Seventh Canadian Masonry Symposium
McMaster University
Hamilton, Ontario

June 4-7, 1995

CONTROLLING SOUND TRANSMISSION WITH CONCRETE BLOCK CONSTRUCTIONS.

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ABSTRACT

This paper summarizes information on sound transmission through concrete blocks, unfinished or with gypsum board attached in various ways. The importance of block porosity and the depth of the cavity behind added drywall is illustrated. Methods for dealing with the detrimental resonance involving the blocks, the gypsum board and the trapped air are discussed. The importance of low frequency sound is emphasized and some guidance for optimal acoustical design of concrete block walls is given.

INTRODUCTION

In the last several years it has become more evident that many noise problems in buildings arise at low frequencies, that is around 125 Hz or less. In the past, as required by standards (ASTM E90, ISO 140), measurements of sound transmission loss did not extend below that frequency and so very little information on low-frequency sound transmission was available. This paper summarizes and integrates the information from several sets of measurements of sound transmission loss made on concrete blocks to frequencies below 125 Hz (Warnock 1990, 1991, 1992, 1993). Made at the National Research Council of Canada and partly supported by the Ontario Concrete Block Association (OCBA), the measurements revealed aspects of sound transmission through walls that had not been widely appreciated before.

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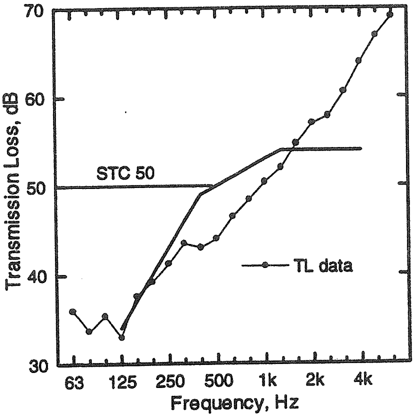

Fig. 1: Sound Transmission Loss for a 190 mm Concrete Block Wall with a Sound Transmission Class (STC) of 50.

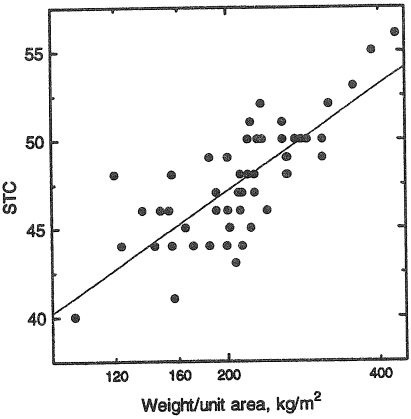

Fig. 2: STC vs. Block Surface Weight in kg/m^2 for single layer blocks walls. The regression line is given by STC = 1.35 + 19.9*log(weight/unit area).

SOUND TRANSMISSION THROUGH BASIC CONCRETE MASONRY WALLS.

Before discussing the changes in sound transmission loss that occur when gypsum board is attached to block walls, the physical factors that determine sound transmission through concrete blocks with no attached gypsum board is first reviewed.

Sound Transmission Class

For significant noise reduction between two rooms, the separating wall or floor must transmit only a tiny fraction of the incident sound energy. The ratio of the sound energy striking the wall to the transmitted sound energy, expressed in decibels (dB), is called the transmission loss (TL): the less sound energy transmitted, the higher the transmission loss. Fig. 1 shows the transmission loss in one-third octave bands measured for a 190 mm thick concrete block wall. The curve shows typical behavior for blocks; transmission loss is lower at low frequencies and increases about 6 dB each time the frequency doubles.

Sound transmission class (STC) is a single number rating that summarizes transmission loss data; it is obtained by fitting the standard reference contour shown in Fig. 1 to the data. Transmission loss values that fall below the reference contour determine the STC value. No transmission loss value may lie more than 8 dB below the contour, a requirement that often determines STC from a single value of low-frequency transmission loss. The 1990 edition of the National Building Code of Canada sets the minimum STC for party walls and floors at 50. However, occupants of multi-family dwellings are usually more satisfied with values of 55 or higher, and this paper shows that attaining STC values greater than 60 is relatively simple.

Effect of block weight

An increase in transmission loss is expected with increasing mass; the heavier the wall, the less it vibrates in response to sound waves, and the less sound energy it radiates on the other side. Fig. 2 shows sound transmission class ratings for single layer block walls from a number of sources in the literature. The scatter is considerable showing that block weight is not the only factor that determines sound transmission class.

Concrete blocks vary widely in physical properties. The interaction of weight, stiffness, porosity, internal vibrational damping, and the shape of normal hollow block is too complicated to allow accurate prediction of sound transmission loss. One has to rely on empirical approaches and measurement. In the absence of measured data, the regression line Fig. 2 can be used to predict STC. Alternatively, Table 1 gives STC values, and typical values of block weight and weight per unit area for hollow blocks that have been sealed on at least one side.

Table 1: STC Ratings for Standard Hollow normal and Lightweight Block Walls Sealed on at Least One Side.

	lightweight			normal weight		
Nominal thickness, mm	kg/block	kg/m^2	STC	kg/block	kg/m^2	STC
100	8	105	43	10	130	44
150	10	130	44	15	190	46
200	14	180	46	18	225	48
250	17	215	47	21	260	49
300	20	250	49	25	310	51

Effect of porosity

Where the block is porous, sound passes through the pores of the block to reach the other side of the wall, thus reducing the sound transmission loss. The porosity of acoustical materials is characterized by the airflow resistivity. This quantity is calculated from the volume velocity of air flowing through a specimen and the air pressure drop across it (ASTM C522). The data in Fig. 3 shows the relationship between airflow resistivity and STC for some unsealed concrete blocks. The data are from three different laboratories and include results for 90, 140, and 190 mm blocks (Sabine 1960, Williamson and Mackenzie 1971, Warnock 1992, denoted S, M, and NRC respectively in the figure). Different block weights would give different STC ratings even if all were correctly sealed.

To compensate for this, it was assumed that STC would increase approximately as 20 log M, where M is the surface mass of the block wall in kg/m^2. Thus, a normalized STC, STC$_n$, was calculated from STC$_n$ = STC - 20 log (M/100). If all the blocks had been correctly sealed, the normalized STC would be around 40, the value at the extreme right of the chart. The difference between 40 and the actual value on the chart represents the improvement obtainable by sealing the block wall. The figure shows that sealing the surface of a porous block wall significantly reduces the sound transmission; the more porous the block (the lower the flow resistivity), the greater the improvement due to sealing. Improvements of 5 to 10 STC points are not uncommon after sealing. Leaking walls were eliminated as far as possible from the data plotted shown Fig. 2, but some of the results that lie far below the regression line may still be from block walls where sound is leaking through unsealed surfaces.

Fig. 3 can be used to estimate the improvement in STC that will occur when blocks are sealed *provided* the flow resistance for the blocks is available. It seldom is. Blocks with resistivities greater than about 2 x 10^5 mks rayl/m show no improvement after sealing. In the absence of information on block airflow resistivity, to ensure the maximum sound reduction from a block or masonry wall it is safer to seal the wall completely using plaster or coats of block sealer. In any case, all the mortar joints must be properly finished and free from leakage.

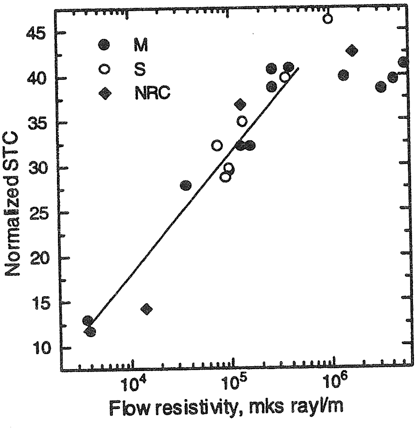

Fig. 3: Relationship between Normalized STC and Airflow Resistivity for Unsealed Concrete Blocks. The solid line is a linear fit to the data below 5 x 10^5 rayl/m.

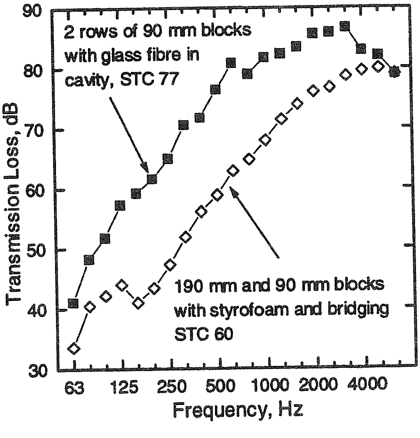

Fig. 4: Sound Transmission through Two Cavity Block Walls.

TWO-LEAF MASONRY WALLS

Two-leaf masonry walls can in principle provide very high sound insulation. They appear to meet the recipe for an ideal double wall: two heavy layers not in physical contact and separated by an airspace. The improvement over a single-layer wall with the same total weight should be considerable because of the air gap. There are, however, practical difficulties associated with constructing two block layers that are not solidly connected at some point. Unless extreme care is taken, there is always some transmission of energy along the floor, ceiling, and walls abutting the periphery of the cavity wall, and through other parts of the structure. Sound can travel along wire ties and seriously impair the sound insulation unless the ties are sufficiently flexible. Physical breaks in the floor, ceiling, and abutting walls are needed to reduce transmission along these flanking paths. In some cases, one of the wall layers may be supported on resilient pads. Even if construction breaks are included in the design, mortar droppings or some other error can bridge the gap and increase sound transmission. Fig. 4 shows results for a two-leaf wall formed from two isolated 90 mm block layers with glass fibre in the cavity. Also shown are the results for a 190 mm/90 mm cavity block wall, but with styrofoam replacing the glass fibre and with accidentally dropped mortar connecting and reducing the isolation between the layers. Despite the heavier block, the faulty internal construction resulted in a much lower transmission loss. Such errors are usually concealed and impossible or too expensive to fix after the wall is complete.

It is difficult to give reliable STC ratings for cavity block walls. Even when comparing results from different laboratories, where construction is carefully controlled, it is possible to get widely differing answers. In practical installations great care, careful supervision, and a good system design are needed for two-leaf block walls to achieve their potential.

INCREASING SOUND REDUCTION BY ADDING GYPSUM BOARD — LOW POROSITY BLOCKS.

Fig. 2 shows that using heavier block to get a greater STC rating leads to walls which are impractically heavy except in special circumstances. The maximum STC in Fig. 2 is 56 for a surface weight of over 400 kg/m^2 which corresponds to two layers of blocks mortared together. Adding materials such as sand or grout to the cores of the blocks makes them perform like solid blocks; the increase in transmission loss is due to the increase in weight and can be estimated from Fig. 2. Adding sound absorbing materials inside blocks is not effective because the sound transmission is primarily through the structure of the block. High STC ratings for block walls are more easily obtained by adding layers of gypsum board to them to form a cavity construction. Sound transmission through the wall is expected to decrease because sound has to make the transition air-solid-air more than once. Separate studs or resilient furring are used to avoid direct transmission from the gypsum board to the blocks. Sound transmission through the wall is further reduced if the cavity behind the gypsum board is filled with sound absorbing material. This is beneficial when there are no rigid connections between the gypsum board and the blocks, otherwise, the improvement is small.

The methods used in the OCBA study to support the gypsum board included some common techniques (13 mm resilient metal channels, 40 mm wood furring, 65 mm steel studs) and alternatives that are not in common use (50 and 75 mm Z-bars). The combination of 38 mm wood strapping and 13 mm resilient metal channels was not tested but would perform about the same as 50 mm Z-bars. For each method of attachment, the wall was tested with the cavity behind the gypsum board empty and filled with glass fibre batts. The blocks were 190 mm thick, weighed 17.5 kg each and gave a finished surface weight of 236.2 kg/m^2.

Effect of cavity depth

Fig. 5 gives two results for walls with unfilled cavities. The striking feature in this plot is that at low frequencies the transmission loss has decreased relative to the unfinished block, while at high frequencies it has increased. The reduction in TL at low frequencies is caused by a resonance, called the mass-air-mass resonance, that involves the mass of the gypsum board, the air in the cavity and the mass of the block wall. This resonance occurs in all two layer structures at a frequency given by

$$f_{mam} = \frac{1}{2\pi k}\sqrt{\frac{\rho_0 c^2}{m_e d}} \qquad [1]$$

where

d is the depth of the cavity, m,
ρ_0 is the density of air, kg/m^3,
c is the speed of sound in air, m/s, and

$$\frac{1}{m_e} = \frac{1}{m_1} + \frac{1}{m_2} \qquad [2]$$

where

m_1 and m_2 are the masses of the two layers of the wall, kg/m^2.

The factor k is 1 if there is no sound absorbing material in the cavity, 1.4 if the cavity is filled and is uncertain if the cavity is partially filled.

Around this resonance, vibrational energy will transfer from the gypsum board through the air in the cavity to the block and through the wall more effectively than in the case of the bare block. This increased sound transmission usually occurs at low frequencies and can result in a lower STC. In Fig. 5, the resonance with the 75 mm Z-bars occurs at 100 Hz. For the 13 mm resilient metal channels, the resonance is less well defined, but is actually around 200 Hz, as will be seen later. This confirms the predictions of equation [1]: the larger the air space, the lower the frequency of the mass-air-mass resonance.

This resonant behavior occurs in any type of multi-layer wall, not just in block walls. Unless measurements are made at low frequencies, however, the mass-air-mass resonance is not always visible on transmission loss plots.

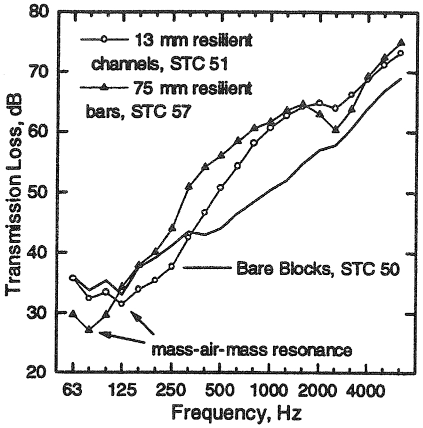

Fig. 5: Sound Transmission Loss through a 190 mm Concrete Block Wall with 16 mm Gypsum Board attached on 13 mm Resilient Metal Channels and 75 mm Z-bars.

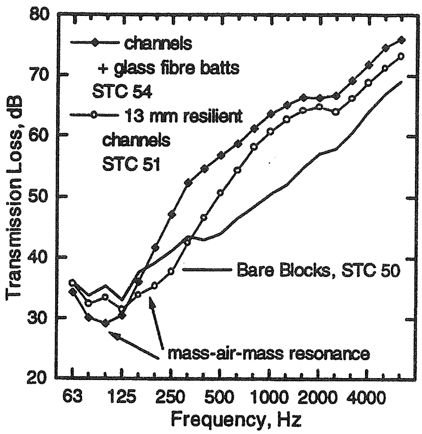

Fig. 6: Sound Transmission Loss through a 190 mm Concrete Block Wall with 16 mm Gypsum Board attached on 13 mm Resilient Metal Channels with and without Sound Absorbing Material in the Cavity.

Effect of sound absorbing material.

Adding sound absorbing material to the cavity is a common way to improve the sound insulation of walls or floors. The sound absorbing material lowers the mass-air-mass resonance frequency by lowering the speed of sound and making the cavity appear deeper. As well, the absorptive material in the cavity reduces the effects of cavity resonances at higher frequencies and the detrimental effects of leaks through the gypsum board around power outlets and the like. Fibrous materials used for thermal insulation, such as cellulose fibre, glass fibre or mineral wool insulation, are good materials for this purpose. Closed cell thermal insulators, such as polystyrene, do not absorb much sound. Fig. 6 shows results for a block wall with gypsum board supported on 13 mm resilient metal channels with and without sound absorbing material in the cavity. The sound absorbing material lowers the mass-air-mass resonance frequency and improves STC. The TL at higher frequencies is also improved. Similar data were obtained for other cavity depths.

Gypsum board added on one or two sides.

Figure 7 shows results for walls with gypsum board applied to one side and both sides of the blocks. The addition of the second layer further improves transmission loss at higher frequencies but further reduces it around the low frequency mass-air-mass resonance. This and similar results for other cavity depths show that improvements and degradations are cumulative; adding a second layer deepens the resonance due to the mass-air-mass resonance. It is somewhat depressing to see that the addition of so much material results in a lower STC.

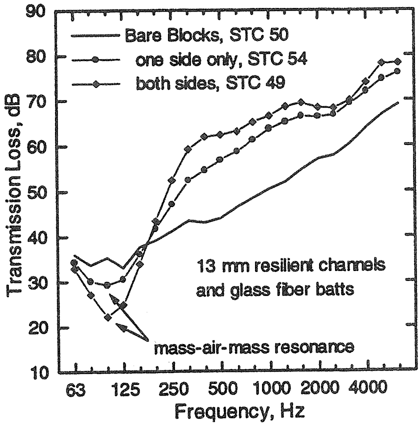

Fig. 7: Sound Transmission Loss for a 190 mm Concrete Block Wall with 16 mm Gypsum Board attached on 13 mm Resilient Metal Channels to one side and to both sides of the wall. Sound Absorbing Material in the Cavity

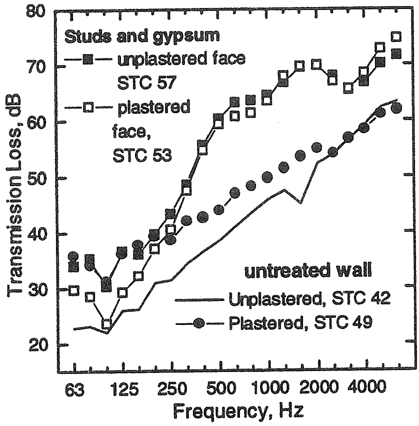

Fig. 8: Effect of Plastering One Face of 190 mm Lightweight Block and of Adding Gypsum Board and 40 mm Steel Studs on each Face.

INCREASING SOUND REDUCTION BY ADDING GYPSUM BOARD — MEDIUM POROSITY BLOCKS.

Effective cavity depth

Some 190 mm lightweight concrete blocks gave an STC of 42 when unplastered and a significantly better 49 when plastered. The blocks weighed 13.4 kg each and gave a surface weight for the wall of 183 kg/m^2. While the need for plastering may be viewed as a disadvantage, the block porosity gave unexpected benefits. It allowed sound waves to penetrate the blocks thus increasing the effective depth of the air space behind the gypsum board with a consequent lowering of the frequency of the mass-air-mass resonance. In Fig. 8 the effect of plastering may be seen. The figure also shows the TL curves for the cases when 13 mm gypsum board supported on 40 mm steel studs was added to the plastered and unplastered face in turn. These two curves should be compared with the curve for the bare plastered blocks. The obvious differences occur near the 100 Hz resonance. When the gypsum board was attached on the *unplastered* side, the block porosity eliminated the mass-air-mass resonance.

Fig. 9 compares this result for these lightweight blocks with a similar one for normal weight blocks. The normal weight blocks have 16 mm gypsum board supported on 50 mm Z-bars while the lightweight blocks have 13 mm gypsum board supported on 40 mm steel studs. In practice, the nominal depth of the air cavities would be very similar

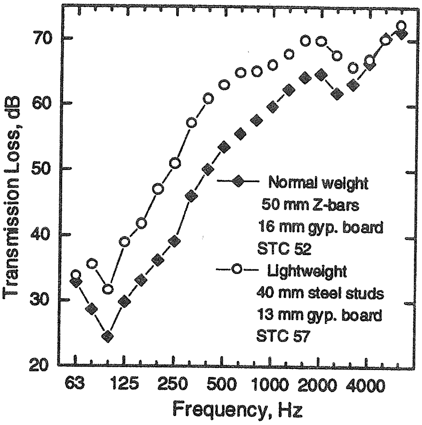

Fig. 9: Comparison between Normal Weight Blocks and Lightweight Blocks with added Gypsum Board.

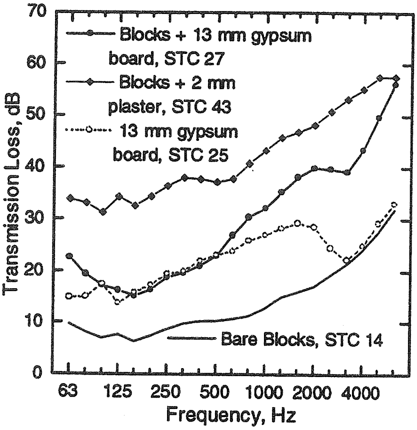

Fig. 10: Transmission Loss for Very Porous Blocks made with a Wood Fibre Aggregate.

because of gaps between the steel studs and the blocks. Despite the lower weight of the blocks and the thinner gypsum board, the lighter wall gives a higher STC rating because the effective cavity depth has been increased and the effect of the mass-air-mass resonance reduced.

INCREASING SOUND REDUCTION BY ADDING GYPSUM BOARD — HIGH POROSITY BLOCKS.

Some extremely porous 90 mm blocks using a wood fibre aggregate were tested. These weighed 7.1 kg each and the wall surface weight was 98 kg/m^2. Unplastered, the wall constructed from them gave STC 14. When one surface was plastered, the STC rose to 43 (see Fig. 10). Also shown in Fig. 10 is the result when a single sheet of 13 mm gypsum board was screwed to one face of the wall. This result may be compared with a result for a single sheet of gypsum board alone, also included in the figure. It is very clear that attaching the gypsum board with screws is not as effective as a coat of plaster; the gypsum board may be sealed but it is not completely attached to the blocks and the benefit of the block wieght is lost.

The very low airflow resistance of these blocks meant that the increase in effective cavity depth was even more marked than in the case of the lightweight blocks. The TL data in Fig. 11 illustrate this quite clearly. There is a shift of three one-third octave bands in the frequency of the mass-air-mass resonance from about 160 down to 180 Hz. To reduce the detrimental effect of the mass-air-mass resonance on the plastered side, sound absorbing material should be added to the cavity or the cavity depth increased. To benefit from the block porosity, *blocks should be sealed on one face only.* Any added gypsum board should be applied on the unplastered face.

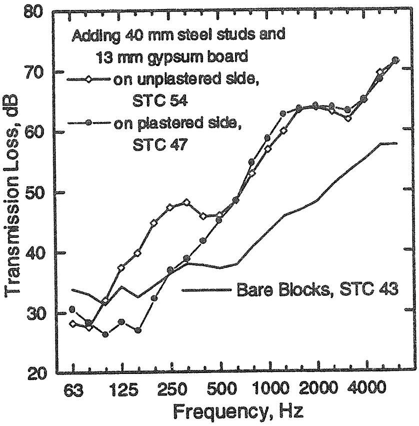

Fig. 11: Transmission Loss for Wood Fibre Aggregate Blocks, Plastered on one Side.

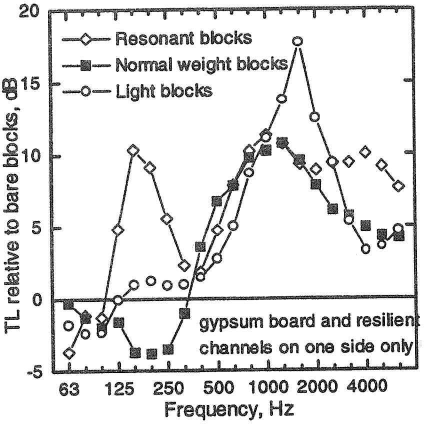

Fig. 12: Transmission Loss Relative to Untreated Concrete Blocks for Three Kinds of Blocks with gypsum Board and 13 mm Resilient Metal Channels on One Face.

RESONANT BLOCKS WITH ADDED GYPSUM BOARD.

Resonant blocks have slits in one face opening into the internal block cavities. The combination of slit and cavity acts as a Helmholtz resonator and the blocks absorb sound quite effectively at the resonance. Resonant blocks offer one way of counteracting the deleterious effects of the mass-air-mass resonance. The Helmholtz resonance counteracts the mass-air-mass resonance and actually increases the sound transmission losses of the wall system near the resonance. To test this notion, we constructed a wall from 140 mm thick resonant blocks at NRC in the manner shown in Fig. 13. The blocks weighed 14.6 kg each and the surface weight of the completed wall was 197 kg/m^2. The flow resistivity of the block material was 1.7 x 10^5 mks rayl/m. When this wall was tested with 13 mm resilient metal channels and 13 mm gypsum board on one face; it achieved an STC of 55. This is significantly higher than the 51 obtained for a similar construction using normal weight blocks. Other configurations were measured but this one case serves to illustrate the benefits of the Helmholtz resonance.

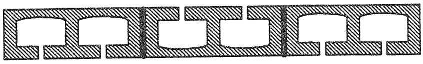

Fig. 13: Cross section through a wall constructed from resonant blocks facing in alternate directions.

In Fig. 12 the sound transmission losses for three types of blocks, normal weight, lightweight, and resonant blocks with gypsum board supported on resilient metal channels are compared. To eliminate the differences between the basic blocks, the transmission losses for the composite walls are shown as differences from those for the basic blocks in each case. The differences in the curves around 200 Hz are quite striking. For the normal weight blocks, the mass-air-mass resonance causes a reduction in sound transmission loss. The lightweight blocks show no resonance around this frequency because of the block porosity. The resonant blocks show a strong absorptive resonance at 160 Hz, the Helmholtz resonance for these blocks, that counteracts the mass-air-mass resonance and leads to an increased STC. Constructing walls from slotted blocks in the manner shown in Fig. 13 may not be practical, but the result is acoustically satisfying.

SUMMARY

The data presented here show that while concrete blocks can provide good sound reduction because of their weight, there are other important factors to be considered.

Block porosity is an important factor but information is often unavailable. In its absence, it is safer to seal blocks on one face only to get full benefit of the weight without losing any benefit of an increased cavity depth. Added gypsum board should go on the unplastered face. If gypsum board must be added on both faces then sound absorbing material should be added at least in the cavity on the plastered face, but preferably in both.

It is never good design to have small cavities in a wall or floor containing lightweight layers. This leads to a mass-air-mass resonance and a reduction in TL in the frequency range where STC is calculated. The mass-air-mass resonance controls the STC rating for many types of multi-layer walls.

The improvement in transmission loss due to added gypsum board begins two to three one-third octave bands above the mass-air-mass resonance. To maximize the improvement, the mass-air-mass resonance frequency should be as low as practical. As a guide, designing for a mass-air-mass resonance of 63 Hz means that the transmission loss improves from 125 Hz upward, thereby ensuring an increase in STC. This can be ensured by satisfying the relationship

$$m_g d \geq c_1 \qquad [3]$$

where m_g is the mass per unit area of the gypsum board, kg/m^2, d is the cavity depth, mm, and c_1 is 450 for a cavity filled with sound absorbing material or 800 for an unfilled cavity. In simpler terms, cavities should be deep enough and filling them with sound absorbing material allows them to be less deep. If these factors are accounted for, even relatively light weight block walls can provide excellent sound insulation.

During the testing of these blocks walls, STC ratings higher than 70 were measured. The walls that achieved these high ratings had cavities about 75 mm deep filled with sound absorbing material. More information on the tests performed can be found in the references. As it happens, all of the blocks mentioned above achieved STC ratings close to 64 when 13 or 16 mm gypsum board was supported independently or on resilient supports at a distance of about 50 mm from the block face. The cavity was filled with sound absorbing material in each case and the porous blocks were plastered on one face. The thicknesses of the walls varied from 215 to 315 mm. STC ratings at this level ensure occupant satisfaction in all except the most extreme circumstances.

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