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COMPARASION OF SOUND INSULATION PREDICTION METHODS OF LIGHTWEIQHT PARTITIONS

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Abstract

It is important to know the sound insulation of partitions in order to be able to compare different constructions, calculate acoustic privacy between apartments or noise levels from outdoor sources such as road traffic, and engineer optimum solutions to noise control problems. There are various methods for predicting the sound insulation of partitions that can be used by noise control engineers. This paper presents a comparison of experimental measurements of the sound insulation of lightweight partitions with theoretical models. Single homogenous panels are examined first, with mass, stiffness, damping and panel size found to be adequate to describe most common building constructions. Double panel walls are the examined, with additional factors of airgap between the panels, connections between the panels and acoustic absorption in the cavity.

INTRODUCTION

In many situations it may not be feasible to modify the characteristics of the noise sources. In these cases, a possible solution to a noise problem it to modify the acoustic transmission path or the paths between the noise source and the receiver. In such a situation the first task for the noise-control purposes is to determine the relevance quantities. The quantities that define the acoustical quality of constructions in buildings are airborne and impact sound insulation between rooms, airborne sound insulation of facades, reverberation time of rooms and noise level caused by noise source.

Airborne sound insulation is the most important physical quantity defining the acoustical quality of buildings. Depending on the activities in the rooms, it may be necessary to place sound insulation requirements to the party walls, either to isolate the room from the neighboring noisy spaces or vice versa.

The use of lightweight partitions as party walls between dwellings has become common because sound insulation requirements can be achieved with low overall surface weights. These partitions can be built by using a single frame partition assembly or, when high sound insulation is required, by using a double frame partition assembly. Choosing a suitable combination of gypsum board layers, air cavity and sound absorbing material thickness, double frame partitions with a wide variety of high weighted sound reduction indices can be achieved.

Laboratory measurements can be made for many different types of partitions, but it is impractical to test every possible design and so it is necessary to have reliable methods for predicting the sound transmission loss of typical building constructions.

In this paper, a general overview of the prediction models of sound insulation will be presented. Also, this paper presents a comparison of experimental measurements of the sound insulation of lightweight partitions with theoretical models.

PARTITION SOUND TRANSMISSION LOSS

When sound is incident upon a wall or partition some of it will be reflected and some will be transmitted through the wall. The fraction of incident energy which is transmitted is called the transmission coefficient τ. As values of the transmission coefficient are mainly small the logarithmic index of sound transmission, the transmission loss (sometimes referred as sound reduction index *R*), is used to quantity transmitted energy. The transmission loss is defined in terms of the transmission coefficient as [1]:

$$TL = -10\log\tau, \; TL[\text{dB}] \tag{1}$$

The transmission coefficient and thus the sound reduction index depend upon the angle of sound incidence and therefore the following terms have been commonly used: normal incidence, diffuse field incidence and field incidence sound reduction index. Field incidence sound reduction index is commonly observed in measurement and prediction methods.

Single panels

Single panels can be divided into four main types: thin panels, corrugated (profiled) panels, stiffened (ribbed) panels and thick monolithic walls. The main physical factors controlling the sound transmission through impervious single panels are [2]:

- surface mass, which is mainly responsible for the forced vibration,
- bending stiffness, which together with surface mass determines the critical frequency of the panel,
- dimensions, which together with bending stiffness and surface mass determine the lowest natural resonances (normal modes) of the panel,
- loss factor, which determines the amplitude of resonant vibration, and
- sound incidence angle.

An illustration of typical transmission loss curve of single panel is shown in

Figure 1, in which various characteristic frequency ranges are indicated. At the low frequency, the transmission loss is controlled by the stiffness of the panel. At the frequency of the first panel resonance, the sound transmission is high and transmission loss curve has a minimum determined in part by the damping of the panel. The resonance frequencies of a simply supported rectangular isotropic panel of width *a*, length *b*, and bending stiffness *B* per unit width may be calculated using the following equation [3]:

$$f_{i,n} = \frac{\pi}{2}\sqrt{\frac{B}{m}}\left[\frac{i^2}{a^2} + \frac{n^2}{b^2}\right], \quad i,n = 1,2,3\ldots \quad f_{i,n}[\mathrm{Hz}] \tag{2}$$

At the frequency above the first panel resonance, in the broad frequency range, transmission loss is controlled by the surface density of the panel *m*. In this mass law range the transmission loss increases with the frequency at the rate of 6dB per octave. In the region of the critical frequency the wavelength of sound in air and the bending wave coincide and the transmission loss collapses. Critical frequency is the lowest coincidence frequency of a single panel and may be calculated using the following equation [4]:

$$f_c = \frac{c^2}{1.81h}\sqrt{\frac{\rho(1-\nu^2)}{E}}, \quad f_c[\mathrm{Hz}] \tag{3}$$

where h is the panel thickness, ρ is the material density, E is Young's modulus and ν is Poisson's ratio.

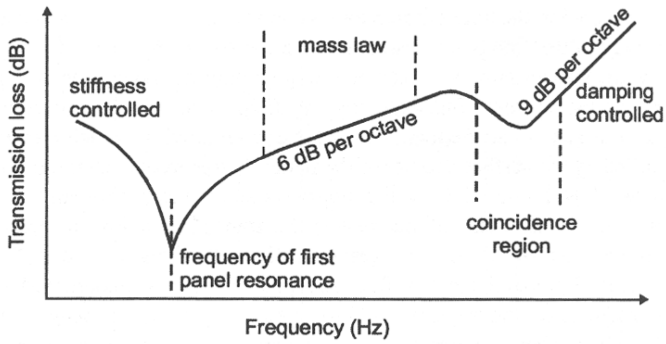


Figure 1 – Typical single panel transmission loss as a function of frequency [3]

At and above the critical frequency, resonant vibration determines the sound transmission coefficient. This is called the stiffness-controlled region where the slope of the transmission loss curve is 9 dB per octave. The transmission loss rises and gradually approaches an extension of the original mass law portion of the curve.

Double panels

Theoretical and experimental analysis of sound transmission through single panels show that the transmission loss increases by 5-6dB per doubling of mass. High transmission loss can be provided by double panels composed of two separate panels separated by airspace. Sound absorbing material can be placed in the airspace of double panels and their principal function is to suppress acoustic resonances of the airspace [1].

There are two major paths by which sound energy is transmitted through a double panel: the first involves radiation from the first panel into the airspace, where it excites the second panel; the second involves structure borne transmission of vibrational energy from the first panel to the second panel through mechanical links between the panels [5].

Sound transmission through double panels is more complex because a mass-air-mass resonance [1],

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c^2}{d}\left(\frac{1}{m_1}+\frac{1}{m_2}\right)},\ f_0[\mathrm{Hz}], \tag{4}$$

and cavity resonances [4],

$$f_k = k\frac{c}{2d},\ f_k[\mathrm{Hz}], \tag{5}$$

which can seriously affect the transmission loss of the double panels (d is the distance between the inner surfaces of double panels). In practice, it is necessary to introduce an empirical factor 1.8 into equation (4) to give better agreement with existing data for ordinary wall construction [3].

An illustration of typical transmission loss curve of double panels is shown in Figure 2, in which various characteristic frequency ranges are indicated.

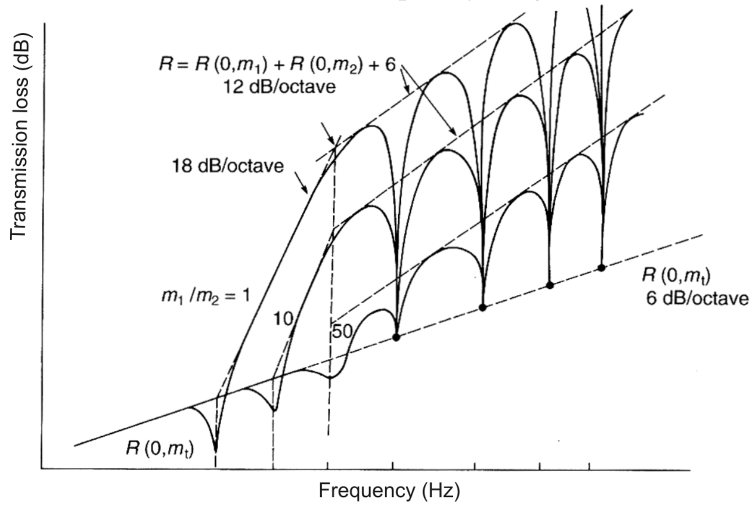


Figure 2 – Typical double panel transmission loss as a function of frequency [1]

At low frequencies, the double panels can be seen as two masses (m_1, m_2) acting together as a single panel, in which the air chamber has a negligible effect, and this element behaves like a single element with the same total mass $m_t = m_1 + m_2$. In the region of the mass-air-mass resonance the sound transmission is damping controlled and the transmission loss collapses.

If the frequency of the sound incident on a double panel is higher than the resonance frequency, the air chamber absorbs part of the sound energy, resulting in greater acoustic insulation than is observed in a single element with the same mass. The transmission loss therefore raises 18dB/octave from the value it would have at the resonance frequency.

At the high frequencies successive reflections may occur inside the air chamber, generating stationary waves. This phenomenon occurs when the thickness of the air chamber is a multiple of half the wavelength. The variation of transmission loss with frequency is complicated; it varies between maxima, which correspond to acoustic anti-resonance of the cavity, and minima at acoustic cavity resonances (5). The transmission loss raises 12dB/octave from the value it would have at the lowest order acoustic resonance frequency related to the gap between the panels [3].

PREDICTION METHODS

Single panels

The prediction scheme used by the most authors is shown in Figure 3. For simple panels the most important property is the mass per unit area of the panel, and the well-known mass law gives a very simple prediction of the transmission loss below $f_c/2$. However, for most practical building materials the static stiffness must be sufficiently high that coincidence between airborne and structure borne waves will occur about the critical frequency.

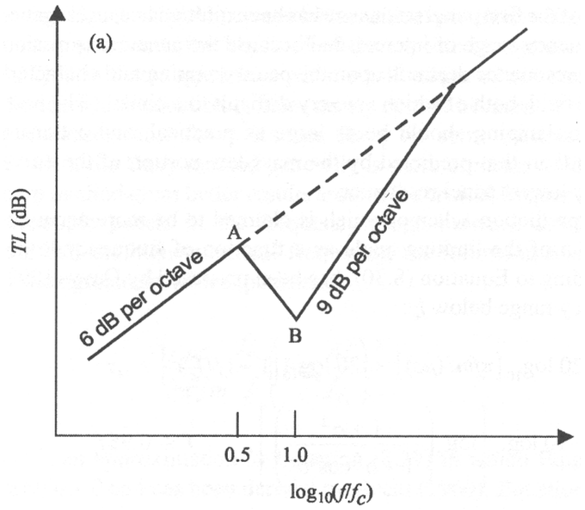


Figure 3 – Prediction scheme for estimating the transmission loss [1]

The prediction scheme shown in Figure 3 can be summarized by the following equation [1,6]:

$$TL = \begin{cases} 20\log\dfrac{\pi f m}{\rho c} - 5.5 & f \le f_c/2 \\ 20\log\dfrac{\pi f m}{\rho c} + 10\log\dfrac{2\eta f}{\pi f_c} & f \ge f_c \end{cases}. \qquad (6)$$

The transmission loss between $f_c/2$ and f_c can be approximated by connecting with a straight line the points corresponding to $f_c/2$ and f_c.

For the lightweight panels the prediction scheme is slightly different [7]:

$$TL = \begin{cases} 15\,\mathbf{log}\dfrac{\pi f m}{\rho c} - 5.5 & f < f_c/2 \\ 15\,\mathbf{log}\dfrac{\pi f m}{\rho c} + 10\,\mathbf{log}\dfrac{2\eta f}{\pi f_c} & f > f_c \end{cases}. \tag{7}$$

The transmission loss for the critical frequency has value:

$$TL_{\mathrm{B}} = 15\,\mathbf{log}\, m f_c + 10\,\mathbf{log}\,\eta - 42.5\,, \tag{8}$$

and for $f_c/2$:

$$TL_{\mathrm{A}} = TL_B - 3\,\mathbf{log}\,\eta\,. \tag{9}$$

Double panels

The prediction scheme used by the most authors is shown in Figure 4. Predicting the transmission of double panels is often very complex. The simplest case to analyze is a partition consisting of two thin single panels, separated by an airgap containing an acoustically absorbing blanket, and with no interconnections between the two panels. The expected transmission loss is given by the following equations [6]:

$$TL = \begin{cases} 20\,\mathbf{log}[f(m_1 + m_2) - 47 & f \le f_0 \\ TL_1 + TL_2 + 20\,\mathbf{log}\, fd - 29 & f_0 < f < f_1 \\ TL_1 + TL_2 + 6 & f \ge f_1 \end{cases}. \tag{10}$$

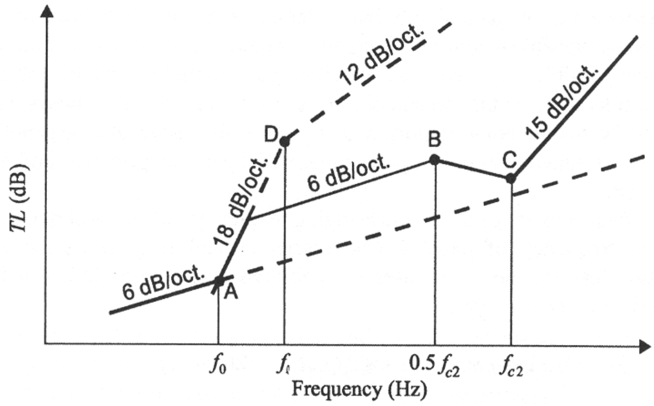


Figure 4 – Prediction scheme for estimating the transmission loss [1]

The equation (10) is shown in Figure 4 by dash line. These expressions do not contain any parameters to describe the variation in transmission loss due to different acoustic absorbers in the airspace. Some authors [6] give an alternative equation for high frequency transmission loss that includes effect of acoustic absorbers:

$$TL = TL_1 + TL_2 + 8.6\alpha d + 20\,\mathbf{log}\,\beta / k\,, \tag{8}$$

where α and β the real and imaginary parts of the propagation coefficient of the absorbers.

The transmission loss predicted by equation (10) is difficult to realize in practice. The effect of connecting the panels to supporting studs at points or along lines is to provide mechanical bridge for the sound transmission. While some constructions can approach the ideal of double panels without interconnections, in practice most construction will have some type of solid or resilient connection between the panels. Relatively simple expressions for the transmission loss of double panels with either point or line interconnections has developed [1]. In the frequency range above the bridging frequency and below about one-half of the higher critical frequency, the transmission loss is as follows solid line in Figure 4 and following equations:

line-line support $$TL = 20\mathbf{log}\, m_1 f + 10\mathbf{log}\, f_{c2} b + 20\mathbf{log}\left(1 + \frac{m_2\sqrt{f_{c1}}}{m_1\sqrt{f_{c2}}}\right) - 72\,, \qquad (9)$$

point-point support $$TL = 20\mathbf{log}\, m_1 f + 20\mathbf{log}\, f_{c2} e + 20\mathbf{log}\left(1 + \frac{m_2 f_{c1}}{m_1 f_{c2}}\right) - 99\,, \qquad (10)$$

line-point support $$TL = 20\mathbf{log}\, m_1 f + 20\mathbf{log}\, f_{c2} e - 93\,. \qquad (11)$$

The slightly different equations also can be used [6]:

line-line support $$TL = TL_1 + TL_2 + 10\mathbf{log}\, f_{c2} b + 20\mathbf{log}\frac{m_1}{m_1 + m_2} - 18\,, \qquad (12)$$

point-point support $$TL = TL_1 + TL_2 + 20\mathbf{log}\, f_{c2} b + 20\mathbf{log}\frac{m_1}{m_1 + m_2} - 45\,. \qquad (13)$$

where b and e are the spacing between line and point connections.

For the lightweight panels the prediction scheme is slightly different [8]:

$$TL = 15\mathbf{log}\left(10^{0.1TL_1} + 10^{0.1TL_2}\right) + 10\mathbf{log}\frac{1}{10^{-0.1\Delta TL_I} + 10^{-0.1\Delta TL_{II}}}\,, \qquad (14)$$

where ΔTL_I and ΔTL_{II} are the transmission loss improvements achieved by the sound transmission paths:

$$\Delta TL_I = 20\mathbf{log}\left(\frac{f^2}{f_0^2} - 1\right),\ \Delta TL_{II} = 20\mathbf{log}\frac{v_1}{v_2} + 10\mathbf{log}\frac{1}{\sigma}\,. \qquad (15, 16)$$

In equation (16), σ is radiation factor and v_1 and v_2 are the vibration velocity of the panels in partition.

COMPARASION RESULTS

A comparison of theoretical and experimental results is made for single panel consisting 12.5 mm thick gypsum board, mass per unit area of the gypsum board of 10.8 kg/m^2. The comparasion results are shown in Figure 5.

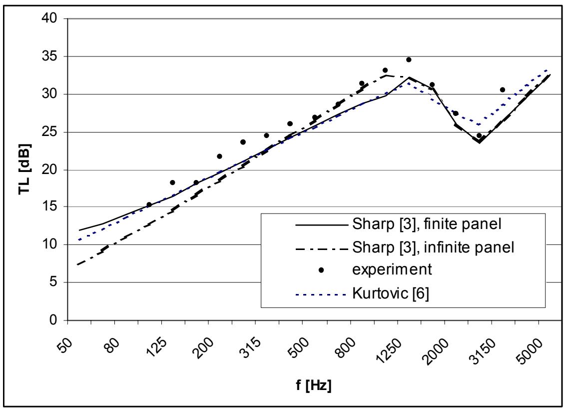
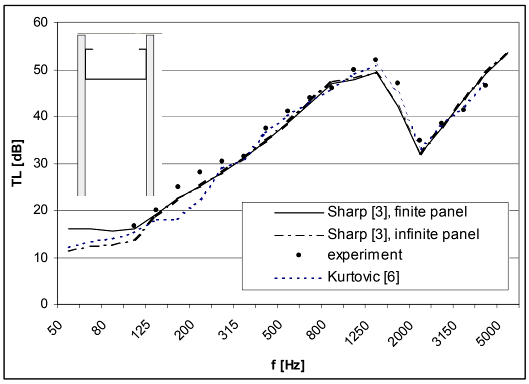


Figure 5 – Comparasion for single panel

A comparison of theoretical and experimental results is also made for double panel consisting two panels of 12.5 mm thick gypsum board, with the line conection between them. The construction of double panel with and with no acoustical blanket between panels has been examined. The comparasion results are demonstrated in Figure 6.



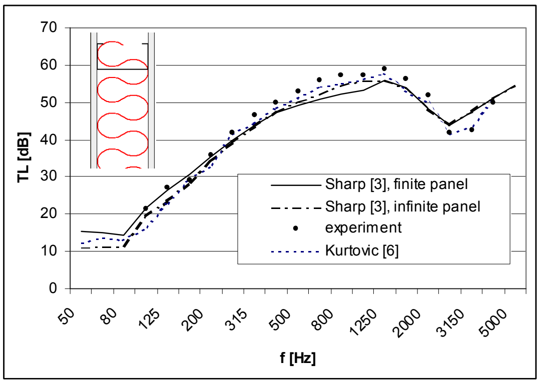


Figure 6 – Comparasion for double panel

CONCLUSIONS

The experimental result show that the predictive theoretical models described in this paper are close to the experimental results for examined simple and double panels. It can be seen that the agreement between theory and measurement is excellent for most engineering purposes. However if the effect of the radiation efficiency of a finite panel is not taken into account then the agreement at low frequencies is not so good.

The sound insulation of typical lightweight building constructions can be predicted with acceptable engineering accuracy over the frequency range 50-5,000 Hz using simple and readily available expressions given in this paper.

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