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Sound transmission through slotted concrete blocks with attached gypsum board

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Measurements of sound transmission loss through slotted concrete blocks with attached gypsum board showed that the cavity resonance of the blocks has an important beneficial effect. It counteracts the mass-air-mass resonance that occurs when gypsum board is added to the surface of a concrete block wall leaving an air space behind it. This significantly increases the sound transmission class rating relative to the same systems with normal-weight nonslotted blocks. The effects of the two resonances could be seen at different frequencies when there was no sound-absorbing material in the air space behind the gypsum board. When the air space was filled with sound-absorbing material, however, both resonances moved together and could not be separated, but the transmission losses and sound transmission class for the composite wall were still significantly greater than those for wall systems using nonresonant blocks. Sound absorption measurements for the slotted blocks showed the need for one-third octave band data in place of the octave band data often found in trade literature.

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INTRODUCTION

Previous work presented sound transmission loss data for normal weight¹ and porous, lightweight² block systems with attached gypsum board. This previous work demonstrated the importance of the mass-air-mass resonance and the influence of sound-absorbing material and block porosity on this resonance. Specially constructed blocks with slots in their faces connecting to internal cavities show a Helmholtz resonance, generally at low frequencies. Such blocks absorb sound strongly around the cavity resonance. Their properties have been discussed by Junger³ who refers to earlier work by Westphal⁴ and Lindahl.⁵ Junger gives the following equations for predicting the resonance frequency f_{cav} :

$$f_{\text{cav}} = (1/2\pi) \sqrt{K/M}, \quad (1)$$

$$K = \rho c^2 A_{\text{slot}}^2 / V, \quad (2)$$

$$M = \rho A_{\text{slot}} (L + \Delta L), \quad (3)$$

where K = stiffness of air in the cavity, M = mass of air slug in slot, V = volume of the cavity in the block (m^3), A_{slot} = area of the slot opening (m^2), L = length of the slot (m), $\Delta L = 0.4 \sqrt{A_{\text{slot}}}$ — the end correction for the slots, ρ = density of air, kg/m^3 , c = speed of sound, m/s .

Using electroacoustic analogs, Westphal predicted that an array of resonators on the surface of a wall would result in increased transmission loss at and around the resonance frequency. He presented transmission loss data for a honeycomb partition formed from 3.5-mm-thick sheets of material with and without 5-mm holes in one face. Predictions and measurements agreed well. On the basis of this and Lindahl's measurements, Junger suggests that slotted concrete blocks should also give an improved transmission loss around the resonance frequency relative

to normal blocks. The data from Lindahl and Westphal showed improved transmission loss at frequencies higher than the resonance; this is not predicted by Westphal's simple model.

Other workers have looked at the effects of Helmholtz resonators in double-panel cavities. The impetus for some of the work comes from the interest in attenuating propeller noise passing through the fuselage of aircraft.⁶ Enger and Vigran⁷ presented data for double-pane windows where there were Helmholtz resonators around the edge of the cavity. As well, they added some sound-absorbing material around the reveals. At the conference where the data were shown, an electroacoustical analog of the double-panel wall with an enclosed resonator was presented.⁸ Mason and Fahy⁹ presented a more detailed model and narrow-band measurements that were in general agreement with their model. Both models predict the same kind of behavior; the Helmholtz resonance decreases sound transmission around the resonance frequency. This increase in sound insulation can counteract the increase in sound transmission due to the mass-air-mass resonance. The Mason and Fahy model predicts that the improvement in sound insulation depends on the ratio of the volume of the resonators to the volume of the cavity of the double wall. The electroacoustical analog contains no such dependence. In both cases the added resonators were placed around the periphery of the cavity.

The purpose of the work presented in this paper was to find how the Helmholtz cavity resonance in slotted concrete blocks interacts with the mass-air-mass resonance that arises when gypsum board is added to the surface of concrete blocks leaving an air space behind it. In this type of construction, the gypsum board is fairly close to the resonator slot and may alter the resonance in some way. It is also common to add sound-absorbing material in double-

FIG. 1. Dimensions of slotted acoustical blocks used in the measurements.

wall cavities to increase the sound insulation. The presence of the sound-absorbing material might also have an effect on the Helmholtz resonance.

Three possibilities existed: (1) The two resonances would remain independent of each other and the improvement due to the Helmholtz resonance would counteract the detrimental effects of the mass-air-mass resonance. (2) The addition of gypsum board in front of the slots in the block face might destroy the Helmholtz resonance, because of the proximity of the gypsum board to the slots. The cavity inside the block might then contribute to the total volume behind the gypsum board and lower the mass-air-mass resonance. (3) There might be some interaction where both resonances are strongly influenced, for example shifted in frequency, with no obvious benefits or disadvantages.

To investigate these possibilities, a wall was built from slotted, acoustical blocks. The paper that follows presents the data for the bare wall, the wall with gypsum board added to one or both faces with and without sound-absorbing material in the cavity.

I. MATERIALS

The slotted blocks used for these measurements were 140-mm thick and each weighed 14.6 kg. The dimensions of the block are shown in Fig. 1. The surface weight of the completed wall was 197 kg/m². The flow resistivity of the block material was 1.7×10^5 mks rayl/m. Alternate blocks faced in opposite directions so slots were exposed on both faces of the wall. It is essential when the wall is constructed in this way that a full mortar bed is used. If this is not done, sound easily passes through the slots on one face, through the gaps in the mortar and out through the slots on the other face. The sound insulation of a wall built with such errors would be very low.

FIG. 2. Cross sections of the furring and studs used to support gypsum board. (a) 13-mm resilient metal channels, (b) 40-mm steel studs.

Gypsum board with a thickness of 12.7 mm and weighing 8.8 kg/m² was attached to the block wall using 13-mm resilient metal channels and 40-mm steel studs. The stud systems had top and bottom tracks and were not in contact with the blocks. This resulted in the distance from the gypsum board to the block surface being about 5 to 10 mm larger than the stud depth. Channels and studs were formed from 0.5-mm-thick galvanized sheet metal and were installed 600-mm apart. Figure 2 shows cross sections and dimensions of the channels and studs.

When sound-absorbing materials were installed in the air space between the gypsum board and the blocks, two types were used. With 13-mm resilient metal channels, a 25-mm-thick blanket of low-density glass fiber weighing 0.3 kg/m² was installed. (Because of the low density, the compression was deemed unimportant.) With 40-mm steel studs, a 38-mm-thick blanket of mineral fiber weighing 2.3 kg/m² was installed.

II. MEASUREMENT FACILITIES AND PROCEDURES

Measurements were made in the sound transmission loss suite at the National Research Council Canada in accordance with ASTM E90.¹⁰ For wall transmission loss measurements, the source room has a volume of 65 m³ and the receiving room has a volume of 250 m³. Wall specimens measure 2.44 × 3.05 m and are constructed on a steel, wheeled frame lined with wood. The frame fits between the rooms and is isolated from both. Each room has fixed and rotating diffusers and four corner-mounted loudspeaker systems fed from independent, pseudorandom noise sources. To measure transmission loss, white noise is fed to the loudspeakers in the source room. Pink noise is used to measure decays in the receiving room. Condenser microphones sample the sound fields at nine positions in the central volume of each room. Measurements are controlled by a computer system interfaced to a Norwegian Electronics type 830 real-time analyzer and cover the one-third octave band frequencies from 63 to 6300 Hz.

III. SOUND ABSORPTION MEASUREMENTS

Sound absorption for the blocks was measured according to ASTM C423.¹¹ Room reverberation times were measured with no specimen in the room—the empty room condition. They were then measured with the blocks installed. The blocks were laid on the floor of the reverberation room with 13-mm-thick pieces of plywood between

FIG. 3. Sound absorption coefficients for 140-mm slotted blocks in three configurations: On the floor with all slots exposed; on the floor with half of the blocks facing up; in wall opening with half of the slots exposed. The solid dots are the coefficients given in the manufacturers' literature.

them to simulate mortar. A frame of the same plywood surrounded the array of blocks. Joints between the frame and the blocks and between adjacent blocks were covered with fabric-backed tape. This was done to eliminate sound absorption due to the crevices at these locations. Without this tape, measurements showed increased sound absorption. There is no standard procedure for preparing concrete blocks for sound absorption measurements, but the installation just described is typical laboratory practice. The blocks were tested once with all slots facing upwards and once with alternate blocks facing down so only half of the slotted faces were exposed.

Sound absorption was also measured with the blocks mortared together as a wall in the transmission loss opening. It was not practical to replace the wall with a highly reflecting surface, so, to get the "empty" room case, the slots were sealed with 3-mm-thick, 25-mm-wide polysulfide glazing tape. The flaw in this procedure is that the absorption due to the block material is eliminated from the measurement; this biases the measurement. To compensate for this, the wall absorption coefficients are increased by 0.17 at all frequencies for plotting in Fig. 3. This somewhat arbitrary increase was adopted to give reasonable agreement between the floor and wall measurements at frequencies around 500 Hz.

The three absorption spectra together with the manufacturer's data are shown in Fig. 3. Some features of these data should be noted. Almost all of the data from the present work are lower than those given by the manufacturer. Without more information, it is not possible to say exactly why this is so. The manufacturer's data are for blocks manufactured and tested in the USA. The blocks used in the present work were manufactured in Canada. There may be differences in materials. The manufacturer's data are for one-third octave bands one octave apart. From these data, one might have thought that the block resonance was at 250 Hz. One-third octave band data allow a

FIG. 4. Sound transmission losses for bare 140-mm slotted blocks. Results with all slots exposed, all sealed and sealed on one side only.

more precise estimate of the position of the resonance frequency, which in this case is 160 Hz. Using the dimensions given in Fig. 1 and Eqs. (1), (2), and (3) gives a calculated resonance at 175 Hz. The measured resonance is in fair agreement with this prediction.

With the *ad hoc* addition of the constant 0.17 to all coefficients to compensate for the block absorption, the absorption coefficients measured for the blocks tested as a mortared wall agree fairly well with those measured for the blocks on the laboratory floor with half the slots exposed. The peak in the absorption is less sharp for the blocks lying on the floor because the resonance seems to lie between two one-third octave bands. This is not a serious difference and probably arises because the plywood separators did not seal the cavities in the same way as the mortar did.

IV. SOUND TRANSMISSION LOSS FOR BARE BLOCKS

Sound transmission through the bare wall was measured for three conditions: (1) All slots sealed with 3-mm-thick glazing tape; (2) all slots on both sides open; and (3) the slots on one side only sealed with glazing tape. The glazing tape would not alter the wall stiffness but would remove the effect of the cavity resonance. The transmission loss results are shown in Fig. 4.

The figure shows that transmission loss is reduced at frequencies below about 250 Hz when the slots are exposed. Sound enters the cavity in the blocks and then passes through the block material to the receiving room. In Ref. 2, a relationship between STC and the flow resistivity of the block material was given. The value of flow resistivity for the concrete in the present blocks shows that significant transmission through the block material is to be expected. Thus, for these unpainted blocks the slots do not increase transmission loss.

The data presented by Lindahl show the opposite effect—slotted blocks provide higher transmission loss values than the normal blocks he tested. But, as he points out, the slotted blocks he tested were heavier than normal

FIG. 5. Sound transmission losses for slotted blocks and 75% solid normal blocks.

blocks of the same size and same aggregate. Lindahl does not give the weight of the blocks he tested and his data apply to blocks that were sealed on one face. So while his data show better transmission losses for the slotted blocks, it is not conclusive that this was due to the cavity resonance.

Figure 5 shows transmission loss for the slotted blocks used in the present work, for 75% solid, 140-mm-thick blocks from Ref. 1 and for the slotted blocks used by Lindahl. His data have been converted into modern one-third octave band format. The 75% solid blocks weighed 17.8 kg per block. Lindahl's data has the same general shape at low frequencies as the data for the sealed slotted blocks and the 75% solid blocks. There is no obvious feature in these three curves that can be attributed to the action of the resonant cavity. The dips in the curves around 250 Hz are attributed to a structural resonance in the wall, the frequency of which is determined by the stiffness of wall and its dimensions. The peaks just below these dips appear for blocks without slots and are apparently not associated with the cavity resonance of the blocks.

Thus, in contrast to the results obtained by Westphal, these data suggest that the cavity resonance does not increase block wall transmission loss. Westphal's result, while unequivocal, was for a much lighter structure with a cavity resonance at 700 Hz. It is instructive to look at the electroacoustic model used by Junger and Westphal to see what improvement can be expected for block walls. This model is shown in Fig. 6. The values of m_2 , C_2 , and R_2 are given by the following equations which are a rearrangement of those given by Junger.

$$m_2 = M(R/A_{\text{slot}}), \quad (4)$$

$$R_2 = (R/QA_{\text{slot}}) \sqrt{KM}, \quad (5)$$

$$C_2 = A_{\text{slot}}/KR, \quad (6)$$

$$Q = f_{\text{cav}}/\Delta f, \quad (7)$$

FIG. 6. Electroacoustic analog of concrete block wall with cavities on one face. The inductor m_2 represents the mass of the air associated with the slots, C_2 represents the compliance of the cavities, R_2 represents the loss in the cavity, Z_0 is the impedance of the air, and m_1 represents the mass of the blocks. The incident sound signal is represented by a generator with amplitude $2p_0$.

where Q = the Q factor for the cavity resonance, Δf = the width of the resonance at half the peak height, R = the ratio of total wall area to the total area of the slots.

According to the model in Fig. 6, the maximum improvement in transmission loss arises at the cavity resonance frequency given by Eq. (1). The absorption peak in Fig. 3 has a Q of roughly 1.7. Using these relationships and simple circuit theory, it may be shown that the calculated improvement in transmission loss for these slotted blocks at the cavity resonance is only about 1.5 dB, which is rather small.

The superior performance of the slotted blocks seen in Fig. 5 and in Lindahl's work may be due to changes in wall stiffness or some other factor. The block wall used here was not painted and there was apparently significant transmission through the concrete at the rear of the cavities. To clarify the effects of the cavities, measurements should be made on a slotted block wall sealed on the slotted side. Transmission loss measurements with the slots open and sealed with heavy glazing tape as done here would give a clear picture of the effects of the cavity resonance of the blocks.

V. SOUND TRANSMISSION LOSS FOR BLOCKS WITH ADDED GYPSUM BOARD

The transmission loss data for all the systems tested are given in Table I. Figure 7 shows transmission loss results obtained when 13-mm gypsum board was attached to the wall on 13-mm resilient channels. The STC ratings obtained are several points higher than those obtained in Ref. 1 for normal 190-mm blocks.¹² This is entirely due to the improved low-frequency performance. The peak in the transmission loss curves around 160 Hz is undoubtedly due to the cavity resonance of the blocks.

Figure 8 gives results for the gypsum board supported on 40-mm steel studs with the space between the studs unfilled. Again, the STC ratings are higher than those obtained for comparable systems in Ref. 1.¹³

TABLE I. Sound transmission losses for 140-mm slotted blocks with different surface finishes. The codes used in columns side 1 and side 2 have the following meaning: G13—13-mm gypsum board; RC13—13-mm resilient metal channels; SS40—40-mm steel studs; GFB or MFB—glass or mineral fiber batts (the number following gives the thickness in mm).

Test	Side 1	Side 2	STC	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
39	G13—RC13	G13—RC13	57	26	19	20	37	49	50	47	46	48	56	63	69	73	76	76	76	76	72	74	78	76
40	Bare	G13—RC13	55	29	23	24	33	41	43	44	45	46	51	57	61	66	69	69	68	68	64	65	70	72
47	G13—GFB13	G13—RC13	58	27	23	24	34	44	51	51	53	55	61	65	69	74	76	76	76	75	72	74	80	81
	—RC13																							
50	G13—GFB13	G13—GFB13	58	27	24	26	33	39	47	53	60	62	64	68	71	75	76	77	78	77	74	77	80	77
	—RC13	—RC13																						
51	G13—SS40	G13—SS40	60	19	20	26	38	50	48	44	48	57	63	67	69	73	77	78	76	76	75	74	71	66
53	G13—SS40	Bare	57	28	22	25	35	42	41	42	46	52	58	61	63	67	71	74	74	72	69	72	77	77
54	Bare	Bare	49	32	24	26	28	30	34	39	43	44	47	49	51	55	58	59	59	59	55	56	61	64
78	G13—MFB40	G13—MFB40	64	23	25	32	40	50	56	56	61	61	61	63	65	69	76	78	77	73	71	74	80	78
	—SS40	—SS40																						
79	G13—MFB40	Bare	59	29	27	30	35	41	49	50	54	54	56	59	61	65	70	72	72	69	67	71	77	80
	—SS40																							

Figure 9 is for 40-mm steel studs with the spaces between the studs filled with mineral fiber. There is no obvious peak around 160 Hz and the STC ratings are the same as those obtained for similar walls in Ref. 1.¹⁴

In each case, a pattern similar to that in Ref. 1 is seen—at some low frequency, the curve for the bare blocks crosses the curves for the cases with gypsum board added. When both sides are finished, detrimental resonances get deeper and transmission loss improvements increase. When the air space behind the gypsum board is not filled with sound-absorbing material, the cavity resonance of the blocks is quite evident.

To see more clearly the effects of different air spaces, the addition of sound-absorbing material and the behavior of the Helmholtz resonance, the data are presented now as plots of ΔTL . ΔTL is the change in transmission loss, relative to the bare block, that is associated with a given arrangement of gypsum board and support. It is assumed that each time a given gypsum board system is applied to the blocks, it has the same relative effect no matter what is

on the other side of the wall. Thus, in Fig. 7 for 13-mm gypsum board and resilient metal channels, one estimate of ΔTL is obtained by subtracting the transmission losses for the bare block from those for the block with 13-mm gypsum board and resilient metal channels on one side. Another estimate is obtained by subtracting the bare block data from the result for the gypsum board and channels on both sides. This gives $2\Delta TL$, so the result is divided by 2. These two estimates are averaged to get a mean ΔTL . Other procedures followed for finding the mean ΔTL are explained in Ref. 1.

Figure 10 shows the average ΔTL when there was no sound-absorbing material in the air space behind the gypsum board. It also shows for comparison, a result for normal blocks from Ref. 1. In Ref. 1, the crossover frequency f_x was defined as the frequency where the ΔTL curve crosses the zero axis. It is usually about 1.8 times higher than the calculated mass-air-mass resonance frequency. The effect of the cavity resonance of the blocks is clear; it counteracts the detrimental effects of the mass-air-mass

FIG. 7. Sound transmission losses for 140-mm slotted blocks with 13-mm gypsum board added on 13-mm resilient metal channels. The air space between the gypsum board and the blocks was empty.

FIG. 8. Sound transmission losses for 140-mm slotted blocks with 13-mm gypsum board added on 40-mm steel studs. The air space between the gypsum board and the blocks was empty.

FIG. 9. Sound transmission losses for 140 mm using slotted blocks with 13-mm gypsum board added on 40-mm steel studs. The air space between the gypsum board and the blocks was filled with mineral fiber.

resonance and prevents the negative ΔTL seen for the normal blocks around this frequency. The system transmission loss is greatly improved at low frequencies relative to the case of blocks without resonant cavities although there are still negative ΔTL values below 100 Hz. The benefits of the air space are still obtained above the crossover frequency.

If the block cavity acted only to increase the volume of the air space behind the gypsum board, the additional volume would correspond to an increase in air space of about 14 mm. The corresponding shifts calculated for the mass-air-mass resonance and the crossover frequency f_x are rather small. If the rising parts of the curves in Fig. 10 around 250 to 500 Hz are extended back to the zero ΔTL axis, this gives estimated crossover frequencies of about

FIG. 10. Average change in transmission loss ΔTL for air spaces containing no sound-absorbing material. A result for a normal block is included for comparison. The symbols identify the gypsum board and the method used to support it as follows: SS40=40-mm steel studs; RC13=resilient metal channels; G13=13-mm gypsum board; G16=16-mm gypsum board.

FIG. 11. Average change in transmission loss, ΔTL , for the air space behind the gypsum board filled with sound-absorbing material. A result for a normal block is included for comparison. The symbols identify the gypsum board and the method used to support it as follows: SS40=40-mm steel studs; RC13=resilient metal channels; G13=13-mm gypsum board; G16=16-mm gypsum board.

250 and 315 Hz. Crossover frequencies can also be calculated using^{1,2}

$$f_x = 108 / \sqrt{M_d d}, \quad (8)$$

where M_d is the surface mass of the gypsum board, kg/m^2 , and d is the depth in meters of the air space behind it. For the 40-mm studs and the 13-mm channels, the calculated values are 170 and 315 Hz which are in fair agreement with those above. Thus, the data show that when the cavity is not filled with sound-absorbing material, the two resonances do not interact and remain at the frequencies given by the equations above.

The work done in Ref. 1 showed that adding sound-absorbing material to the air space behind the gypsum board lowered the mass-air-mass resonance and the crossover frequency. Figure 11 shows what happens in the case of these slotted blocks. The frequency of the Helmholtz resonance moved to 200 Hz, although the resonance is not prominent in the case of the 13-mm air gap. This shift can be explained by saying that the sound-absorbing material acts to reduce the effective length of the slots in the block; the ΔL correction is zero.¹⁵ This gives a change in frequency of the correct size. The less prominent resonance for the 13-mm air gap can be explained by saying that the Q of the Helmholtz resonance has been reduced by the sound-absorbing material, although it is not obvious why this should be so in one case and not the other. The lowered mass-air-mass resonance makes it impossible to separate the two resonances in the graph. Comparison of the ΔTL curve for normal blocks with the other two curves shows that for both the 13- and 40-mm air spaces there are still substantial benefits obtained at low frequencies due to the action of the Helmholtz resonance; the crossover frequency is lower than the 160 Hz observed for the normal blocks. The shift in crossover frequency cannot be explained by postulating that the volume of the space behind

FIG. 12. Electroacoustic analog of slotted cavity block wall with added gypsum board. The inductor m_2 represents the mass associated with the slots, C_2 represents the compliance of the cavities, R_2 represents the loss in the cavity, Z_0 is the impedance of the air, and m_1 represents the mass of the blocks. C_3 represents the stiffness of the air space behind the gypsum board which has mass m_3 . The incident sound is represented by a generator with amplitude $2p_0$.

the gypsum board is increased by the volume of the block cavity. This indicates that there are still two resonances active.

Calculations using a modification to the electroacoustic analog given above show that the behavior seen here for the empty air space is to be expected. Figure 12 shows the modified model. C_3 represents the stiffness of the air space behind the gypsum board which has mass m_3 kg/m². C_3 is given by $d/\rho c^2$. Using this model, the improvement in transmission loss relative to mass law predictions for m_1 can be calculated.

Calculations were made for air space depths of 13 and 40 mm. The results are compared in Figs. 13 and 14 with measured ΔTL data. The general shape of the calculated ΔTL curves at low frequencies is similar to those measured. Calculated results are sensitive to the value of Q used for the cavity resonance of the blocks. When the value

FIG. 13. Measured and predicted ΔTL for 13-mm air space behind gypsum board.

FIG. 14. Measured and predicted ΔTL for 40-mm air space behind gypsum board.

of 1.7 estimated from absorption measurements was used, the two resonances were not clearly seen. To show them more clearly, a Q of 6 was used in the calculations.

Even this crude model confirms that the cavity resonance of the blocks has a much greater effect on transmission loss when the cavities are behind the gypsum board than when they are exposed to the sound field. The model also predicts low frequency resonances in the 80- and 100-Hz bands for the 13- and 40-mm air spaces, respectively. These are due to a mass-air-mass resonance where the cavity compliance is determined approximately by the sum of C_2 and C_3 , that is the volume of the cavity in the blocks adds to the volume behind the gypsum board. The data show negative ΔTL there which may be due to such resonances. As shown in Ref. 2, the depth of the mass-air-mass resonance can be reduced by the action of block porosity. The airflow resistivity of the concrete in that case was 1.3×10^5 mks rayl/m. In this case, the airflow resistivity was 1.7×10^5 mks rayl/m so one can expect similar reductions of the depth of the mass-air-mass resonance. The data in Fig. 4 also show that there was transmission through the pores of the block material; the model does not simulate this transmission.

The model predicts that ΔTL will increase at 12 dB/octave at frequencies much higher than the mass-air-mass resonance. This is because the model has no element to simulate line and edge connections between the gypsum board and the blocks. Line, edge, or point connections existed in the real wall and would account for the plateau in the ΔTL curves at high frequencies.

Attempts to use these simple, electroacoustic analogs to simulate the effect of adding sound-absorbing material to the air space behind the gypsum board gave results that were in no way similar to those measured. These models are of limited usefulness.

VI. DISCUSSION

The absorption measurements suggest that several refinements to the test procedures are needed to deal with

slotted concrete blocks. Since they are strongly resonant absorbers, absorption coefficients should be measured at least in one-third octave bands; the one-third octave band data at octave band frequencies found in manufacturers' literature can be quite misleading. Differences between specimens measured on the floor of the laboratory and those measured in a wall opening could arise due to inadequate simulation of the mortar between the blocks. A standard installation practice to be used when measuring the absorption of concrete blocks is needed.

The sound transmission loss measurements showed that the Helmholtz resonance associated with the slotted blocks acts independently of the mass-air-mass resonance associated with the gypsum board and the air space behind it. This fact could be used to design walls with high STC ratings and minimum thickness.

Adding sound-absorbing material to the air space behind the gypsum board changes the behavior of the mass-air-mass resonance and the Helmholtz resonance. In this case, when the sound-absorbing material was added, both resonances moved together and could not be seen as separate.

This paper has presented more examples of the interaction between gypsum board and concrete block walls. As in the previous two papers, questions are raised that appear to be unanswered in the literature. The systems presented here might be impractical because of cost but there may well be benefits for building acoustics if inexpensive resonant systems can be developed.

¹ A. C. C. Warnock, "Sound transmission through concrete blocks with

attached drywall," *J. Acoust. Soc. Am.* **90**, 1454-1463 (1991).

² A. C. C. Warnock, "Sound transmission through two kinds of porous concrete blocks with attached drywall," *J. Acoust. Soc. Am.* **92**, 1452-1460 (1992).

³ M. C. Junger, "Helmholtz Resonators in Load-Bearing Walls," *Noise Control Eng.* **4** 1, 17 (1975).

⁴ Wolfgang Westphal, "Beeinflussung der Schalldämmung von Wänden durch Resonatoren," *Proceedings of 4th International Congress on Acoustics*, paper M36, August, 1962.

⁵ Robert Lindahl, "Sound Transmission Loss Characteristics of a Hollow Concrete Block with a Slotted Face," *Proceedings of 6th International Congress on Acoustics*, paper E-3-6, p. E-101, August, 1968.

⁶ H. L. Kuntz, R. J. Gatineau, and R. A. Prydz, "Acoustic Transmission Loss Flight Test Results for an Aircraft Cabin Enclosure," *Inter-Noise* **89**, 211 (1989).

⁷ J. Enger and T. E. Vigran, "Transmission Loss of Double Partitions containing Resonant Absorbers," *Proc. Inst. Acoust.* **7**, part 2, 125 (1985).

⁸ T. E. Vigran (personal communication).

⁹ J. M. Mason and F. J. Fahy, "The Use of Acoustically Tuned Resonators to Improve the Sound Transmission Loss of Double-panel Partitions," *J. Sound Vib.* **124**(2), 367 (1988).

¹⁰ ASTM E90, "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions."

¹¹ ASTM C423, "Standard Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method."

¹² 190-mm-thick normal-weight blocks with 16-mm drywall and 13-mm resilient metal channels on one side gave STC 51. With drywall and channels both sides, an STC of 49 was obtained.

¹³ 190-mm normal-weight blocks with 16-mm drywall mounted on 50-mm resilient metal Z bars on one side gave an STC of 52. With the same treatment on both sides, the STC was also 52.

¹⁴ A normal-weight 190-mm concrete block with 50-mm resilient metal Z bars, sound-absorbing material and 16-mm drywall on one side gave an STC of 59. With the same treatment on both sides, the STC was 64.

¹⁵ The author is indebted to the reviewer who suggested this explanation.