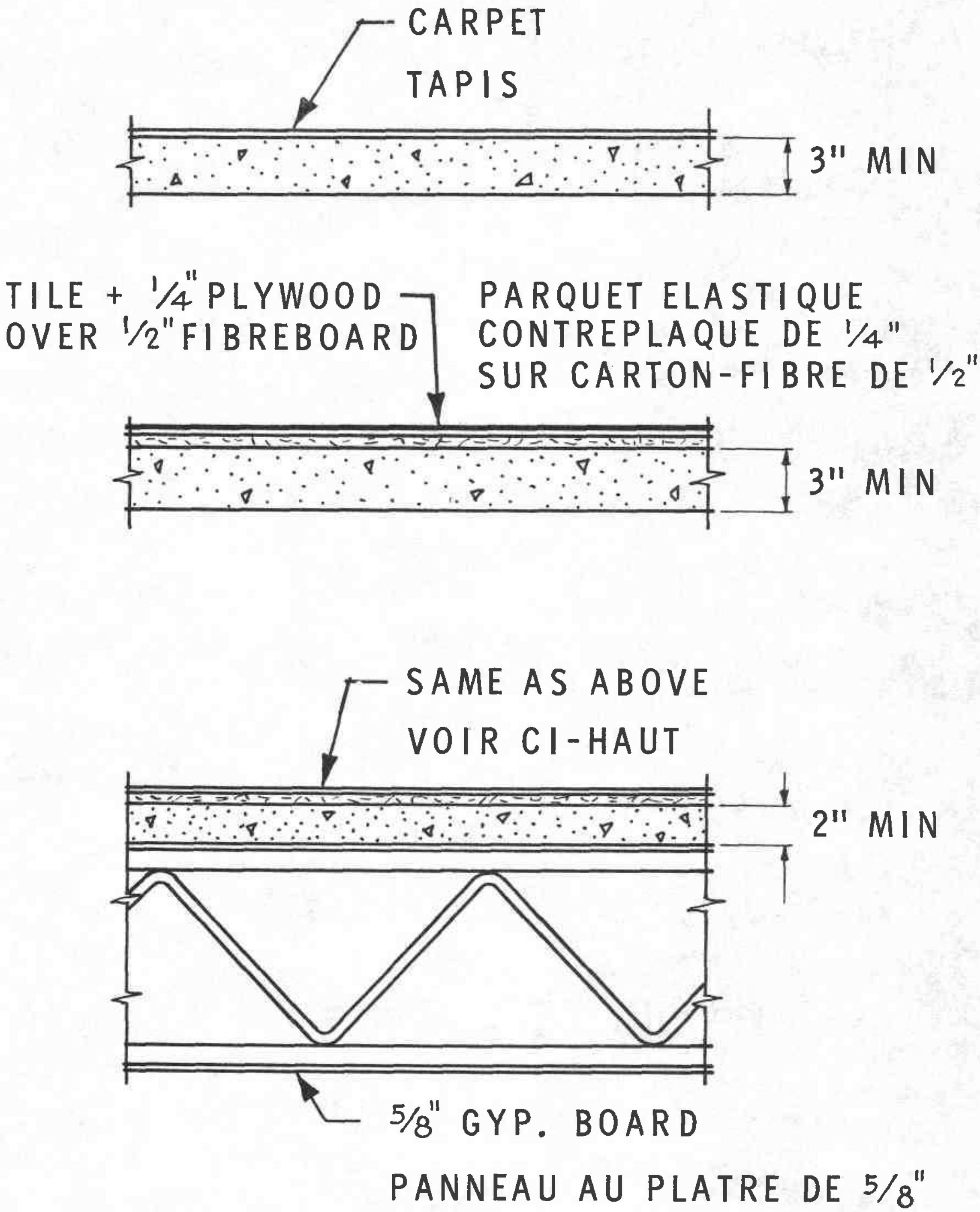


FIGURE 18

NON COMBUSTIBLE FLOORS PROVIDING AN STC 45 OR MORE

PLANCHERS INCOMBUSTIBLES ACCORDANT UN CTS 45 OU PLUS

BR 3577-21

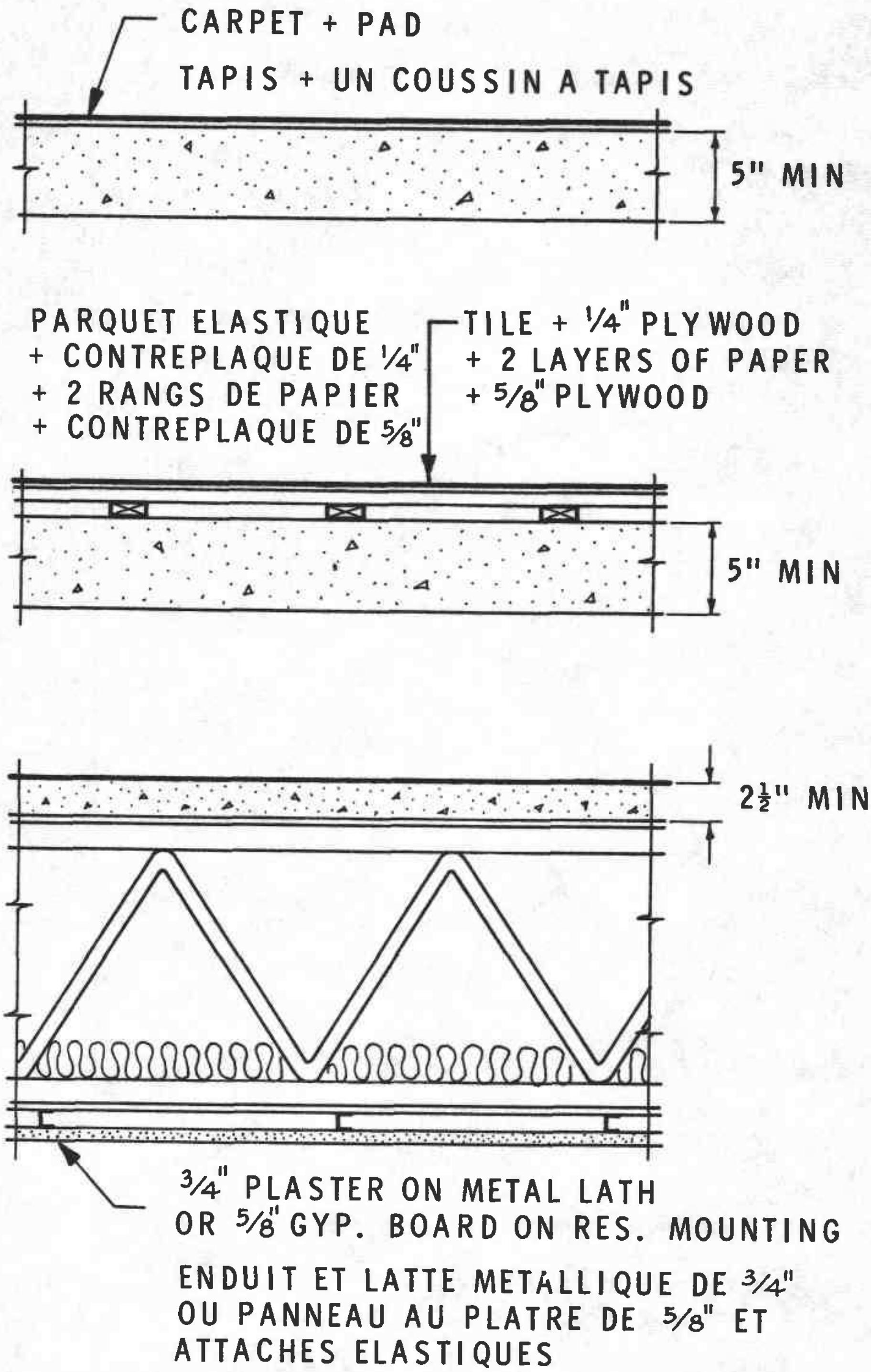


FIGURE 19

NON COMBUSTIBLE FLOORS PROVIDING AN STC 50 OR MORE

PLANCHERS INCOMBUSTIBLES ACCORDANT UN CTS 50 OU PLUS

BR 3577-22

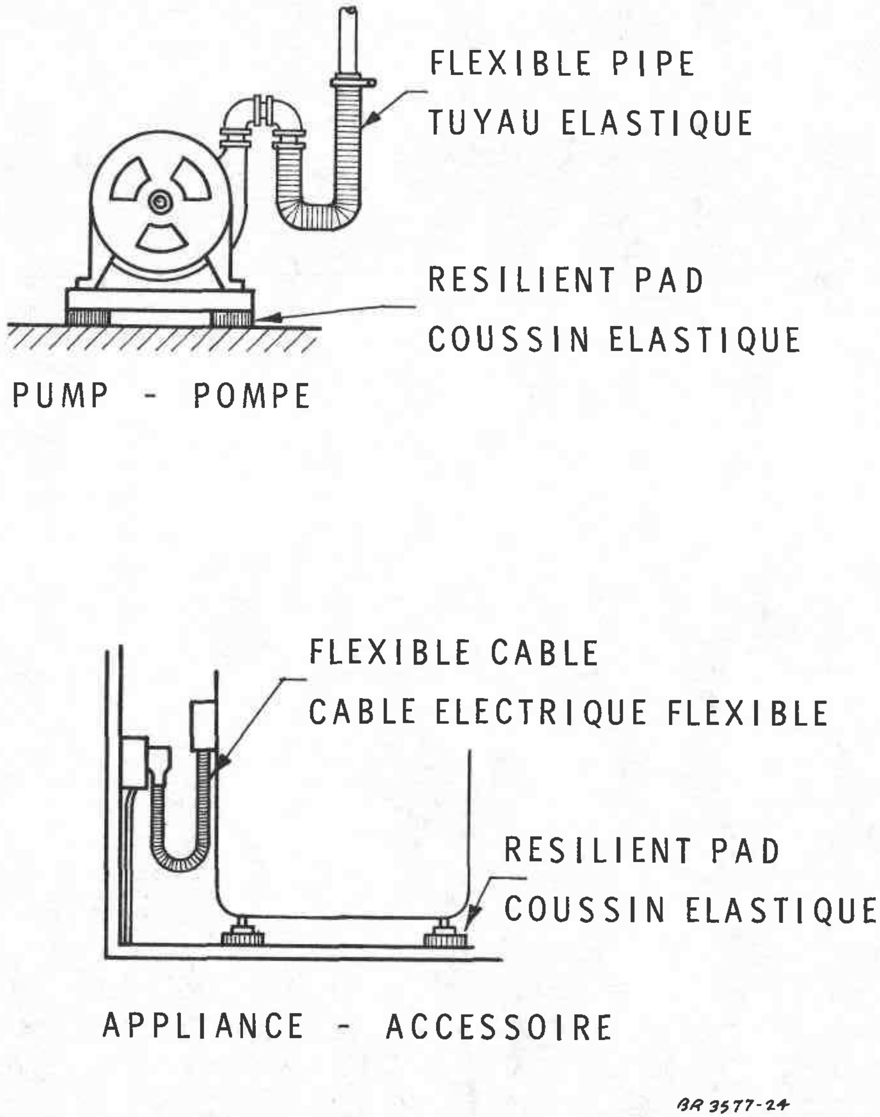


FIGURE 20
ISOLATION OF EQUIPMENT

ISOLATION PHONIQUE DE L'OUTILLAGE

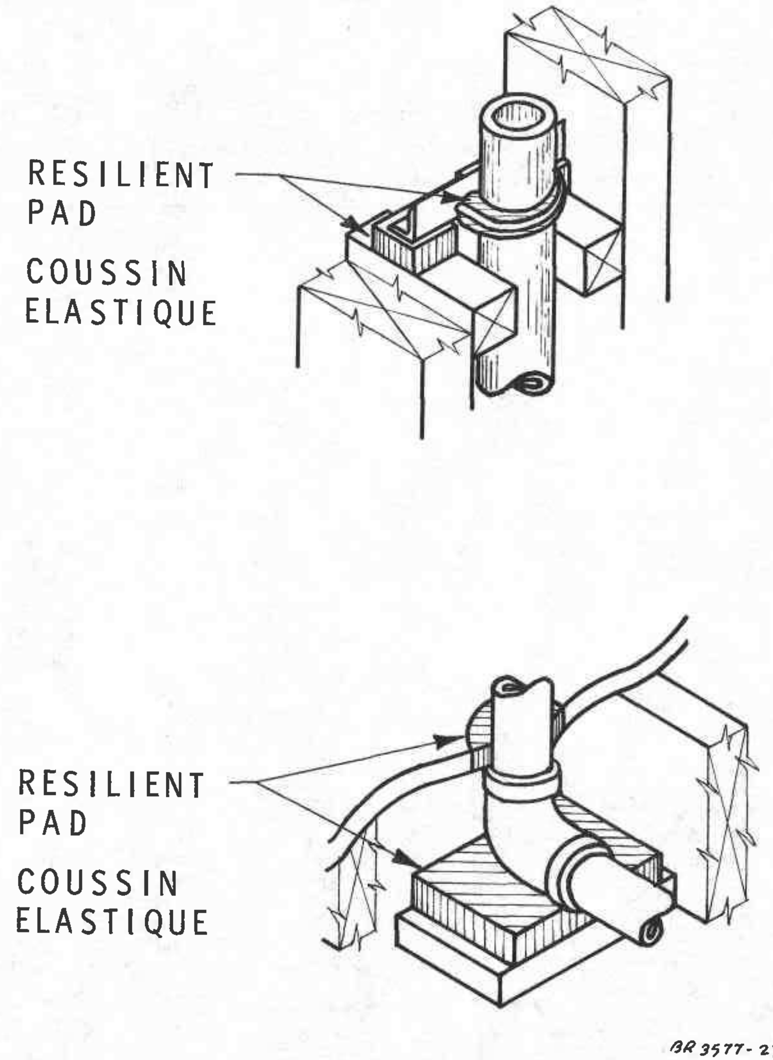


FIGURE 21
ISOLATION OF PIPING

ISOLATION PHONIQUE DE LA TUYAUTERIE

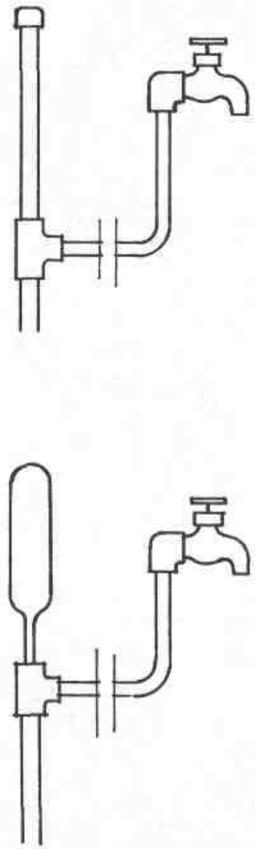


FIGURE 22

AIR CUSHIONS TO CONTROL WATER HAMMER

AMORTISSEUR D'AIR DE MARTEAU D'EAU

BR 3577-28

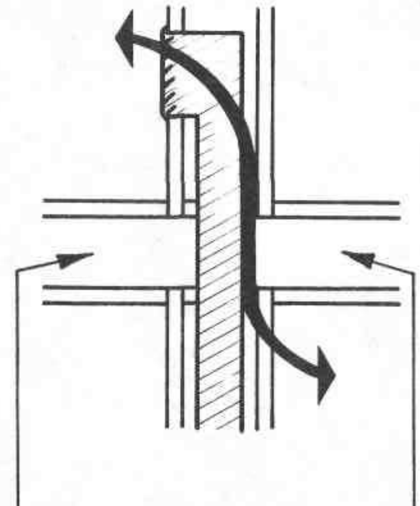
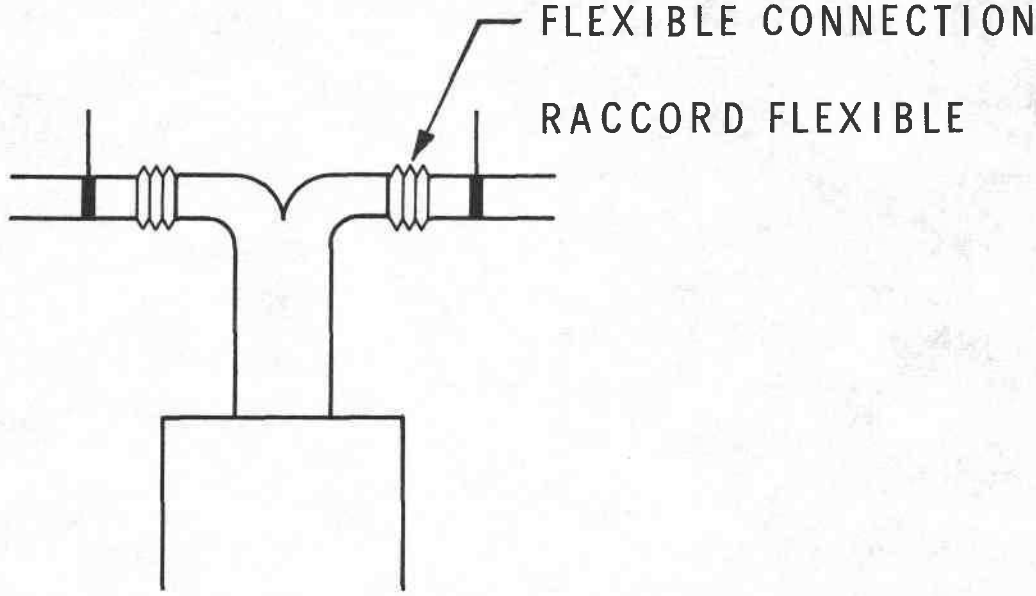


FIGURE 23

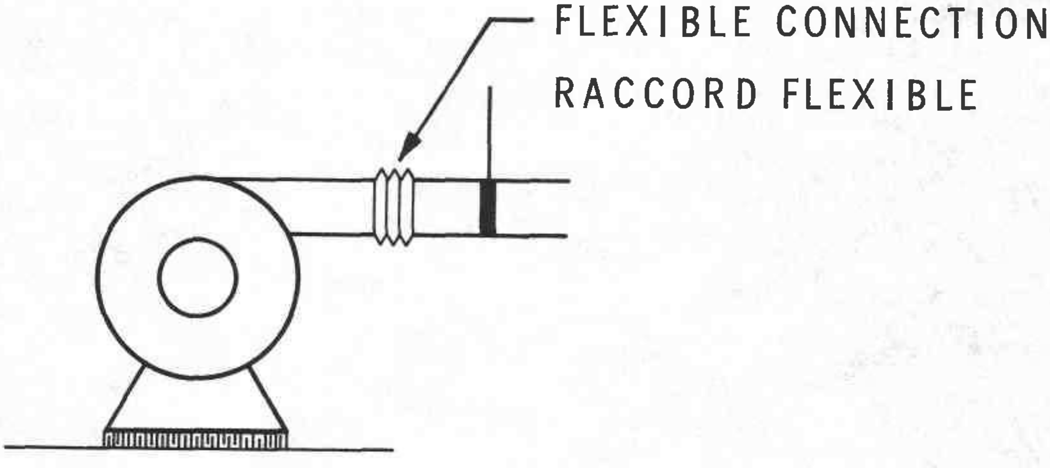
SOUND TRAVEL PATH THROUGH HEATING DUCTS

TRAJET DU SON DANS LES CONDUITS DE CHAUFFAGE

BR 3577-31



FURNACE - FOURNAISE



BLOWER - SOUFFLEUR

BR 3577-33

FIGURE 24

ISOLATION OF FURNACE OR BLOWER

ISOLATION PHONIQUE D'UN SYSTEME DE CHAUFFAGE OU D'UN SOUFFLEUR

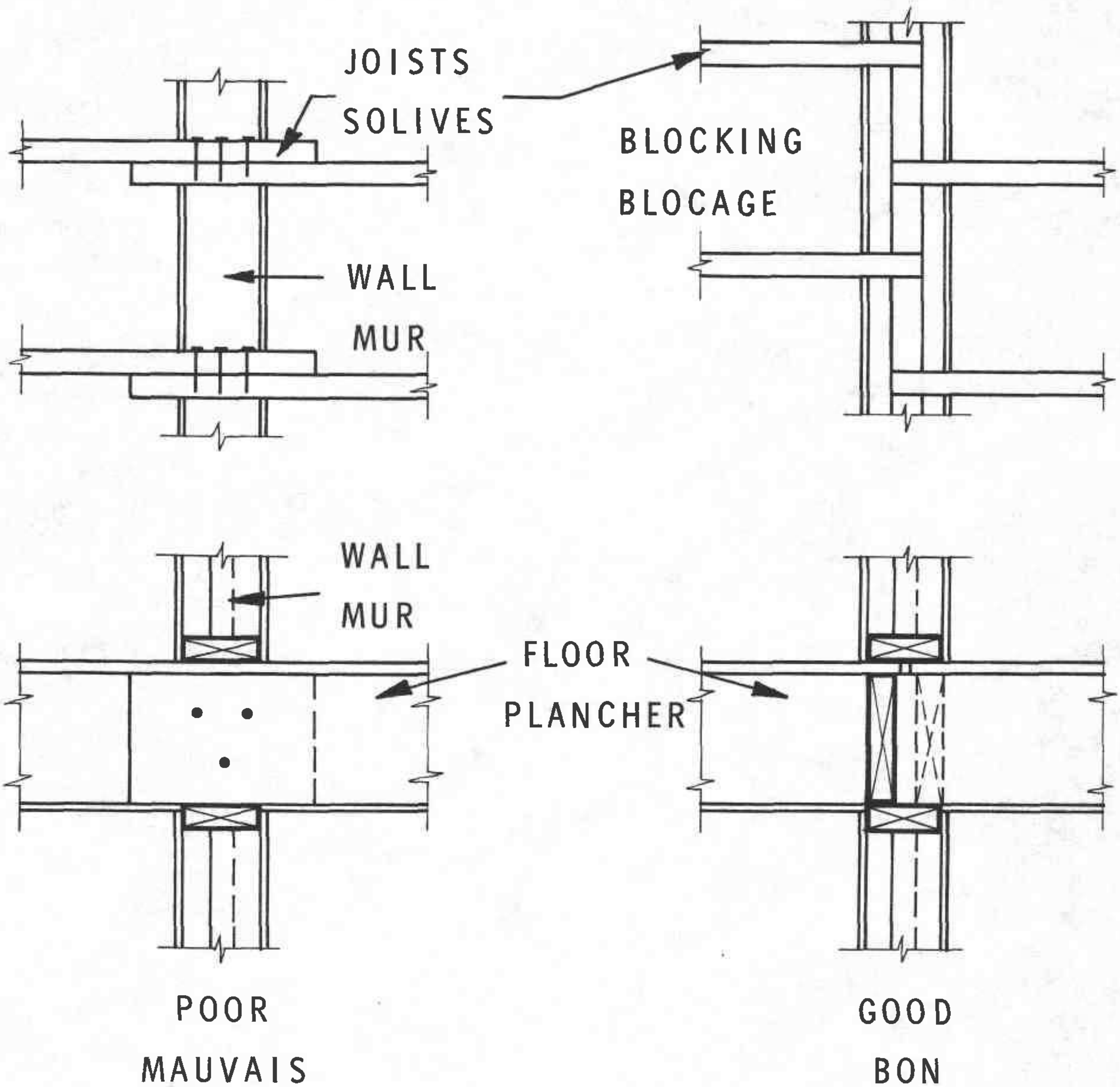


FIGURE 25

WALL-FLOOR INTERSECTIONS (JOISTS PERPENDICULAR TO WALLS)

INTERSECTIONS, MUR A PLANCHER (SOLIVES PERPENDICULAIRES AUX MURS)

BR 3577-37

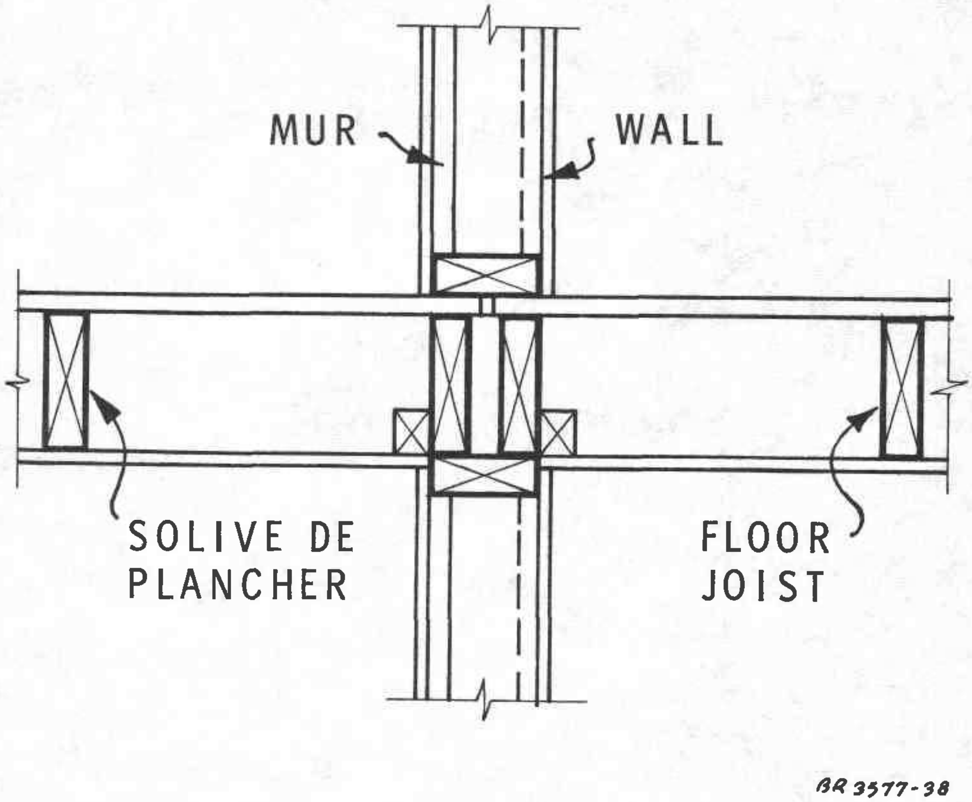


FIGURE 26

WALL-FLOOR INTERSECTION (JOISTS PARALLEL TO WALLS)

INTERSECTIONS, MUR A PLANCHER (SOLIVES PARALLELES AUX MURS)