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# A STUDY OF VIBRATION TRANSMISSION AT JOINTS IN TIMBER FRAMED BUILDINGS USING STATISTICAL ENERGY ANALYSIS

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## ABSTRACT

In this work a series of simplified laboratory models of joints between boards and joists are studied so that the best ways of modelling vibration transmission can be identified. Measured level difference data for transmission between plates representing the floors and walls is presented. The measured data is compared with predictions calculated using SEA models of the joints and good agreement is found. Coupling is calculated using wave methods and wave dynamic stiffness techniques to model the plate elements and beams in the joints. The results show that vibration transmission at this type of joint can be predicted using SEA techniques.

## 1 - INTRODUCTION

Earlier work reported by Nightingale and Steel [1] identified difficulties in predicting structural vibration transmission at joints in wood framed buildings.

In this work a series of simplified laboratory models of joints between boards and joists are studied so that the best ways of modelling vibration transmission can be identified. Coupling between plates is calculated using wave methods and wave dynamic stiffness techniques to model the plate elements and beams in the joints in a similar manner to previous work [2,3,4,5]. For point coupling between plates, at nails or across battens, a mobility model is used [6]. At low frequencies the beams and battens in the joints are modelled as a connecting element between subsystems such as boards which represent floor and wall panels. At high frequencies it is possible that the beams at the joint should be considered as separate subsystems for torsional vibration.

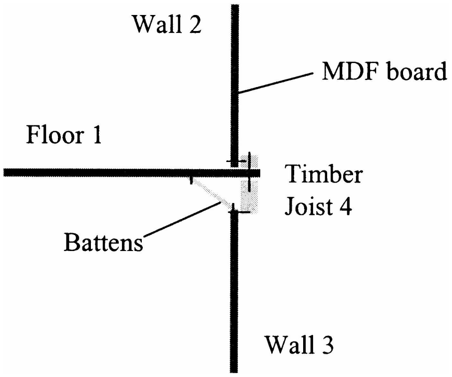

**Figure 1:** Sketch of joint configuration showing subsystem numbering.

## 2 - BACKGROUND THEORY

The joint configuration which is considered here is shown in Figure 1. At low frequencies the plates can be modelled as subsystems supporting bending, longitudinal and transverse vibration. The coupling loss factor [7] can be given in terms of the transmission coefficient, $\tau_{ij}$ as,

$$\eta_{ij} = \left(C_{gi} L_i / \pi \omega S_i\right) \bar{\tau}_{ij} \tag{1}$$

where $C_g$ is the group velocity, $L$ is the joint length and $S$ is the source plate surface area. In this work the transmission coefficient is calculated using the techniques described by Steel and Fraser [5]. Battens are shown in Figure 1 which enable direct vibration transmission between plate 1 (ie. a floor) to plate 3 (ie. a wall panel). The coupling loss factor for point coupling across the battens can be calculated in a similar way to that given by Craik [6] for coupling across wall ties, using the equation,

$$\eta_{ij} = \frac{rY_j}{\omega \rho_i h_i \left[ \left(Y_i + Y_j\right)^2 + Y_k^2 \right]} \tag{2}$$

where $Y_i$, $Y_j$ and $Y_k$ are the mobilities of plates 1 and 2 and the battens respectively. $r$ is the number of connections per $\mathrm{m}^2$. For strong coupling across the battens (assuming the battens are very stiff) the coupling loss factor can be approximated to $\eta_{ij} = 7/f$.
Two SEA models of the joint are shown in Figure 2. At low frequencies there are three plate subsystems connected through elements (node) or battens (dashed lines in Figure 2). At high frequencies the plates are coupled to a beam through 23 screws and the coupling loss factors are all calculated using equation (2) with the beam mobility calculated for torsional vibration. Using the lowest measured wave speed $C_l$=600m/s for the beams coupling loss factors between bending waves in the plates and torsion in the beam can be approximated to $\eta_{pb} = 1/f$ and using the reciprocity principle [7] $\eta_{bp} = 13/f$.

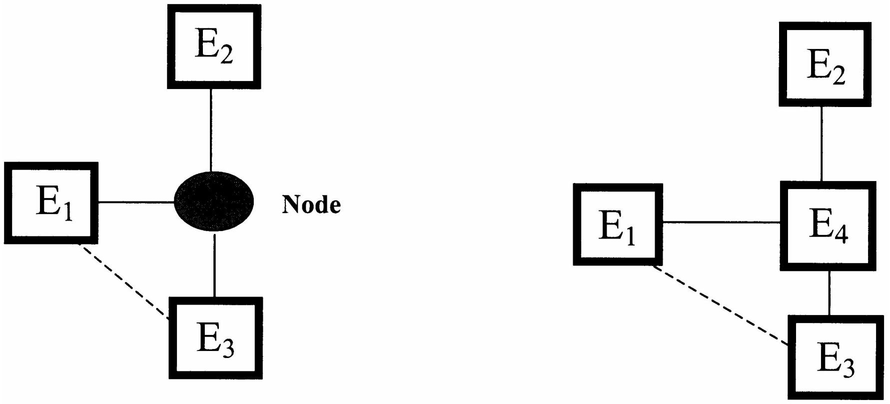

**Figure 2:** SEA models of the joint.

## 3 - EXPERIMENT

Vibration transmission between three medium density fibre board panels, area 1.22m$^2$ was measured. The boards were cut so that they had the same surface area but avoided opposite parallel edges. The material properties used for the MDF board and the beams and battens at the joint are given in Table 1.

| | Density kg/m$^3$ | Longitudinal wave speed m/s | Poisson ratio | Dimensions m |
|---|---|---|---|---|
| MDF Board | 800 | 2900 | 0.3 | 0.012 ×1 ×1.22 |
| Timber | 450 | 600-4900 | 0.3 | 0.05 ×162 ×1 |

**Table 1:** Material properties.

The boards were supported on tables and the damping was measured and could be approximated to $3/f$. The level difference between the vibrational energy in the plates was measured. An accelerometer was attached to each of two plates and the source plate was tapped over the surface using a plastic headed hammer for 16 seconds. The level difference was recorded and the accelerometers were then moved to new positions on the same plates and the measurement was repeated. The measurements were repeated about 30 times to ensure adequate space, time and frequency averaging. The confidence limits for the measured results are around ±1dB for the results shown here.

Figure 3 shows the measured and predicted Energy Level Difference (ELD) for transmission from plate 1 to plate 3. Three predictions are shown (in dB re $10^{-12}$). The curve marked with triangles is predicted for no battens between plates 1 and 3. The curve marked with squares is predicted for strong (very stiff battens) coupling between plates 1 and 3. The curve marked with circles is predicted assuming transmission through two timber battens but also including the point mobility of a beam in flexure and then into plate 3. The measured data lies between the predictions for strong and weak coupling across the battens and shows best agreement with the predicted curve shown solid. The predicted ELD for the low and high frequency models are very similar for transmission from plate 1 to plate 3.

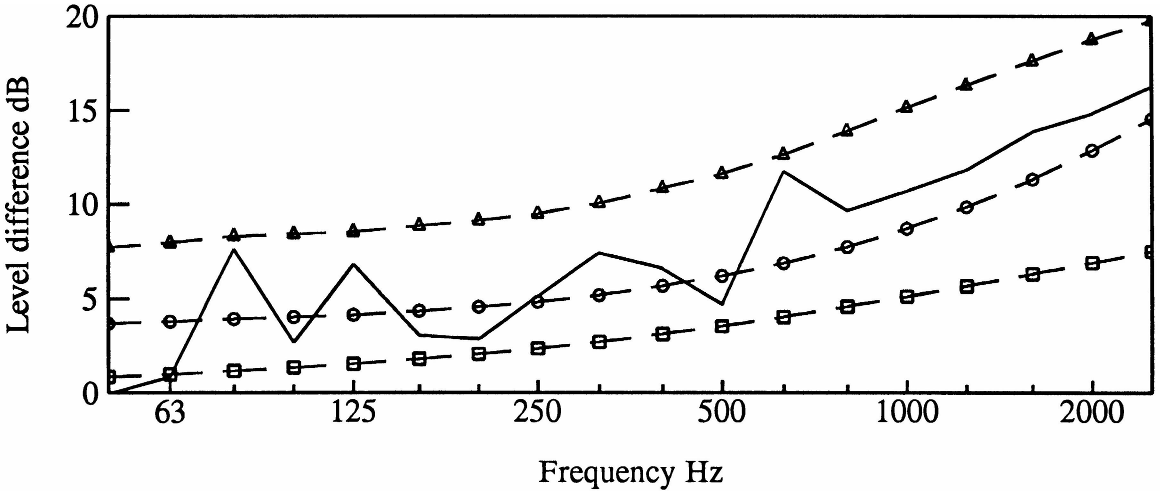

**Figure 3:** Measured and predicted level difference for transmission from plate 1 to plate 3; ____ measured, - - - - predicted.

Figure 4 shows the measured and predicted ELD for transmission from plate 2 to plate 3. Two predictions are shown, calculated using the low and high frequency models. Below 500Hz good agreement is shown between the measured data and the low frequency (3 subsystem) model. Above 500Hz the measured data rises to follow the high frequency prediction (4 subsystem model) which assumes coupling through screws between the bending waves in the plates and torsional vibration in the beam.

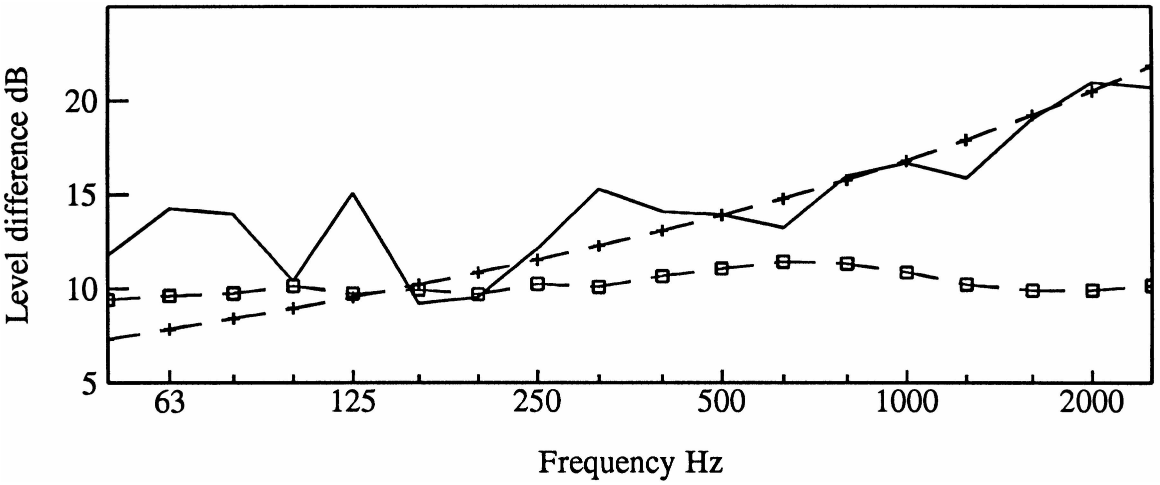

**Figure 4:** Measured and predicted level difference for transmission from plate 2 to plate 3; ____ measured, - - □ - - predicted (low frequencies), - - + - - predicted (high frequencies).

## 4 - CONCLUSIONS

A series of simplified laboratory models of joints between boards and joists have been studied. At low frequencies the joists at the joint are best modelled as connecting elements between the plates. Strong transmission is possible across battens which connect plates and this must be included in the model for good agreement between measured and predicted results. For the Laboratory models studied in this work, at high frequencies it is likely that torsional vibration of the joists in the joint is important and that the joists should be modelled as separate subsystems. Further work is needed to show that this high frequency model is correct and can generally be applied for this type of structure.

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