Bergen, Norway

BNAM 2010

May 10-12

Predicting the sound insulation of building elements – A model based on a transfer matrix scheme with some add-ons.

T. E. Vigran

NTNU–Acoustics Group, Dept.of Electronics and Telecommunications, O.S. Bragstads pl. 2, NO-7491 Trondheim, Norway, **vigran@iet.ntnu.no**

A large number of prediction models for the sound insulation of building elements, massive as well as multilayered types exist in the literature of which many are applicable for special constructions only. The transfer matrix technique is an efficient tool for calculating sound transmission through multilayered structures and recent windowing technique, accounting for finite size specimens, has greatly improved the fit to measurement data. Another improvement is presented in this paper allowing for the calculation of the effect of structural connections, e.g. studs, in double-leaf partitions, where the flexibility of the studs is a parameter. A number of comparisons with measured results will be presented, among them data for lightweight double plasterboard walls. Cases include walls with cavity filling as well with empty (air-filled) cavities.

1 Introduction

For predicting the diffuse field sound transmission through a single plane homogeneous structure, such as a partition between rooms, a number of formulas may be found in the literature, see e.g. reference [1]. Tools for predicting the sound transmission loss, specified by the sound reduction index, of multilayered structures are normally found only for special cases, but in the later years a number of efforts have been directed towards prediction methods for double-leaf partitions, especially to account for the effect of structural connections between the leaves.

Hongisto [2] implemented all together seventeen of existing models making a quantitative comparison between models against measurement results taken from a large series of laboratory measurements; see Hongisto et al. [3].

More recently, Legault and Atalla [4] have, using a special double wall system consisting of two aluminium plates with a cavity filled with a fibrous material, compared altogether five models including their own periodic model. Predictions are compared with measurements results on two cases; with C-sections channels connecting the aluminium plates as well as without these connections. Davy's model [5], one of the better ones in Hongisto's [2] comparisons, gives quite good agreement but cannot predict the finer details in the measured reduction index as the periodic model. The model of Davy has, however recently been improved on; see Ref. [6]

The role of studs in the sound transmission has recently been given broad coverage by Poblet-Puig et al. [7], outlining procedures to obtain more accurate parameters to be used in prediction models. By numerical modelling, metal studs of altogether six different cross sections were tested in three types of lightweight double walls and they present data for the frequency-dependant translational stiffness of these different types of studs. In this paper we shall use these stiffness data to predict the sound reduction index of double walls with flexible studs modifying the method given by Vigran [8] to account for the finite stiffness of the studs. For completeness, some important aspects of the method are repeated here.

For comparison with measurement we shall use data for double-leaf gypsum plasterboard walls in the cases where the flexibility data from Ref. [7] seems appropriate; i.e. when the dimensions of the studs are comparable. However, the special construction used by Legault and Atalla [4] will also be modelled using the present approach.

2 Theory

Following Sharp [9], the diffuse field sound reduction index R of a double-leaf partition with sound bridges (see Fig. 1a), may be expressed as

$$R = R_P - \Delta R = R_P - 10\lg\left[1 + \frac{W_{2,B}}{W_{2,P}}\right], \tag{1}$$

where R_P is the sound reduction index of the double-leaf partition without the bridges and ΔR is the correction term due to the bridges. The power radiated from plate 2 is divided into two parts, $W_{2,P}$ and $W_{2,B}$, the power radiated without the bridges and the power radiated due to the action of the bridges, respectively. It may be shown that the power ratio in the correction term may be expressed as

$$\frac{W_{2,B}}{W_{2,P}} = n\,\sigma_B \cdot \left|\frac{v_B}{v_1}\right|^2 \cdot \left\langle \left|\frac{v_1}{v_2}\right|^2 \right\rangle = n\,\sigma_B \cdot \left|\frac{Z_{B1}}{Z_{B1} + Z_{B2}}\right|^2 \cdot \left\langle \left|\frac{v_1}{v_2}\right|^2 \right\rangle, \tag{2}$$

where σ_B is the radiation factor of the second plate driven by one of a number n bridges acting over the partition area S. The second term contains the input impedances of the plates seen from the sound bridge. Expressions for the radiation factor, both for line- and point-driven plates are given in Ref. [8] and not repeated here.

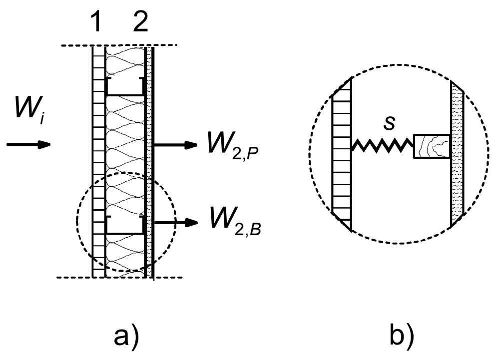

Fig.1 a) Sketch of a double wall with studs (TC-type steel studs), b) Representation of a flexible stud (expanded and redrawn detail indicted in 1a)).

The last term in Eq. (2) is the squared ratio of the velocities of plate 1 and plate 2 in the absence of the bridges assuming diffuse sound incidence, the latter indicated by the outer brackets $\langle\ \rangle$. Sharp [9] gives an approximate expression for this ratio but in the framework of transfer matrices there is no need to do so. For a given angle of incidence we may express this ratio in terms of the resulting transfer matrix comprising the construction without the bridges, i.e. two plates with a cavity partly or wholly filled with a porous layer. Using a thin plate model and representing any porous material as an equivalent fluid we get a 2x2 matrix with components A_{11}, A_{12}, A_{21} and A_{22}, see e.g. reference [2, 10]. Denoting the squared velocity ratio at a given angle of incidence by r_θ, we get

$$r_\theta = \left|\frac{v_1}{v_2}\right|^2 = \left|A_{21} \cdot Z_{\mathrm{L}} + A_{22}\right|^2, \tag{3}$$

where Z_{L} represents the fluid loading impedance of the surrounding medium (air). Averaging this expression over the incidence angle θ, will give us the last term in Eq. (2).

Sharp [9] assumed that the bridges were massless and infinitely stiff, which implies e.g. that the studs shown in Fig. 1a should be represented by massive wooden studs and not by the ones illustrated, which is a common shape of metal studs, denoted TC in Ref. [7]. To allow for flexible studs, we may as a thought experiment illustrated in Fig. 1b, simply insert a spring of mechanical impedance Z_{s} between the stud and plate 1. This will modify the ratio between the velocity v_{B} of the bridge and the velocity v_1 of plate 1, which is represented by the second term in Eq. (2). Introducing the spring of impedance Z_{s} we get a parallel combination with the impedance Z_{B1} of the input plate resulting in

$$\left|\frac{v_{\mathrm{B}}}{v_1}\right| = \left|\frac{Z_{B1}}{Z_{B1}+Z_{B2}\left(1+\dfrac{Z_{B1}}{Z_{\mathrm{s}}}\right)}\right| = \left|\frac{Z_{B1}}{Z_{B1}+Z_{B2}\left(1-\mathrm{i}\,\omega\dfrac{Z_{B1}}{s(\omega)}\right)}\right|, \tag{4}$$

where we have represented the impedance of the spring by a frequency dependant translational stiffness s. As in Ref. [8] a time dependence exp(-iωt) is used.

3 Measured and predicted results

An extensive series of measured results on gypsum board walls is made available by the National Research Council of Canada, see Ref. [11]. Measurements comprise walls with wood studs and steel studs, staggered as well as directly coupling the boards. As for the steel studs, they appear to be of the type TC, mentioned above. Unfortunately, some material data is missing such as the elastic modulus of the boards used but this may be estimated from the surface weight and the coincidence frequency apparent from the measured data.

We shall use the measurement results for several of the walls with steel studs to compare with results using the prediction model outlined above. This necessitates an estimate of the translational stiffness s given in Eq. (4). As mentioned in the introduction we shall use the data given by Poblet-Puig et al. [7] to arrive at an estimate that may be used in our model. It should also be mentioned that data from Ref. [11] is also used by Davy [6] to compare with his model giving reasonably good agreement.

3.1 Stiffness of metal studs

From the calculated vibration level difference of the outer leaves of three different double walls, Poblet-Puig et al. [7] derived the translational frequency dependant stiffness of altogether 5 different types of studs. The material thickness of all studs was 0.47 mm, with a largest cross dimension of 70 mm defining the cavity depth of the tested walls. We have used these data to obtain an approximate expression for the translational stiffness of the TC-type. To do so, we have plotted the data taking the logarithm of both the frequency and the stiffness, the result of which is shown in Fig. 2. Also shown by the dashed curve is a third degree polynomial approximation to this curve, which we shall use in the comparisons below.

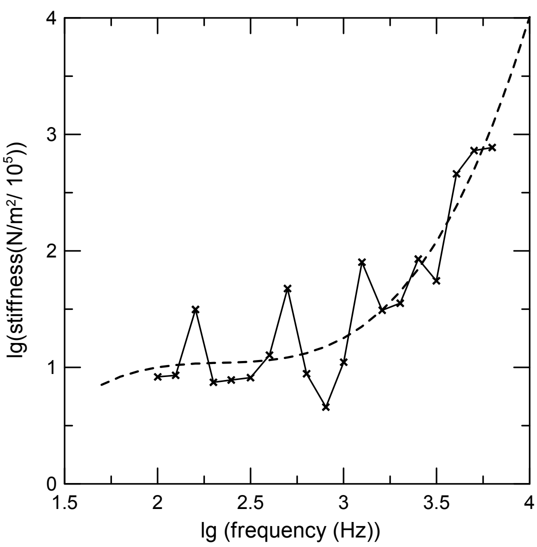

Fig. 2 The translational stiffness of the steel stud type TC represented by the logarithm of the stiffness. Dashed curve – the stiffness represented by a third-degree polynomial.

3.2 Cavity damping

Representing a porous material in the cavity between the leaves, we shall use an equivalent fluid model. As long as the stiffness of the material may be neglected and when the material is not glued to the leaves, the type of model used seems not to be very important. The problem arises when the cavity is empty, i.e. air-filled. There certainly will be energy losses in the cavity and how shall these be represented? A number of suggestions may be found in the literature such as using a fixed absorption coefficient for the cavity (Davy [6]), applying a loss factor η of 10^{-3} (Brunskog [12]) or a frequency independent power attenuation coefficient of ≈ 0.2 m^{-1} (Vigran [13]). The latter was found expedient when applied to narrow air-filled cavities in double glazing's but may not be suitable for cavities being 5–15 times wider. Also, it certainly should be expected that that the absorption in the cavity should, at least slightly, increase with frequency. We have found that representing the air cavity by a porous material having a flow resistivity in the range 10–100 Pa·s/m^2, is suitable for the lightweight double walls used here. The effective power attenuation coefficient, using the relaxational model by Wilson [14] as well as the model by Delany and Bazley [15], given as a function of frequency with the flow resistivity as the parameter, will be presented.

3.3 Walls with metal studs

As mentioned above, measured data used here are taken from the report given in Ref. [11], comprising measurement on double leaf gypsum walls with steel studs of type denoted here as TC-type, the gypsum boards being nominally of thickness 13 and 16 mm, respectively. The measured dimensions of the steel studs, used in the examples here were 32 mm x 65 mm, 30 mm x 91 mm and 30 mm x 150 mm, respectively. All studs had a material thickness of 0.53 mm, i.e. slightly thicker than the ones used in Ref. [7]. The wall test opening measured 3.05 m x 2.44 m, i.e. an area $\approx$ 7.5 m^2.

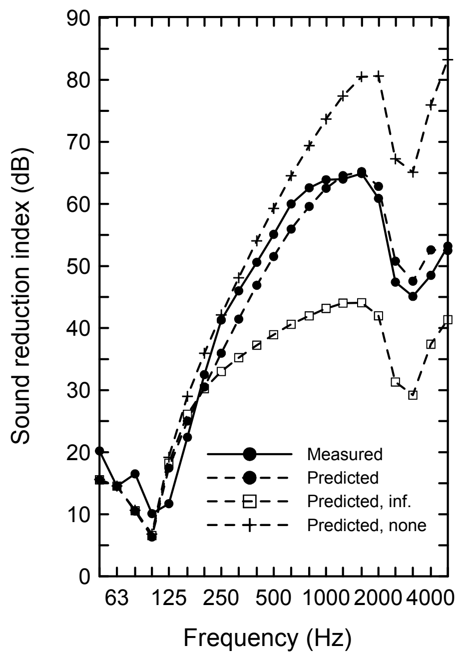

Fig. 3 Sound reduction index of double wall TL-93-064, measured and predicted results. Simulated results are shown for the cases where the studs are of infinite stiffness as well as the same wall without studs.

The first example, shown in Fig. 3, concerns a wall with 13 mm boards with cavity depth of 65 mm, the cavity filled with mineral wool of resistivity 11.4 kPa·s/m^2. As the studs in this case have approximately the same dimensions as the ones with data given by Fig. 2, these data is directly applied when predicting the result of TL 93-064. As seen, the fit between measured and predicted results is reasonably good. To illustrate the effect of the studs the curves for TL 93-064 are plotted together with two simulated results; one giving the result assuming no structural connections, the other assuming studs of infinite stiffness, i.e. the latter result calculated using Eq. (2).

As for the case of assuming studs of infinite stiffness, it is interesting to compare with the results given by Legault and Atalla [4]. The structure was here 1220 mm x 2030 mm aluminium plates (1 and 2 mm thick) with a cavity of 50.8 mm filled with a fibrous material. The "studs" are "C- section" aluminium channels with web length 50.8 mm (cavity depth) and spaced by a distance of 508 mm. As the measurements are performed in 1/24 octave bands and results averaged over 1/6 octave bands we have, when reproducing the results by Legault and Atalla, retained a similar aspect ratio of the axis, i.e. different from the figure above. Fig 4 shows a comparison of the measured results with the predictions using the periodic model and the present model for the coupled case. The C-channels coupling the plates have a material thickness of 3.175 mm, i.e. at least six times more solid than the example above. We have therefore modelled then as being infinitely stiff which in fact give good agreement with the measured result. However, such a simple model cannot be expected to predict any finer details in the result.

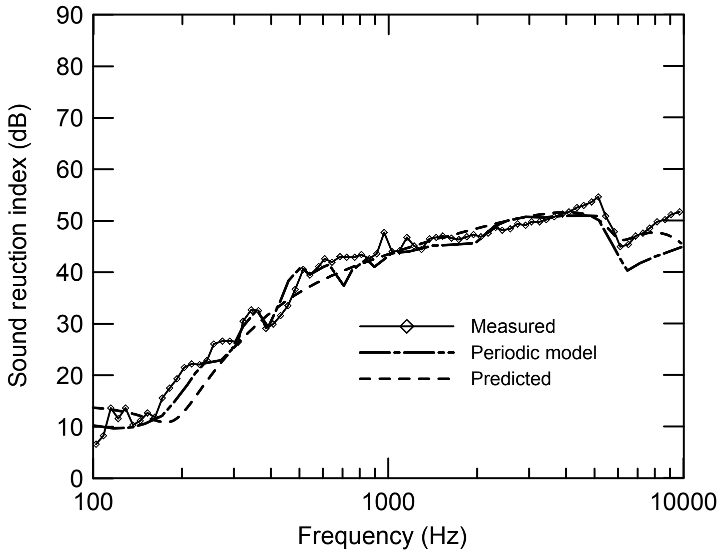

Figure 4 Sound reduction index with C-section channels between aluminium plates. Measured and predicted results with periodic model (non-rigid and massless beam case) reproduced from Fig. 6 in Ref. [4], together with prediction using the present model.

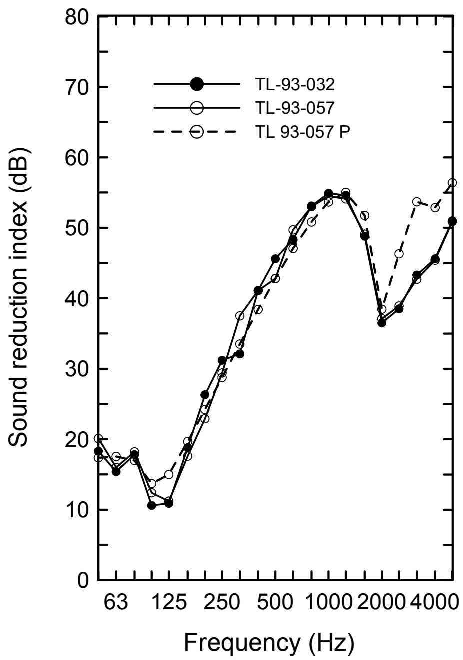

Fig. 5 Sound reduction of double walls with steel studs and an empty cavity of depth 65 mm. The stud spacing is 406 mm (TL-93-057) and 610 mm (TL-93-032), respectively. Predicted result is indicated by the capital letter P.

In the last example, see Fig. 5, the measured data are again taken from Ref. [11] on gypsum board walls. The cavity is empty and the energy losses in the cavity are simulated by a porous medium having a flow resistivity of 50 Pa·s/m^2 using the model of Delany and Bazley [15]. The gypsum boards were of nominal thickness 16 mm fastened to steel studs of 65 mm thickness. Two measured results are shown, where the only difference is the stud spacing being 406 mm and 610 mm, respectively. As seen the difference between the two measured results is quite small with a difference in the weighted sound reduction index is just 1 (one) dB. In the predicted result a stud spacing of 610 mm and the stiffness curve of Fig. 2 are used, giving a weighted sound reduction index 2 dB higher than the measured one.

4 Conclusions

To account for the effect of structural connections (sound bridges) in double walls the semi-empirical method proposed by Sharp [9] was revived by Vigran [8] and used to correct resulting data from the transfer matrix method calculation on the construction without bridges. However, this was limited to cases assuming studs of infinite stiffness. In the present work, the method is extended to include flexible studs using data from Ref. [7] for the effective stiffness for one type of steel stud. A comparison with a number of measured results on the sound reduction index of lightweight double walls with gypsum boards is performed, including cases with and without cavity filling. Some recent results on a construction with aluminium plates, where the bridges are assumed to be of infinite stiffness, are also shown. Taking the simplifications of the method into account, such as neglecting the weight of the studs, the fit between measured and predicted results is quite good.

References

[1] EN 12354–1: 2000, Building acoustics – Estimation of acoustic performance of buildings from the performance of elements. Part 1: Airborne sound insulation between rooms.

[2] V. Hongisto, Sound insulation of double panels – Comparison of existing prediction models. Acta Acustica united with Acustica 2006; 92:61–78.

[3] V. Hongisto, M. Lindgren and R. Helenius, Sound insulation of double walls – An experimental study. Acta Acustica united with Acustica 2002; 88:904–923.

[4] J. Legault and N. Atalla, Numerical and experimental investigation of the effect of structural links on the sound transmission of a lightweight double panel structure. J. Sound and Vibration, 2009; 324:712–732.

[5] J.L. Davy, The sound transmission of cavity walls due to studs. Proc. Internoise 93, Leuven, Belgium, 1993, 975–978.

[6] J.L. Davy, The improvement of a simple theoretical model for the prediction of the sound insulation of double-leaf walls. J. Acoust. Soc. Am, 2010; In Press.

[7] J. Poblet-Puig, A. Rodríguez-Ferran, C. Guigou-Carter and M. Villot, The role of studs in the sound transmission of double walls, Acta Acustica united with Acustica 2009;95:555–567.

[8] T.E. Vigran, Sound transmission in multilayered structures – Introducing finite structural connections in the transfer matrix method. Applied Acoustics 2010;71:39–44.

[9] B.H. Sharp, Prediction methods for the sound transmission of building elements. Noise Control Eng. J. 1978;11:53–63.

[10] T.E. Vigran, Building acoustics. Taylor & Francis, London and New York, 2008.

[11] R.E. Halliwell, T.R.T. Nightingale, Warnock, A.C.C. and J.A. Birta, Gypsum board walls: Transmission loss data, Internal report IRC-IR-761, Institute for Research in Construction, National Research Council of Canada, 1998.

[12] J. Brunskog, The influence of finite cavities on the sound insulation of double-plate structures. J. Acoust. Soc. Am. 2005; 117:3727–3739.

[13] T.E. Vigran, Predicting the sound reduction index of finite size specimen by a simplified windowing technique. J. Sound and Vibration, 2009;325:507–512.

[14] D.K. Wilson, Simple, relaxational models for the acoustic properties of porous media. Applied Acoustics 1997; 50:171–188.

[15] M.E. Delany and E.N. Bazley, Acoustical properties of fibrous materials. Applied Acoustics 1970;3:105.