Journal of Sound and Vibration (1999) **222**(1), 145–151
Article No. jsvi.1998.1624, available online at http://www.idealibrary.com on IDEAL

LETTERS TO THE EDITOR

AN EMPIRICAL SCHEME TO PREDICT THE SOUND TRANSMISSION LOSS OF SINGLE-THICKNESS PANELS

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(*Received* 12 *March* 1998)

1. INTRODUCTION

This technical note describes the evaluation and selection of equations used to predict the sound transmission loss (STL) of a single-layer panel. While one can measure the sound transmission loss of panels experimentally, it is time-consuming and expensive to prepare the samples and conduct the tests. Hence, one would like to calculate the STL of panels to minimize laboratory testing. While the transmission loss of single-layer windows was the primary objective of this study, the results are applicable to any single-layer panel.

2. EXPERIMENTAL APPARATUS

The predicted STL values were compared to experimental data. The sound transmission loss measurements in the experimental portion of this study were made on rectangular windows constructed of either glass or transparent polycarbonate, with the dimensions of 0·61 by 0·91 m. Several different thicknesses of each were tested. The sound transmission loss tests were conducted at ETL Testing Laboratories, Cortland, New York. The testing was in accordance with the standard procedure in ASTM E90-90 [1]. The glass samples were mounted in a wooden frame, and were held in place with "Duxseal," a dense, clay-like material. The sound transmission loss data were provided in 1/3-octave bands, with the centre-band frequencies ranging from 100 to 4000 Hz.

3. SOUND TRANSMISSION LOSS PREDICTION

3.1. *Mass law–Cremer model*

The goal of this study was to find simple, empirical expressions for sound transmission loss. At low frequencies, one can calculate the STL of a typical panel with the mass law, where the transmission loss of the panel depends only upon the frequency of the sound and the mass per unit area of the wall. There are several

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forms of the mass law, which give essentially equivalent results. One form of the field-incidence mass law is

$$TL(\mathrm{dB}) = 10\log_{10}\left\{1 + \left(\frac{\mu\pi f}{\rho_0 c_0}\right)^2\right\} - 5, \tag{1}$$

where TL is the transmission loss in 1/3-octave bands, f is the centre frequency of each band, μ is the mass per unit area of the panel, ρ_0 is the density of air, and c_0 is the speed of sound in air. The mass law is only valid below the coincidence frequency. Below the coincidence frequency, the transverse bending wavelength of the panel in question is smaller than the wavelength of an acoustic wave in air at the same frequency. At the coincidence frequency, the bending wave of the panel and the acoustic wave in air have equal lengths. Above the coincidence frequency, the bending wave is longer than the acoustic wavelength. One can calculate the coincidence frequency for a single-layer panel:

$$f_c = \frac{c_0^2}{2\pi}\sqrt{\frac{12\mu(1-\nu^2)}{Eh^3}}, \tag{2}$$

where ν is the Poisson ratio, E is Young's modulus, and h is the panel thickness. Using the material properties for glass, the coincidence frequency is approximately

$$f_{c,glass} = \frac{12350}{h}\ \mathrm{Hz}, \tag{3}$$

where h is the thickness in millimetres. For example, the coincidence frequency of 4·9-mm thick glass is 2520 Hz.

Since the mass law is only valid below the coincidence frequency, one needs another expression to compute the STL at higher frequencies. Cremer [2] derived the following expression for the transmission loss of panels above coincidence:

$$TL(\mathrm{dB}) = 20\log_{10}\left(\frac{\mu\pi f}{\rho_0 c_0}\right) + 10\log_{10}\left(\frac{2\eta f}{f_c}\right) - 5, \tag{4}$$

where η is the damping loss factor of the panel. One might prefer to use measured values for the loss factor. This study used a value of $\eta = 0{\cdot}025$ throughout, which represented an average value based upon previous measurements [3].

Hence, one can construct an STL model using Cremer's equation above coincidence and the mass law below. Figure 1 shows the experimental results for the STL of 4·9-mm thick glass compared to the mass law/Cremer prediction. The agreement of this model with experimental results is poor, especially at frequencies near coincidence.

3.2. *Mass law–Sharp–Cremer model*

The disparity between the mass law/Cremer prediction and experiment at frequencies near coincidence—the so-called "coincidence dip"—is well known, and others have tried to correct for this. Sharp proposed a successful, empirical

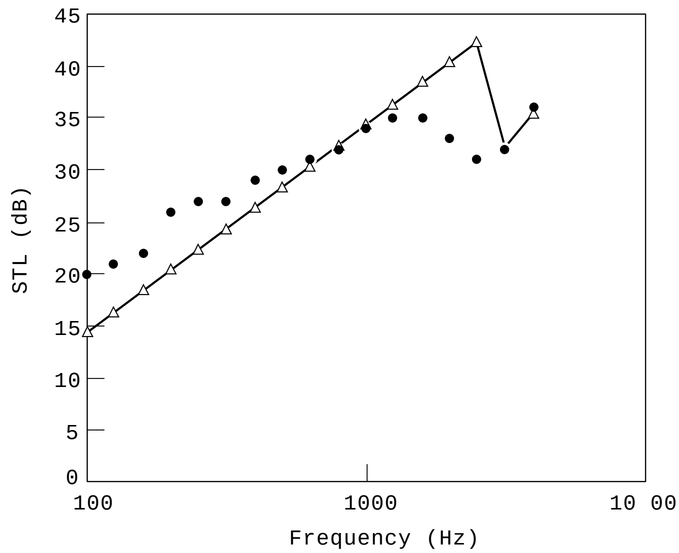

Figure 1. A comparison of the sound transmission loss predicted using the mass law–Cremer scheme and the experimental results for 4·9-mm thick glass: △, predicted; ●, experimental.

method [4]. Since the mass law predicts the STL at frequencies greater than one-half the coincidence frequency so poorly, Sharp suggested using a linear interpolation scheme between the mass law STL at one-half of the coincidence frequency and the STL found with Cremer's expression at the coincidence frequency. This correction worked well (see Figure 2), reducing the disparity between predication and experiment in the range from $f_c/2$ to f_c.

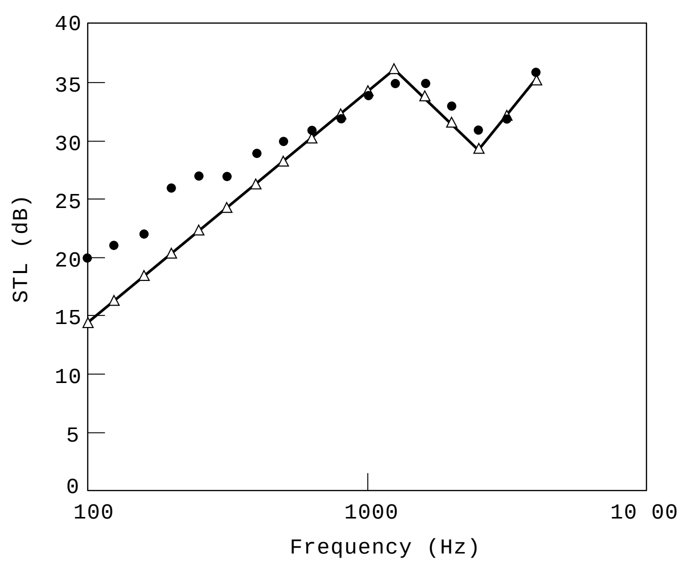

Figure 2. A comparison of the sound transmission loss predicted using the mass law–Sharp–Cremer scheme and the experimental results for 4·9-mm thick glass: △, predicted; ●, experimental.

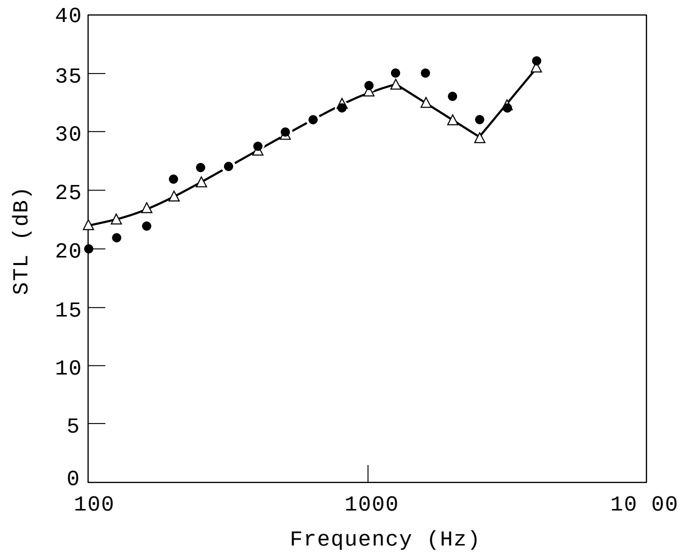

Figure 3. A comparison of the sound transmission loss predicted using the SSC scheme and the experimental results for 4·9-mm thick glass: △, predicted; ●, experimental.

3.3. *Sewell–Sharp–Cremer model*

There is still the problem of the under-prediction of the transmission loss at low frequencies. Some improvement over the mass law would be helpful. Sewell [5] derived the following expression based upon theoretical considerations of the forced transmission of sound through a partition:

$$TL(\mathrm{dB}) = -10\log_{10}\left\{\frac{\ln(k\sqrt{A}) + 0{\cdot}16 - U(\Lambda) + \dfrac{1}{4\pi A k_0^2}}{\left[\left(\dfrac{\mu\pi f}{\rho_0 c_0}\right)\left(1 - \dfrac{f^2}{f_c^2}\right)\right]^2}\right\}, \qquad (5)$$

where k_0 is the acoustic wavenumber, A is the area of the plate, Λ is the ratio of the lengths of the sides of the plate, and $U(\Lambda)$ is a shape factor correction for non-square plates. A useful empirical expression for $U(\Lambda)$ adapted from Sewell is

$$U(\Lambda) = -0{\cdot}0000311\Lambda^5 + 0{\cdot}000941\Lambda^4 - 0{\cdot}0107\Lambda^3 + 0{\cdot}0526\Lambda^2 - 0{\cdot}0407\Lambda - 0{\cdot}00534. \qquad (6)$$

Sewell's expression, equation (5), led to better agreement with experimental data at low frequencies than the mass law. This expression is for forced transmission, and strictly speaking one should add the contribution from resonant transmission. However, the resonant component is several dB lower than the forced component, and will not affect the calculated transmission loss significantly.

To summarize, the best agreement with experimental data was obtained with the following equations: below $f_c/2$—equation (5), from Sewell; from $f_c/2$ to

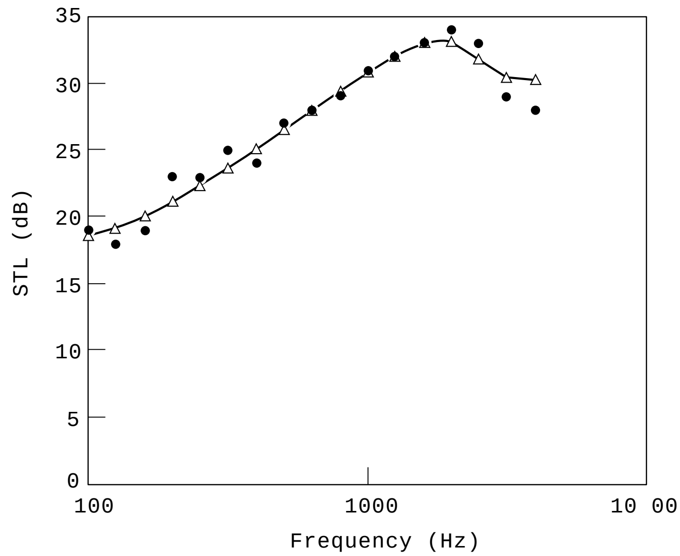

Figure 4. A comparison of the sound transmission loss predicted using the SSC scheme and the experimental results for 3·3-mm thick glass: △, predicted; ●, experimental.

f_c—Sharp's linear interpolation scheme; above f_c—equation (4), from Cremer. Due to the sources of these expressions, this report will refer to the prediction scheme combining the three equations as the Sewell–Sharp–Cremer or SSC model.

4. COMPARISON OF SSC MODEL AND EXPERIMENTAL RESULTS

The predicted STL using the SSC scheme was compared to experimental values obtained at ETL Laboratories for 4·9-mm thick glass (Figure 3). The predicted

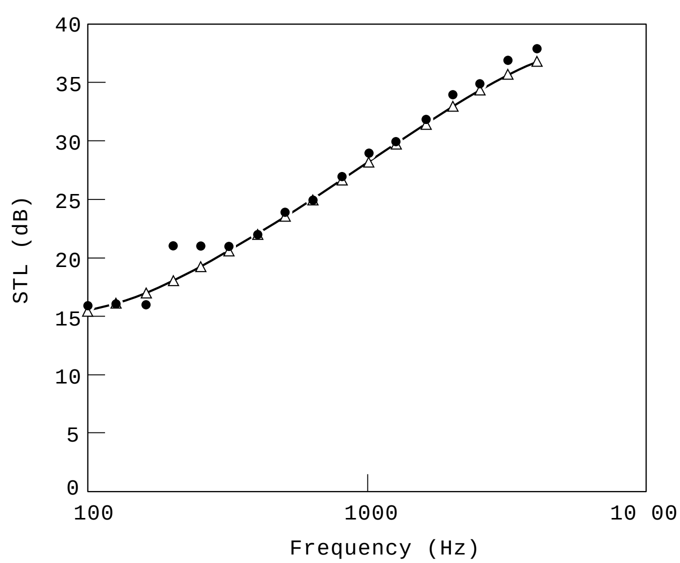

Figure 5. A comparison of the sound transmission loss predicted using the SSC scheme and the experimental results for 4·8-mm thick polycarbonate: △, predicted; ●, experimental.

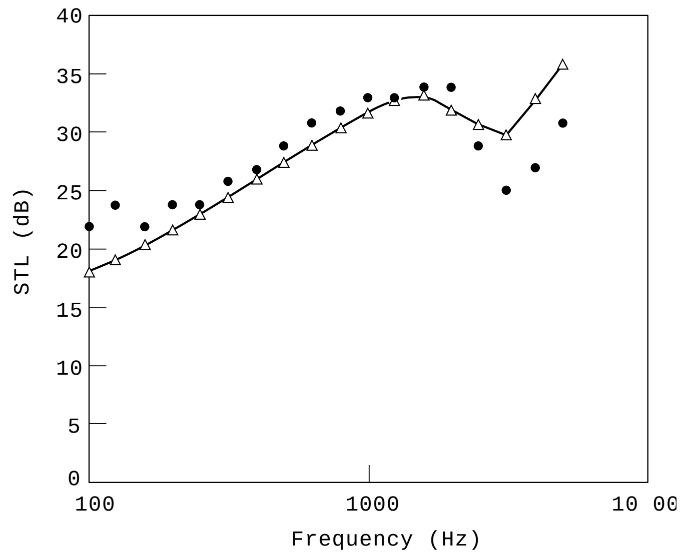

Figure 6. A comparison of the sound transmission loss predicted using the SSC scheme and Quirt's experimental results for 4·0-mm thick glass: △, predicted; ●, experimental.

STL agreed with the experimental results within 2·5 dB. Next, the SSC prediction scheme was applied to 3·3-mm thick glass. The agreement was again quite good, with a maximum disparity of 2·3 dB (see Figure 4). To see how the SSC scheme worked for materials other than glass, the calculated STL of a 4·8-mm thick polycarbonate window was compared to experiment. The prediction matched the experimental results quite well over the entire frequency range, with a maximum disparity of 3 dB (see Figure 5).

Next, the SSC scheme was compared with experimental data obtained under different conditions. Quirt [6] gave results for STL measurements made on $0{\cdot}56 \times 1{\cdot}68$ m windows. The agreement between the SSC prediction scheme and this experimental data was not as good, with a disparity of approximately 5 dB at frequencies above coincidence, using a loss factor of $\eta = 0{\cdot}025$ (see Figure 6). The agreement between prediction and experiment improved considerably when actual measured damping values were used. However, this defeats the purpose of the prediction scheme, as one has merely substituted the rather involved and difficult measurement of the damping value of a panel for the measurement of the STL itself.

The inherent weakness of any STL prediction scheme is that the damping value affects the calculated STL above coincidence to a great degree. However, one can still get acceptable results with reasonable estimates for the damping values of single layer panels, which are largely dependent upon the edge conditions. Conversely, for laminated panels, the majority of the damping occurs in the middle laminated ply of the window itself, and one can calculate the approximate damping level of the laminated assembly, circumventing the problem. However, this procedure is rather involved [7], and will not be described here.

5. SUMMARY

A combination of the STL prediction methods presented by Sewell, Sharp and Cremer was found to agree well with experimental data. This procedure is simple and easy to use, and is a useful tool for automobile window engineers and others interested in the prediction of the sound transmission loss of barriers and partitions.

ACKNOWLEDGMENTS

This work was sponsored by PPG Industries. The authors would like to thank Vern Benson of PPG Industries for preparing the test samples.

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