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FLANKING TRANSMISSION BETWEEN LEAVES OF A DOUBLE WALL

T R T Nightingale (1), R J M Craik (2) & J A Steel (3)

(1) Acoustics Laboratory, Institute for Research in Construction, National Research Council Canada, Ottawa, Canada, (2) Department of Building Engineering and Surveying, Heriot Watt University, Edinburgh, Scotland, (3) Department of Mechanical Engineering, Heriot Watt University, Edinburgh, Scotland

INTRODUCTION

Lightweight double leaf walls are widely used to provide a high degree of sound isolation. For optimal effectiveness each side of the double leaf wall has its own set of framing members with no structural connection between the two sides. This type of construction creates a continuous cavity that may provide unimpeded transmission of smoke and fire. To prevent the propagation of smoke and fire, fire stops are placed in party walls where the wall is intersected by floors.

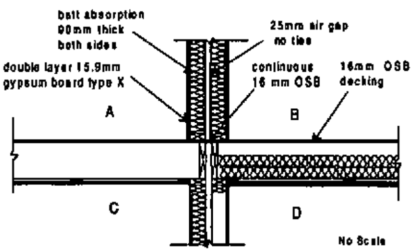

Figure 1: Vertical section through the construction specimen showing the fire stop formed by the continuous floor decking and the superior A-B party wall.

This paper will present a model to predict vibration transmission by bending moments due to horizontally oriented fire stops bridging the nominal 25 mm space at the wall/floor intersection. The model will be used to predict the degradation to the net sound isolation due to using a 16 mm thick oriented strand board (OSB) fire stop formed by continuing the floor decking under the party wall. Figure 1 shows the base construction that was modelled. In the study two different party walls were used to separate the upper two rooms A and B. Figure 2 shows the construction details for the two assemblies.

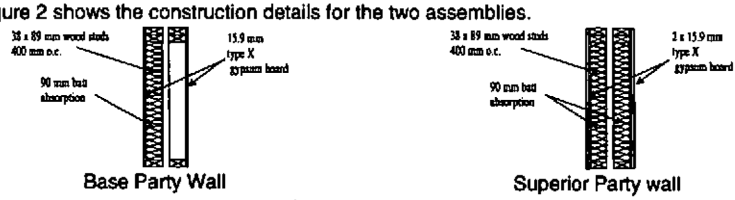

Figure 2: Construction of the Base and Superior wall constructions separating rooms A and B.

JOINT MODEL

The construction shown in Figure 1 can be visualized as being two tee joints formed by the intersection of the floor by the upper and lower party walls and that these two tee joints are coupled by the fire stop at the floor level. However, for this type of wood frame construction, it has been shown that transmission in either tee assembly should be modelled as two corner joints sharing a common plate[1] - the floor decking. This means that when modelling the transmission between the upper two rooms A and B the fire stop joint can be considered to be two corner joints connected by the fire stop as shown in Figure 3.

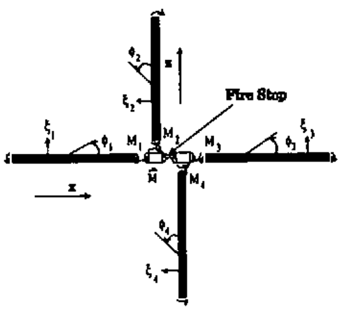

Figure 3: Mechanical representation of the fire stop joint as applied to transmission between the upper two rooms.

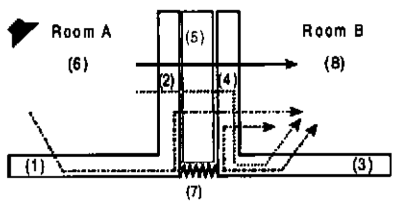

Figure 4: Schematic representation of the sub-systems considered in the model; 1, 3: floor decking; 2, 4: wall leaves; 5: wall cavity; 6: source room; 7: fire stop; 8: receive room.

In forming the model it is assumed that the only method of transmission will be by bending moments of the fire stop and that transmission by inplane forces can be ignored. It will also be assumed that the high frequency attenuation introduced by the polar rotation inertia and shear moment of the 38x89 mm wall sole plates can be ignored[1]. A series of continuity and boundary conditions are now defined to describe the motion and behaviour of the plates and fire stop:

1. At the joint the displacements of all plates are zero;
2. The right angle between plates 1 and 2 is preserved;
3. The right angle between plates 3 and 4 is preserved;
4. The sum of the moments about the left hand pin is zero;
5. The sum of the moments about the right hand pin is zero;
6. The angular deformation of the fire stop is determined by the bending stiffness and the moment.

These conditions give the following governing equations

- $T_{n1} = -1 - T_1$, $T_{n2} = -T_2$, $T_{n3} = -T_3$, and $T_{n4} = -T_4$ (1)
- $\phi_1 = \phi_2$ and $\phi_3 = \phi_4$ (2, 3)
- $M_1 - M_2 + M_f = 0$ and $M_4 - M_3 - M_f = 0$ (4, 5)
- $M_f = (\phi_3 - \phi_1) B_f$ (6)

where the numeric subscript indicates the plate, T is the amplitude of the travelling component and the subscript *'n'* refers to the near field or evanescent component, M is the moment of inertia, ϕ is slope, and B_f is the bending stiffness of the fire stop.

If a pure bending wave on plate 1 is incident at angle, θ, then the transverse displacements on the four plates are given by,

$$\xi_1 = (e^{-ik_1\cos\theta_1 x} + T_1 e^{ik_1\cos\theta_1 x} + T_{n1} e^{k_{n1} x})(e^{-ik_1\sin\theta_1 y} e^{i\omega t}), \tag{7}$$

$$\xi_2 = T_2 e^{-ik_2\cos\theta_2 z} + T_{n2} e^{-k_{n2} z} \tag{8}$$

$$\xi_3 = T_3 e^{-ik_3\cos\theta_3 x} + T_{n3} e^{-k_{n3} x} \tag{9}$$

$$\xi_4 = T_4 e^{ik_4\cos\theta_4 z} + T_{n4} e^{k_{n4} z} \tag{10}$$

where k is the wave number and the last term of equation 7 is common to all displacement equations and is not given in subsequent equations. The term k_{n} is the near field wave number and is given by $k_n^2 = k^2(1 + \sin^2\theta)$ for any plate. The angle at which the waves leave the joint can be found from Snell's law which requires that $k_1\sin\theta_1 = k_m\sin\theta_m$. The slopes, ϕ, and moments, M, used in the governing equations are related to the transverse displacement by, ξ, by

$$\phi = \frac{\partial\xi}{\partial x} \text{ and } M = -B\left(\frac{\partial^2\xi}{\partial x^2} + \mu\frac{\partial^2\xi}{\partial y^2}\right) \tag{11,12}$$

where μ is Poisson's ratio and B is the bending stiffness of the plate.

Equations 7-10 are now substituted into equations 1-6 to give four simultaneous equations having the transverse displacements of the four plates as the unknown variables,

$$T_1[-k_{n1} + ik_1\cos\theta_1] + T_2[-k_{n2} + ik_2\cos\theta_2] = k_{n1} + ik_1\cos\theta_1 \tag{13}$$

$$T_3[k_{n3} - ik_3\cos\theta_3] + T_4[k_{n4} - k_4\cos\theta_4] = 0 \tag{14}$$

$$\begin{aligned} &T_1[2B_1k_1^2 + B_f k_{n1} - iB_f k_1\cos\theta_1] + T_2[-2B_2k_2^2] \\ &+ T_3[B_f k_{n3} - iB_f k_3\cos\theta_3] = -2B_1k_1^2 - B_f k_{n1} - iB_f k_1\cos\theta_1 \end{aligned} \tag{15}$$

$$\begin{aligned} &T_1[-B_f k_{n1} - iB_f k_1\cos\theta_1] + T_3[-2B_3k_3^2 - B_f k_{n3} + iB_f k_3\cos\theta_3] \\ &+ T_4[2B_4k_4^2] = B_f k_{n1} + iB_f k_1\cos\theta_1 \end{aligned} \tag{16}$$

The stiffness of the fire stop can be found by considering a small element of beam and using fundamental mechanics

$$B_f = \frac{Yh^3}{12(1-\mu^2)L} \tag{17}$$

where L is the span of the fire stop (typically 25 mm), h is the thickness of the fire stop (such as 16 mm for the OSB decking) and Y is Young's Modulus of the fire stop material.

The transmission coefficient can then be found from

$$\tau_{12}(\theta) = \frac{\rho_{s2}k_1\cos\theta_2}{\rho_{s1}k_2\cos\theta_1}|T_2|^2 \tag{18}$$

The angular average transmission coefficient is then given by

$$\tau_{av} = \int_0^{\pi/2} \tau(\theta)\cos(\theta)d\theta \tag{19}$$

In the special case that there is normal incidence at the joint and all the plates have the same bending stiffness the equations can be solved analytically. The transmission from plate 1 to 3 or 1 to 4 is given by,

$$R_{13} = R_{14} = 10\log 8\left(\frac{2}{c^2}+\frac{2}{c}+1\right) \quad (20)$$

where

$$C = \frac{B_f}{Bk} \quad (21)$$

When C tends to zero, as occurs at very high frequencies or for very soft fire stops, then the transmission loss tends to infinity. When C tends to infinity, then the transmission loss tends to 9 dB. The joint transmission loss for normal incidence is about 1.8 to 1.9 dB lower that for random incidence.

MEASURED AND PREDICTED RESULTS

The eight sub-system SEA model shown in Figure 4 was used to represent the key elements in the transmission between rooms A and B. The purpose of this paper is not to define the theory for modelling sound transmission through double leaf constructions as this is available elsewhere[2,3], but rather issues surrounding the joint are discussed. Table 1 shows the material properties used in the joint calculation.

Material or Structural Element	Joint Stiffness (L = 25 mm) (Nm)	Young's Modulus (N/m^2)	Poisson's Ratio	Density (kg/m^3)	Decay Time (s)
16 mm OSB	54700	4.04x10^9	0.2	600	$9.9f^{-0.78}$
16 mm Gypsum Board	n/a	1.9x10^9	0.2	720	$9.9f^{-0.78}$
Wall Cavity	n/a	n/a	n/a	n/a	Base: $3f^{-0.58}$ Superior: $5.7f^{-0.63}$

Table 1: Material properties of the fire stop and elements in the SEA model.

Continuous Floor Decking: The fire stop is formed by continuing the OSB floor decking across the nominal 25 mm air space between the joist headers. There is reasonable agreement between the measured and predicted results as shown in Figure 5A. Differences in the very low frequencies may be explained by the mass-air-mass resonance of the wall cavity which has been calculated to occur at about 40 Hz. The prediction underestimates the transmission loss near the critical frequency of the floor and wall (2000 and 2500 Hz, respectively). This is due to an overestimation in the strength of coupling between the room and wall and vice versa and is a result of assuming that the surfaces were isotropic. Both gypsum board and OSB are highly orthotropic.

Figure 5B shows the measured and predicted transmission loss results for all flanking paths involving the receive room floor. There is reasonable agreement between measured and predicted results through most of the range. The exception occurs at the critical frequency where there is much stronger transmission than was measured.

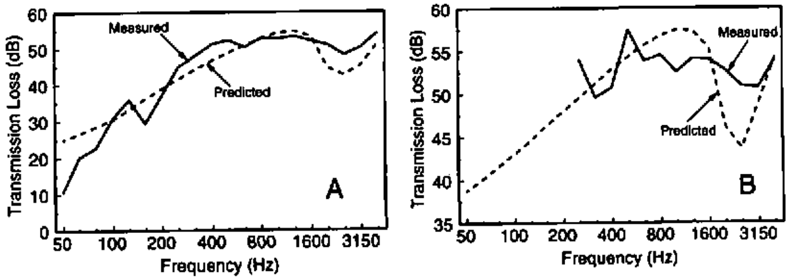

Figure 5: Measured and predicted net transmission loss between rooms A and B with base case party wall construction and the 16 mm thick OSB fire stop formed by continuing the floor decking; A: Net transmission loss, B: Transmission loss for flanking paths involving the receive floor.

Figure 6 shows the transmission loss for the four most important flanking paths involving the fire stop joint. From the figure it can be seen that the dominant flanking path is *floor-to-floor* directly under the party wall and does not involve any of the party wall elements. Paths involving the party wall leaves are about 5 dB less important relative to the path only involving the floor decking.

The base party wall was replaced with a the wall of *superior* construction and the measured and predicted net transmission loss are shown in Figure 7. From the figure it can be seen that there is good agreement over the most of the frequency range. There is an overestimation of the transmission loss in the frequency range 500 to 1600 Hz.

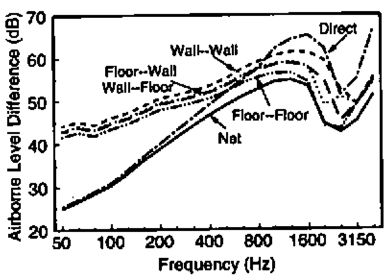

Figure 6: Predicted airborne level difference for the most important flanking paths with the base party wall construction and the 16 mm thick OSB fire stop formed by the continuous floor decking.

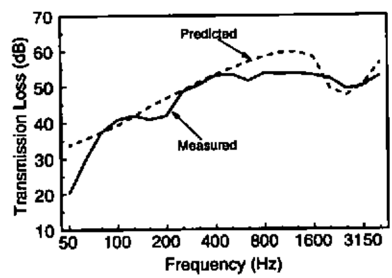

Figure 7: Measured and predicted net transmission loss with the superior party wall construction and the 16 mm thick OSB fire stop formed by the continuous floor decking.

Simple Retro-Fit: Since the dominant flanking path is *floor-to-floor* via the fire stop, improving the performance of the floor decking through a retro-fit may be useful. An additional layer of 16 mm OSB was placed over the exposed surfaces. Doubling the effective thickness of the deck will reduce the efficiency of the floor to accept and/or radiate sound energy. It will also reduce the amount of energy transmitted across the joint since there will be a 2 to 8 fold increase in bending stiffness of plates 1 and 3 while the bending stiffness of the joint remains constant. A factor of four was used in the prediction model as complete composite action was not achieved by the 100 mm nailing grid.

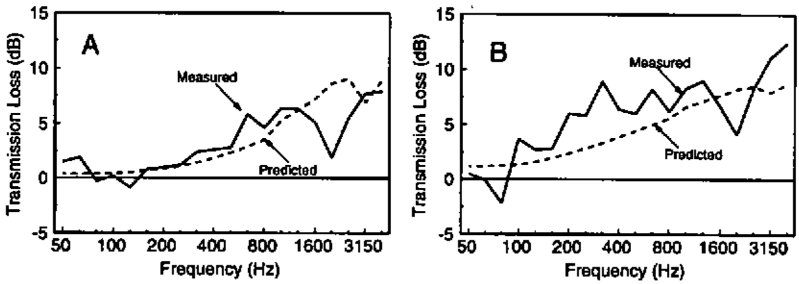

Figure 8: Measured and predicted change in the net sound isolation due to the placement of a 16 mm thick OSB underlay to the existing floor decking. A: Base wall construction, B: Superior wall construction.

Figures 8A and 8B show that there is a significant change in the net transmission loss when the additional layer of floor decking is used. There is a slightly greater benefit when used with the superior party wall since all wall paths have been reduced. Trends are correctly shown with the exception of 2000 Hz where the additional layer of OSB was placed at right angles to the first caused a shift in the critical frequency which was not reflected in the model. This could be solved by changing the implementation in the model.

CONCLUSIONS

A mathematical model has been presented to describe the transmission through a joint formed by a thin horizontally oriented material bridging either side of a party wall. The model assumes that transmission will occur only by bending moments. This was shown to be an acceptable approximation for a very stiff fire stop material (e.g., 16 mm OSB). The model accurately predicted the net sound isolation and that for flanking paths involving the receive room floor. The model was able to accurately predict the improvement due to the underlay treatment of the floor decking.

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[1] Nightingale, T.R.T., Steel, John, A., "Statistical energy analysis applied to lightweight constructions Part 2: Joints between floors and party walls, Canadian Acoustics Vol. 23, No. 3, pp. 43-44, 1995.
[2] Craik, Robert J.M., " ", Proceedings Issue INTERNOISE 96 Liverpool, 1996.
[3] Craik, Robert J.M., Steel, John A., Nightingale, Trevor, R.T., "Sound transmission through framed buildings," IRC-IR-672, Institute for Research in Construction, National Research Council Canada, May 1995.