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A COMPARISON OF THE SOUND TRANSMISSION OF PROFILED METAL CLADDING WHEN MEASURED IN THE LABORATORY AND IN SITU.

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1. INTRODUCTION

Work is currently being undertaken at the University of Salford to develop a noise prediction scheme which should enable design engineers to accurately predict environmental noise from proposed industrial constructions. This project involves an analysis of many acoustical topics; from a consideration of the internal sound field (e.g. using ray-tracing), through the transmission and directivity of various building elements, to considerations of meteorological and outdoor propagation effects such as wind and temperature gradients, screening and the ground effect.

Preliminary measurements of sound transmission have shown that the relationship between Standard laboratory tests and in situ performance is not simple and it is known [1,2] that even stringent laboratory conditions can produce variable results when tests are repeated. This is important to the development of a generalised environmental noise prediction scheme because it produces an error almost "at source"; i.e. before algorithms for outdoor propagation, etc. can be implemented.

Recent work at Salford has included measurements on a simple, proportionately shaped building constructed entirely from one single-skinned profiled metal cladding. The same material has also been tested in a transmission suite and using intensity techniques. Thus it is possible to make accurate comparisons between performance in situ and those Standard or predicted values of sound transmission.

2. THEORY

2.1 Relating the S.R.I. to in situ observations.

The transmission coefficient, τ, may be defined as the ratio of transmitted intensity, I_t, to incident intensity, I_i :

$$\tau = I_t/I_i \qquad (1)$$

The Sound Reduction Index, or transmission loss, is simply this value expressed in terms of decibels :

$$SRI = 10.\log_{10}(1/\tau) \text{ dB.} \qquad (2)$$

If one assumes that a panel/wall is excited by a diffuse field, the intensity incident on its surface can be found from :

$$I_i = p^2/4p_o c \qquad (3)$$

where p is the r.m.s. pressure (Pa.), p_o the density of air and c is the speed of sound in air. One may also express the sound power radiated by the wall in terms of the incident intensity :

$$W = I_t.S = \tau.I_i.S \qquad (4)$$

where S is the radiating surface area of the wall (m^2.). Hence, it is possible to write the sound power level (PWL) of the radiating panel as a function of the intensity level (IL) measured over the excitation sound field :

$$PWL = 10.\log_{10}(\tau S) + IL \text{ dB.} \qquad (5)$$

Substituting equation (3) into this provides an expression for PWL in easily-measurable quantities (such as the sound pressure level inside a building, L_{in}) :

$$PWL = L_{in} - SRI + 10.\log_{10}S - 6 \text{ dB.} \qquad (6)$$

Now, a building can be said to radiate into 2π-space, taking the ground as a reflecting plane. Therefore, the radiated (or transmitted) intensity measured at a distance r (m.) from the building is described by the inverse square law :

$$I_t = W/2\pi r^2 \qquad (7)$$

This may be expressed as a PWL in terms of an IL as before. One may also say that the IL will be very close to the SPL (L_{out}) in free-field conditions, such that :

$$L_{out} = PWL - 8 - 20.\log_{10}r \text{ dB.} \qquad (8)$$

If one considers equations (6) and (8), a simple expression for the SRI can be formed :

$$SRI = L_{in} - L_{out} + 10.\log_{10}(S/r^2) - 14 \text{ dB.} \qquad (9)$$

This may be further simplified if it is required that measurements are taken close to the wall. By expressing the transmitted power as in equation (4) and assuming the IL to be about equal to the SPL in free-field conditions (i.e. outside), one can describe the radiated sound power of the wall as:

$$PWL = L_{out} + 10.\log_{10}S \text{ dB.} \qquad (10)$$

Substituting this into equation (6) gives :

$$L_{in} - L_{out} = SRI + 6 \text{ dB.} \qquad (11)$$

This is a result commonly quoted in standard acoustic texts, providing a simple conversion of the SRI into a level difference (L_{in}-L_{out}) which is independent of frequency and building material. However, it should be obvious that both expressions (9) and (11) will only hold where the wall is seen to radiate hemispherically into 2π-space. In the case of equation (11) measurements are taken in the near field of a plane source radiating into π-space. Equation (9) may be used with large values of r, but measurements at such distances will be affected by the finite impedance of the ground and any number of meteorological effects. In order to provide a more physically meaningful prediction of the relationship between simple level difference and SRI, the wall may be treated as a homogeneous plane source composed of evenly distributed, uncorrelated point sources. This has been shown [3] to lead to the solution :

$$L_{in} - L_{out} = SRI + 3 \text{ dB.} \qquad (12)$$

A similar approach was used by Gösele and Lutz [4], who obtained the expression :

$$L_{in} - L_{out} = SRI + 4 \text{ dB.} \qquad (13)$$

2.2 Prediction of the S.R.I.

The transmission coefficient is normally calculated, in the region below critical frequency, using the "normal incidence mass law" :

$$SRI_0 = 20.\log_{10}(Mf) - 42 \text{ dB.} \qquad (14)$$

where M is the surface mass (kg/m^2) and f is the frequency. As this only applies to sound at normal incidence an empirical correction is used - known as the "field incidence" mass law :

$$SRI_F = SRI_0 - 5 \text{ dB.} \qquad (15)$$

This approach is often inaccurate, even in its specified frequency range, although it is still widely used to provide figures for common building materials, e.g. [5].

Metal cladding panels, such as represented in Figure 1, are usually profiled. The effect of the corrugations is to produce different bending stiffnesses in different dimensions. This results in two distinct critical frequencies related to the horizontal and vertical sections of the panel. It has been shown [6] that the critical frequency in the vertical dimension, f_{c1}, may typically be reduced by a factor of about 100 in relation to the f_c of a homogeneous plate of the same material. As the mass law only holds for frequencies $f<f_c$, there is further error.

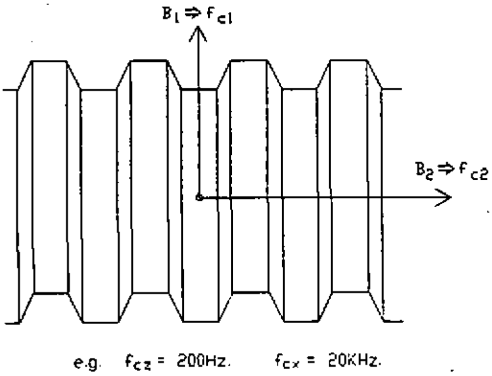

Figure 1 Profiled cladding.

Heckl [7] derived approximate solutions for the transmission coefficient of an orthotropic plate. His method had the advantage of considering the second moment of area of the panel such that the profile is taken into account in both dimensions. Hence, both critical frequencies are included. However, one requires a method of calculating the second moment of area : the equations given by Bies and Hansen [8] were used in this study, although it should be noted that the method used by Cederfeldt [6,9,10] produces similar results.

3. MEASUREMENTS

The material tested in all of the measurements described below, was a single-skinned profiled-steel cladding known as Topsheet 35/1000, fabricated by Ayrshire Metals (Daventry) Ltd. of thickness h=0.5mm. and surface mass M=5.13 kg/m^2. All calculations and predictions used typical parameters for steel where required (i.e. Young's modulus $E=19.5\times10^{10}$, Poisson's ratio $\sigma=0.28$).

3.1 Laboratory techniques.

These measurements were carried out in the transmission suite of the Dept. Applied Acoustics, University of Salford which meets all International Standards for such testing.

3.1.1 The transmission suite method. The Sound Reduction Index is most commonly measured in accordance with B.S.2750:part3:1980. This requires the use of two isolated reverberant chambers linked only by an aperture of 10m^2 in which the test panel is placed. The panel was, in this case, bolted to two Zeta-purlins in order to simulate the in situ fixings as closely as possible. Spatially and temporally averaged sound pressure levels were measured in the source (L_S) and receiver (L_R) room simultaneously and the SRI was computed from :

$$SRI = L_S - L_R + 10.\log_{10}(S/A) \text{ dB.} \qquad (16)$$

where A (m^2.) is the total absorption in the receiver room.

3.1.2 Intensity measurements. The measurement of SRI with an intensity probe requires the use of one reverberant chamber (source room). In this case, the receiver room of the transmission suite was filled with absorbent material such that the space was virtually anechoic and the panel fixings remained identical. The sound pressure, p_{rms}, was measured as before in the source room : as this was a diffuse field, the intensity incident on the panel can be simply found from equation (3). An intensity probe (Nortronics Sound Intensity Microphone type 216) was used about 5cm. from the panel in order to directly measure the intensity transmitted along its normal (preliminary measurements showed that this distance was not critical). Two techniques were employed : (a) the panel was split up into notional areas (54 and 6 in this case) and the probe was held at the centre of each for an appropriate time such that an average I_{eq} could be found over the entire area, (b) the probe was swept manually over the surface of the panel for a range of averaging times. The SRI is easily calculated using equations (1) and (2).

3.2 In situ measurements.

These measurements were taken at the "Structures Building", A.F.R.C. Engineering, Silsoe during February and July, 1990. The building is a simple proportionate shape (24 x 12 x 4 m., roof pitch=10°.), has an earth floor and is wholly constructed from the single-skinned cladding described above. Two sound sources were used (a 24" and a 15" loudspeaker) which together covered the frequency range 20Hz. to 5KHz.

3.2.1 "Level difference" measurement. The "level difference" is simply a measure of the difference in sound pressure level 1m. from either side of the wall, i.e. $L_{in}-L_{out}$. This was calculated at 26 positions across the surface of the wall. A sound level meter was used to check that the variance in SPL was small around this distance and up to the wall.

3.2.2 Intensity measurements. Exactly the same methods of measurement of SRI were employed as in the laboratory. However, problems in calculating the incident intensity occurred as the internal sound field was not "diffuse"; therefore, an error will be incurred in equation (3). In an attempt to quantify this, the spatial averaging of sound pressure was accomplished in two ways; (a) five random positions were selected exactly as is stipulated in B.S.2750 for a transmission suite, (b) six positions were selected 2m. from the inner surface of the wall to closer resemble the magnitude driving it - sound level meter checks were carried out to ensure no significant pressure doubling occurred due to reflections back from the wall.

3.2.3 Impulse response measurement. The impulse response was obtained, inside and outside the building, making use of a maximum length sequence (or "pseudo-random noise") analyzer ("D.R.A. laboratories MLSSA"). In simple terms, a signal is produced with a very long period such that it can, in effect, be measured as random noise. However, because of its periodicity, the generated signal is not lost like true random noise during auto-correlation. Averaging is performed on many measured pressure levels ("pre-averaging") before an impulse response is computed. Further averaging may then be applied to several sets of impulse response data such that the resultant impulse response has a very high signal-to-noise ratio. An F.F.T. is performed on each impulse response to give a system transfer function on either side of the wall : subtracting one from the other eliminates the responses of equipment (especially loudspeakers) and leaves one with $L_{in}-L_{out}$. Such measurements were repeated in several positions across the wall's surface with microphones at 1m. and 2m. away on either side.

4. RESULTS

A selection of the different measurement techniques is shown in figure 2. It can be seen that the sound reduction spectra have a high correlation, especially in the frequency range 160Hz. to 3150Hz. The results from the intensity measurement technique (both in the laboratory and on-site) and the transmission suite method compare especially well in this frequency range. B.S.2750 states that the S.R.I. should be measured at least over the range 100Hz. to 3150Hz. such that one may say that this method is accurate over most of the specified range. At low frequencies, however, it is obvious that the transmission suite method produces much higher values for sound reduction than any of the other methods shown. This will not only be caused by strong room modes at wavelengths similar to the rooms' dimensions, but also by an amount of "back transmission" from the receiver to the source room. In general, it is seen that, above low frequencies, the value of $L_{in}-L_{out}$ measured in situ is about 4dB. above the laboratory S.R.I. This is much as predicted by Gösele and Lutz

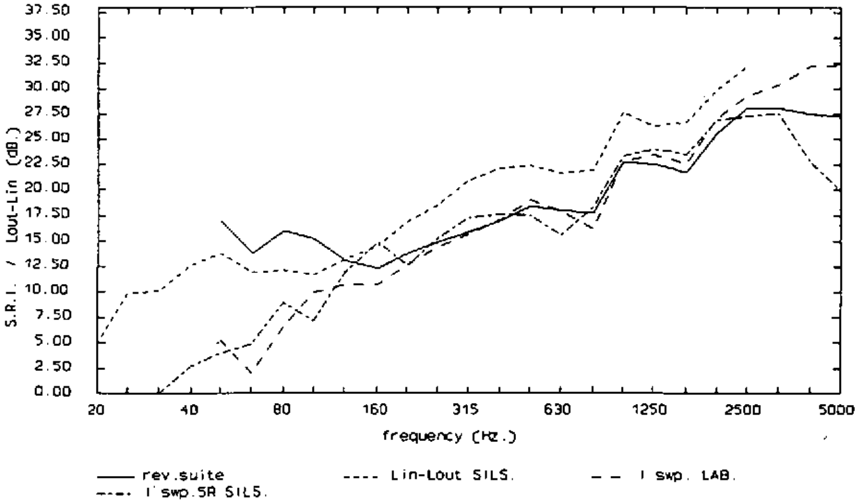

Figure 2 Comparison of SRI with $L_{in}-L_{out}$

[4] (equation 13). However, one should be wary of transmission suite results as it has been shown [1,2] that they can vary by several decibels between laboratories.

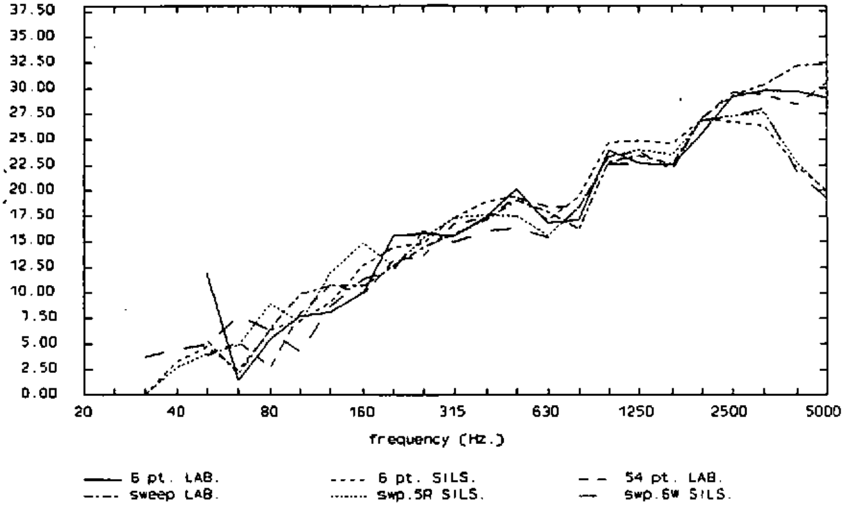

Figure 3 Comparison of intensity measured SRI

Measurements of S.R.I. using intensity techniques should not be so prone to error as they only rely on one fairly diffuse field. It can be seen (figure 3) that intensity measurements remain almost identical in different conditions and using a variety of methods. Splitting the radiator into many incremental areas (as opposed to using only a few areas or a rough manual sweep) did not provide any significant increase in accuracy. In fact, it was found that reliable results could be obtained using quite a fast hand-held sweep over the radiating surface with the intensity probe. It is also noted that the different means of averaging p_{rms} in order to calculate the incident intensity produced little change. This may simply indicate that the sound field in the Silsoe building is relatively diffuse and it should be noted that one would not normally expect this to be the case. However, the close similarity of the sound reduction spectra indicates that the intensity method can be used to accurately predict the actual value of level difference across a wall ($L_{in}-L_{out}$) by adding a factor of 4dB. (as in equation 13) above 60Hz. Below this frequency the intensity technique gives significantly lower values of S.R.I. This may be explained by the fact that energy is not simply radiated into the far-field, but circulates close to the panel. This will cause an energy-flow vector component opposite to that energy which does radiate into the far-field. Hence, cancellation occurs and will be especially apparent at large wavelengths.

A common factor in all of the measurements are the dips in sound reduction of about 6dB. and 4dB. in the 630Hz./800Hz. and 1600Hz. bands respectively. The cause of these is not yet known and all estimations of critical frequencies put them in between the two (the Heckl approximation described predicts f_{c1}=252Hz. and f_{c2}=27.1KHz.). As the dips occur constantly over all measurement techniques and situations, they are not thought to be a result of fixing methods or of the finite panel size. It is speculated that the dips are caused by the periodicity of the cladding (where the period is of a similar length to the wavelength of sound in air) producing an effect similar to wave coincidence. Another explanation may be that vibrational modes occur in any one of the profile dimensions. Both of these explanations are feasible given the panel dimensions in this study and previous reports which have noted this effect [11]. It should be noted that one dip is at about twice the frequency of the other, such that both dips are probably due to the same effect; e.g. a harmonic of one vibrational mode. Whatever the reason may be, it is obvious that the dips are detrimental to the performance of the cladding as they occur in the centre of the frequency range one must consider for industrial noise.

Values for sound reduction calculated from impulse response measurements did not show the same correlation as other techniques. The result of subtracting the outdoor transfer function from that measured inside the building is shown in figure 4. These results were found to be very inconsistent, even using a long maximum length sequence with many pre-averages and averages. In order to compare m.l.s. results with others, the high-frequency-resolution data is converted into 1:3 octave spectra. Figure 5 shows results from three similar measurements in different positions over the radiating area and a measurement using the maximum length of sequence and averages. It is clear that the values of S.R.I. are very much higher than in any other spectrum and that the error increases with frequency (to about +10dB. at 5KHz.).

Comparisons between predictions and measurements are shown in figure 6. Heckl's method predicts the critical frequencies to be at 252Hz. and 27.1KHz. As expected, the mass law overestimates the S.R.I., although it should only be used below the first

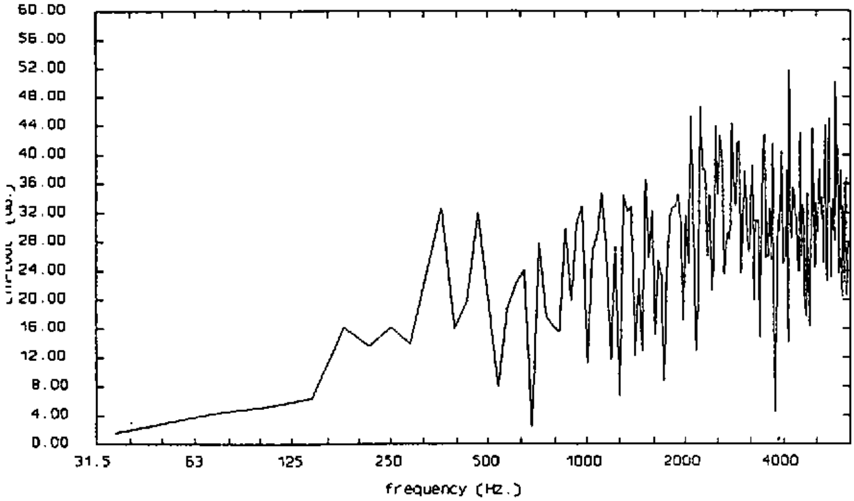

Figure 4 L_{in}-L_{out} using impulse response measurements

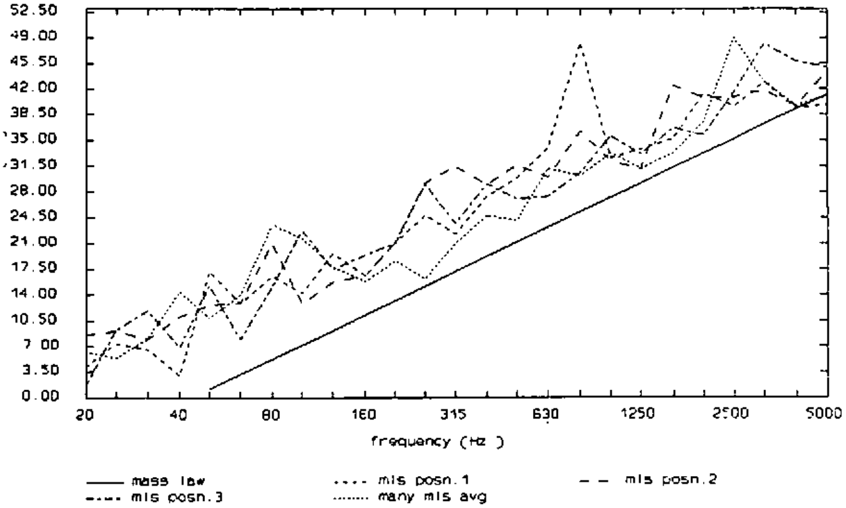

Figure 5 Comparison of impulse response SRI

critical frequency. Heckl's prediction can be shown to match very well with all of the intensity-measured sound reduction spectra over the whole of the frequency range considered : it is within 2 dB. of the spectrum shown, apart from the two dips described. One can assume, then, that this prediction method underestimates at low frequencies. Above 80Hz., Heckl is also consistently about 4dB. below L_{in}-L_{out}, the only deviations being the two dips.

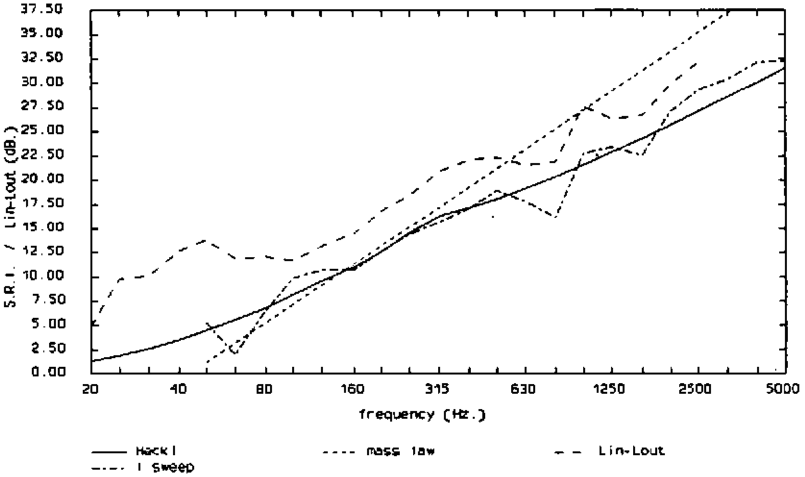

Figure 6 Comparison of predictions and measurements

5. CONCLUSION

The method of measuring the sound reduction index using intensity techniques has been shown to be consistent. It agrees well with the standard transmission suite method at mid-range frequencies and measurements are alike both in the laboratory and in situ. Further, the S.R.I. was seen to be about 4dB. below the sound level difference measured across the wall on-site, as predicted by Gösele and Lutz [4]. The impulse response method using pseudo-random noise was found to overestimate sound reduction. The approximation developed by Heckl [7] was shown to give a good idea of the trend in reduction, although significant dips were observed around 1KHz. which could not be predicted using any method dependant on the critical frequencies of the panel only.

6. ACKNOWLEDGEMENTS

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