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Structure-borne sound transmission through a lightweight T-junction

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ABSTRACT

This paper examines structure-borne sound transmission through a T-junction formed by a plywood worktop (source plate) and a lightweight partition. This type of structure is typically found in kitchens, where impact sound originated from a worktop can be responsible for noise complaints in adjacent places. Tests have been carried out for a variety of connection arrangements and measured data has been compared with predictions given by statistical energy analysis models. Results indicate that the junction does not behave rigidly (even when glued and screwed along its length) and that large variations in transmission occur depending on the fixing method used to connect the worktop to the partition.

1. INTRODUCTION

The T-junction examined in this paper represents a type of construction which can be found in kitchens where worktops are connected to lightweight partitions. Impact transmission from worktops can often be responsible for annoyance and complaints in adjacent spaces[1]. However, impact transmission requirements are limited to floors in most countries (an exception being Australia), a reason why impact sound insulation is rarely taken into account in the design of walls. The results presented here are intended to clarify the nature of such junctions as well as the importance of fixing methods for structure-borne sound transmission.

2. TEST STRUCTURE

Tests have been carried out in the acoustics laboratory of Heriot-Watt University, and the structure tested and statistical energy analysis (SEA) subsystems used for modelling are shown in Figure 1. The T-junction consisted of a plywood plate (subsystem 1), two plasterboard plates (2+3 and 4), timber beams (5-10) and a small plywood plate (11). As shown in Figure 1(a), two timber supports were placed under the worktop and the structure was enclosed within heavy masonry walls (negligible flanking transmission between the lightweight structure and the masonry walls). Material properties are listed in Table 1.

In view of comparisons with theoretical models assuming rigidity of the junction, the worktop was initially glued and screwed to the small plywood plate (5 screws), these elements being in turn glued and screwed to the plasterboard plate (8 screws connecting the small plate to the timber frame). Plasterboard sheets were attached to the frame using screws spaced at 300mm vertically and 400mm horizontally. Tests have been repeated after removing half of these screws. Further measurements have also been carried out with a resilient layer placed between the small plate and plasterboard sheet.

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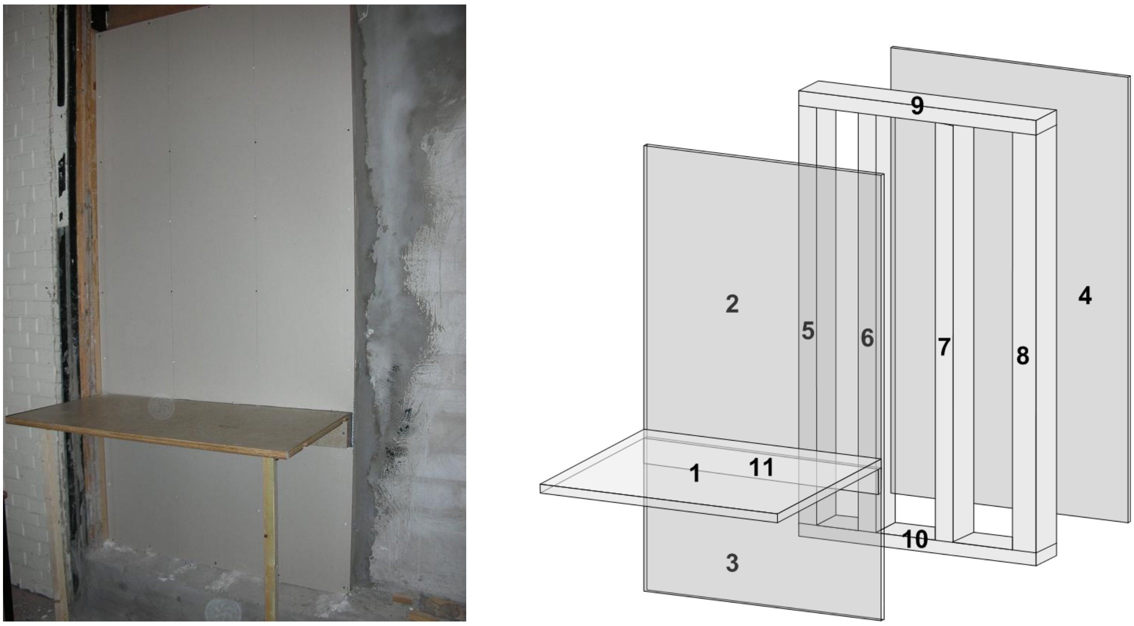


(a) Structure (b) SEA subsystems

Figure 1: Structure tested.

Table 1: *Material properties (longitudinal wavespeed measured in the axial direction of the beams). All values were measured except Poisson's ratio which was assumed.*

	Dimensions (m)	Density (kg/m^3)	Longitudinal wavespeed (m/s)	Poisson's ratio	Damping (ILF)
Worktop 1 Plate 11	1.164 × 0.61 × 0.026 1.164 × 0.30 × 0.026	618	4231	0.2	0.016
Plate 2 Plate 3 Plate 4	1.655 × 1.2 × 0.0125 0.745 × 1.2 × 0.0125 2.4 × 1.2 × 0.0125	680	1879	0.2	0.008
Beams 5, 6, 7, 8 Beams 9, 10	2.4 × 0.088 × 0.038 1.2 × 0.088 × 0.038	480	4330	-	0.012

Standard measurement procedures were applied and acceleration level differences between elements were obtained using a plastic-headed hammer as the sound source. The worktop was used as the source element throughout experiments, and responses of the plates were space averaged over 15 positions.

3. RESULTS

Initial measurements indicated a strong variation of acceleration levels across the worktop. It was found that levels decrease significantly when moving towards the junction. This can be seen in Figure 2, where acceleration level differences between plates 1 and 4 are given for different accelerometers' positions used across the source plate: the dotted line was calculated using 5 positions which were within 150mm of the junction; the dashed line was calculated using 15 positions which were at least 150mm away from the junction; and the plain line corresponds to the 20 readings' average. The large differences observed appear to be related to the clamped condition of the T-junction, as similar experiments made using hinges to connect the worktop and partition did not show such a variation of levels[2]. The vibration field of the source plate is therefore not diffuse, but the field becomes reasonably uniform at distances greater than 150mm from the junction. All the measured results presented in this paper are based on the 15 readings' averages (i.e. positions far from the junction), as these are more appropriate for comparison with theoretical models that assume diffuse fields.

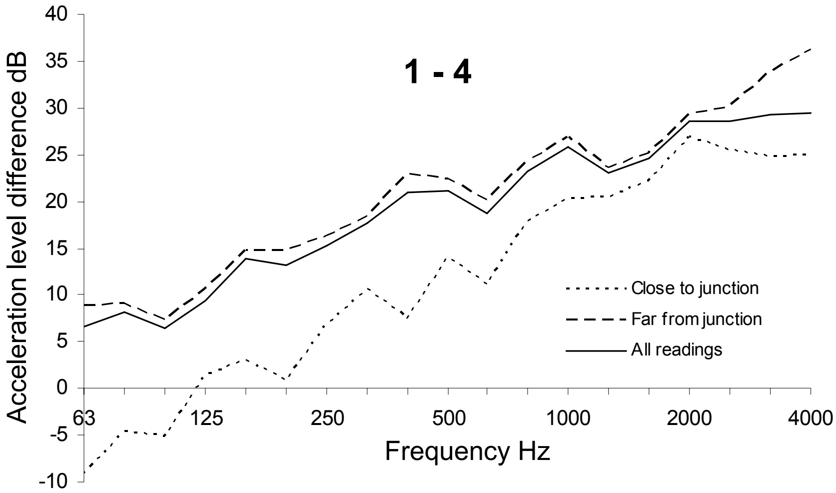


Figure 2: Acceleration level differences measured between plates 1 and 4.
The curves correspond to different accelerometers positions used on plate 1.

Statistical energy analysis predictions have been used for understanding the structure's behaviour, rather than for providing an exact representation of the system. It should be noted that the models tested included a number of important simplifications and underlying hypothesis, precision of predictions not being the aim of the study. Furthermore, the applicability and accuracy of current models is anyway limited for lightweight structures[3]. The modelling details applied are not discussed here, but can be found in Craik[4]. It is just worth noting that the coupling between plates and beams was calculated using the theory for point coupling as[4]

$$\eta_{12} = \frac{r\,\mathrm{Re}(Y_2)}{\omega m_1 \left|Y_1 + Y_2\right|^2} \tag{1}$$

where Y is the mobility (inverse of impedance), m is the mass of the respective subsystems and r is the number of point connections. The beam and plate point force mobilities were used[5],

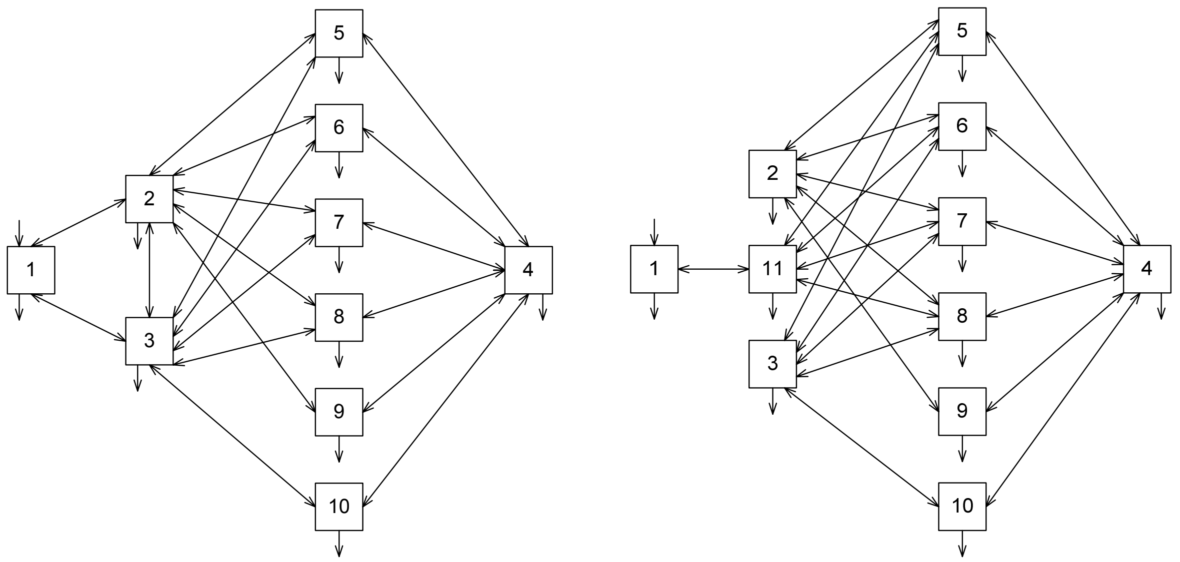
$$Y_b = \frac{1}{2\rho_l \left[\dfrac{B_b \omega^2}{\rho_l}\right]^{1/4} (1+i)} \quad \text{(beam – centre excited)} \tag{2}$$

$$Y_p = \frac{1}{8\sqrt{B_p \rho_S}} \quad \text{(plate - centre excited)} \quad ; \quad Y_p = \frac{1}{3.5\sqrt{B_p \rho_S}} \quad \text{(plate - edge excited)} \tag{3-4}$$

where ρ_s is the surface density of the plate, ρ_l is the mass per unit length of the beam, B_p is the plate bending stiffness per unit width and B_b is the beam bending stiffness.

Point theory was used as point behaviour occurs over most of the frequency range considered (according to the rule of thumb given by Craik and Smith[6], the transition between line and point behaviour occurs at 125 Hz for a screws' spacing of 300mm).

Two SEA models have been tested. In the first model it was assumed that the worktop is rigidly connected to the plasterboard plate (i.e. the T-junction between subsystems 1, 2 and 3 is rigid), and that the plasterboard plates and frame are point connected. In this model the small junction plate (subsystem 11) is ignored (see Figure 3(a)).



(a) Model 1

(b) Model 2

Figure 3: SEA models of the structure tested.

For the second SEA model, it was assumed that the worktop is rigidly connected to the small plate (i.e. the L junction between subsystems 1 and 11 is rigid), which is in turn point connected to the frame (see Figure 3(b)). This is a significant over-simplification of the system, as the direct coupling between the worktop and plasterboard, as well as between the small plate and plasterboard, are ignored. Furthermore, it should be noted that the junction plate is small and has a low mode count and modal overlap (the mode count is smaller than 1 below 800 Hz). Nevertheless, this model can give a further insight into the behaviour of this T-junction. In both models, all the coupling loss factors between the frame and plates were calculated using equations (1-4) and coupling between the timber beams was ignored. It can also be noted that the plasterboard sheet on the receiving side was modelled as a single subsystem, as similar acceleration levels were found above and below the worktop's height on plate 4[7].

Measured and predicted results are given in Figure 4, which shows the acceleration level differences $D_{1\text{-}2}$, $D_{1\text{-}3}$, and $D_{1\text{-}4}$. The results suggest that the T-junction is not rigid, as the vibration transmission predicted by the SEA model 1 is significantly overestimated for plates 2 and 4, and slightly overestimated for plate 3. This is in line with what was previously found for timber-framed structures[8]. It can be noted that the low $D_{1\text{-}3}$ (e.g. negative value at 160 Hz) might be related to resonances in subsystem 3. The second SEA model provides predictions closer to the measured results $D_{1\text{-}2}$ and $D_{1\text{-}4}$, which further point to the non-rigid nature of the junction.

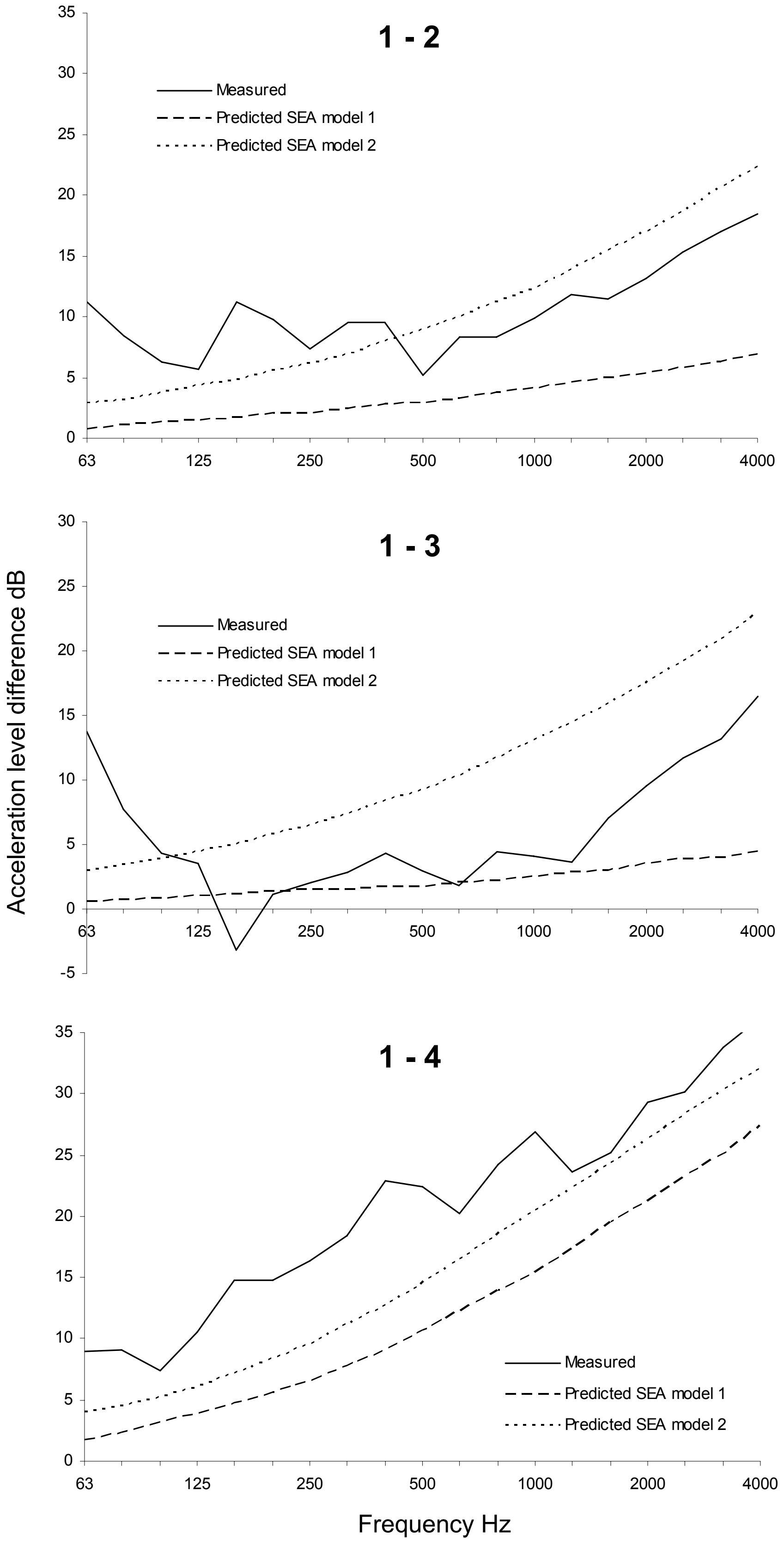


Figure 4: Measured and predicted acceleration level differences.

The influence of the number of screws used was also examined and results obtained for D_{1-4} are shown in Figure 5. It can be seen that, according to the SEA model 2, halving the number of screws (from 38 to 19) is expected to reduce transmission of approximately 4 dB over most of the frequency range considered. Measured results show comparable variations above 500 Hz, but are less consistent below that frequency.

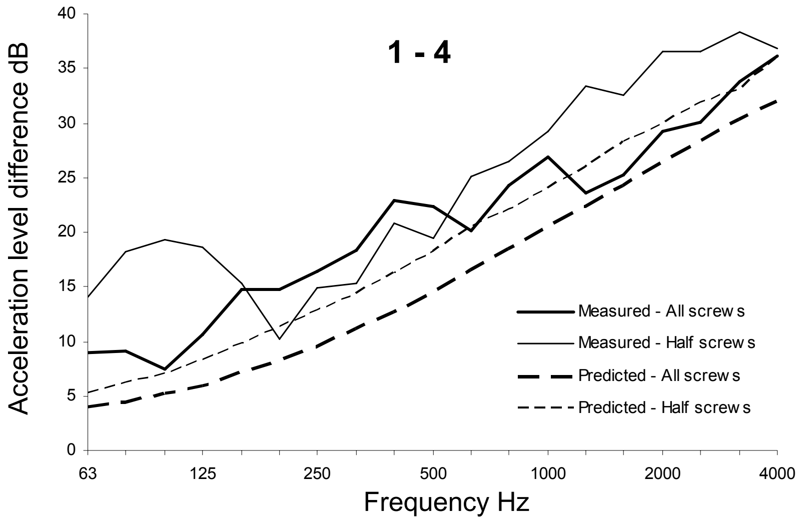


Figure 5: Measured and predicted acceleration level differences for varying number of screws used.

A resilient layer of 22 kg/m^3 density and 1,250,000 N/m compression stiffness was then placed between the small plate (11) and plasterboard sheet (2+3), the small plate being still connected to the frame with screws. The comparison of the measured acceleration level differences D_{1-4} suggests that the resilient layer is an effective noise control solution only above 500 Hz, where differences of up to 10 dB can be obtained (Figure 6).

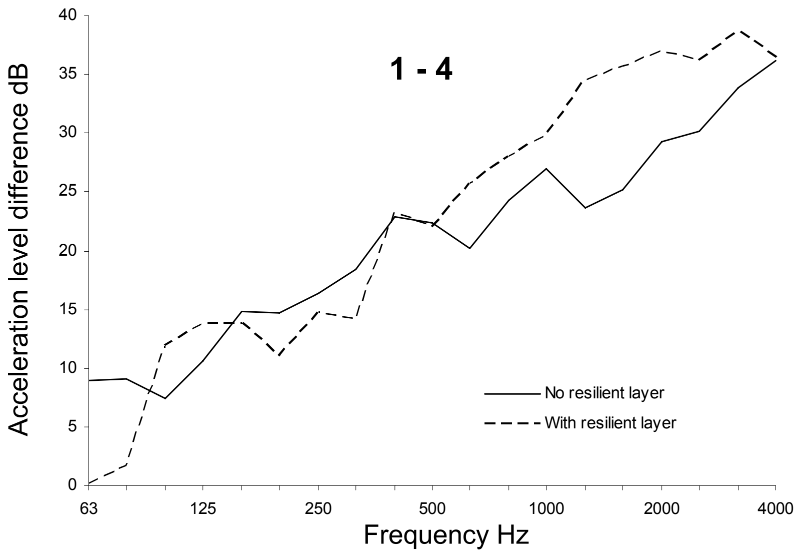


Figure 6: Measured acceleration level difference with and without a resilient layer placed between the small plate (11) and plasterboard sheet (2+3).

It is worth noting that in real constructions, kitchens' worktops are normally fixed to the partition using hinges (common types of hinges are attached to the wall with two screws and fixed to the worktop with one screw). Compared to the results obtained using the fixing arrangement presented in this paper, hinges can significantly reduce coupling between the worktop and partition. Differences in acceleration levels of up to 10 dB can be obtained at mid-frequencies, as well as down to relatively low frequencies such as 200 Hz. This was found for tests made on a structure similar to the one presented here[2]. However, as results are not strictly comparable, these are not given in this paper.

5. CONCLUSIONS

Structure-borne sound transmission through a T-junction formed by a plywood worktop and a lightweight partition has been examined. In the structure studied, the worktop was connected as rigidly as possible to the partition by using a small junction plate screwed and glued to the partition. However, comparisons made with simple predictive models suggested that the junction did not behave rigidly. Further tests indicated that reducing the number of screws used for fixing, or placing a resilient layer between the worktop and partition, can reduce transmission only at mid and high frequencies. Nevertheless, it was pointed out that the use of different fixing methods, such as hinges, can reduce transmission even at relatively low frequencies.

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