inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 5.1

ESTIMATING JUNCTION ATTENUATION IN LIGHTWEIGHT CONSTRUCTIONS

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Keywords:
JUNCTION, ATTENUATION, VLD, SEA

ABSTRACT
In-situ estimates of junction attenuation between connected surfaces in heavy monolithic constructions have been successfully obtained by treating the surfaces as coupled resonant systems. The concept of power balance is used to obtain an indirect measure of the junction attenuation from measures of velocity level difference (VLD), and damping. The paper highlights assumptions relating the measured VLD to junction attenuation. Measured VLD, and hence estimate of junction attenuation, is found to be very sensitive to measurement positions which should not be the case if the surfaces behave as single subsystems and the vibration fields are diffuse. Draw-away curves are used to show that the method may not be generally applicable for in-situ measurement of framed constructions.

1 - INTRODUCTION
Accurate estimates of junction attenuation are important for validating junction models and as input data for building acoustics prediction models (e.g., SEA and EN12354). Unfortunately, junction attenuation can not be measured directly in-situ. It must be measured indirectly. Thus, the estimate of junction attenuation is only as good as the theory and assumptions relating the directly measured quantities to the estimate of junction attenuation. A brief discussion of the generally accepted method for estimating junction attenuation is now given and important, and sometimes implicit assumptions are noted.

2 - THEORY AND BACKGROUND
The concept of power balance is used to relate the energy stored in the source and receive plates to the attenuation of the junction that connects them. The incident structure borne power on the joint from the source plate (indicated by the subscript 1) is assumed to be only a function of the steady state energy stored in the plate (E), the group speed of bending waves in the plate (C_{g1}), the mean-free path of the plate (term in brackets), and the length of the joint (L). This gives the following equation,

$$W_{inc} = E_1 \left[\frac{C_{g1}}{\pi S_1} \right] L \tag{1}$$

Assumption 1: Equation 1 is valid only for a diffuse field since the incident sound power is a function of the mean-free path. Thus, the source plate must be excited using a technique that generates a diffuse field.

Under steady-state conditions, the power transmitted to the receive plate (indicated by the subscript 2) must be equal to the power dissipated by the receive plate which is given by the product of the stored energy in the receive plate (E), the total loss factor (η), and the angular frequency (ω),

$$W_2 = E_2 \omega \eta_2 \tag{2}$$

Assumption 2: The resulting build-up of energy in the plate is determined solely by the total loss factor; the sum of internal and edge losses. It is generally assumed that edge losses will exceed internal losses

(a necessary condition for the field to be diffuse) and that neither is excessively large allowing sampling of the energy well away from the source.
The constant of proportionality between the incident and transmitted sound power is the junction transmission coefficient τ. Combining equations 1 and 2 gives an expression for τ in terms of the energies of the two plates and the damping of the receive plate,

$$\tau_{12} = \frac{E_2}{E_1}\frac{\eta_2 \omega \pi S_1}{C_{g1} L} \tag{3}$$

Assumption 3: Perhaps, the most fundamental assumption is that surfaces are single subsystems and that the energy will be sampled only in that subsystem. It is also assumed that the coupling is sufficiently weak, and the damping of the receive system sufficiently great, that there will be a difference in the modal energies of the two surfaces.
The energy in the source and receive plates can be expressed in terms of measurable properties, the mass (m) of the surface and the mean surface velocity (v). The resulting equation for the junction attenuation, expressed in decibels, is given by,

$$R_{12} = 10\log\left[\frac{\langle v_1^2\rangle_{surface1}}{\langle v_2^2\rangle_{surface2}}\right] + 10\log\left[\frac{m_1}{m_2}\frac{C_{g1}L}{\eta_2 \omega \pi S_1}\right] \tag{4}$$

The first term is the measured VLD. Equation 4 is a simple expression fully consistent with SEA (and all derivative prediction methods). It has been successfully applied to heavy monolithic constructions that provide a reasonable approximation to a diffuse vibration field. If equation 4, and the assumptions used to develop it, are not fully satisfied for lightweight constructions then one must question the suitability of assessing junction attenuation using VLD's, and also the applicability of power-based prediction models (i.e., SEA and prEN ISO 12354) to describe lightweight constructions.

3 - VELOCITY LEVEL DIFFERENCE MEASUREMENTS

A practical method for determining the VLD between two connected plates has been defined by Craik. In the procedure the surface velocity on each plate is sampled simultaneously using a pair of accelerometers which are connected to a dual-channel real-time analyzer. Randomly distributed impacts, using a lightweight hammer, excite the modes of the source surface. Impacts too close to an accelerometer or joint will cause near-field effects that may potentially contaminate the results. Further spatial averaging is accomplished by choosing multiple accelerometer positions on both the source and receive surfaces. For the measurements presented here, ten accelerometer pairs are used which is more than is required for measurements down to 100 Hz according to draft prEN ISO 10848-1:1999.
VLD measurements were made between the gypsum board wall and the subfloor surface of the wood-framed floor assembly shown in Figure 1. It is important to note the orientation of the framing members in the two surfaces as this determines the orientation of the butt joints between the sheathing panels. In the floor, the 38 $\times$235 mm solid wood joists, spaced 400 mm o.c., are parallel to the wall/floor junction so the 1.2 $\times$2.4 m sheathing panels are oriented with the short axis and butt joints parallel to the junction. The long side of the panel joins to adjacent panels using interlocking tongue and groove joints. The 1.2 $\times$2.4 m gypsum board panels do not have a profile on the edges and the butt joints are oriented perpendicular to the wall/floor junction. Heavy dashed lines indicate the butt joints between panels.
Figure 2 shows the measured VLD from the gypsum board wall to the subfloor using two methods of excitation: airborne and impact. It is clear from the figure that the two methods of excitation provide different results. Airborne excitation tends to give lower VLD's. Since the operator is standing on the receive surface (the subfloor) while impacting the wall, it might be tempting to attribute the difference in measured VLD's to mass-loading of the receive surface by the operator. However, comparing the measured VLD's with the operator standing on the floor surface and standing on a platform that was not supported on the floor (curves with the rectangular symbols), it is evident that the mass of the operator did not appreciably affect the results. The exception is the range 2.5-5 kHz where the VLD was noticeably higher with the operator standing on the subfloor.
Two additional tests were made to check the sensitivity of the measured VLD's to the location of the hammer impacts. In the first measurement, the wall was excited by striking the heads of the screws which attach the gypsum board to the wood studs. In the second measurement, the gypsum board was excited by impacts to the gypsum board at locations midway between the studs to ensure that the studs were not excited directly. These represent extremes in how the wall could be excited.
Compared to the VLD due to random impacts, there is a higher VLD when the gypsum board wall is excited by impacts located midway between the studs and a slightly lower VLD when only the screw

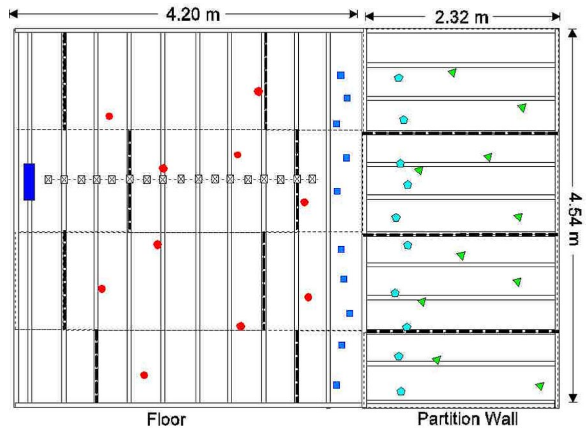


Figure 1: Accelerometer locations for the measurement of VLD between the subfloor and wall are shown by the solid symbols; also shown by the open symbol are the positions used for the draw-away measurements on the floor.

heads are impacted. This raises the question, which excitation method is more correct and is beyond the scope of this paper. Regardless of the answer, the two extremes are not sufficient to explain the difference between the airborne and impact excitation methods. The underestimation of the VLD's measured using airborne excitation can be attributed to the fact that, since all source room surfaces are excited, there are multiple paths to the receiving surface which increase the velocity of the receive surface thereby decreasing the VLD. Consequently, airborne excitation should be used with caution, especially if the source room surfaces are not shielded.

If the vibration response of the plates is truly diffuse then the measured VLD should be reasonably insensitive to the measurement positions with the largest change occurring in the low frequencies where there are fewer modes. The sensitivity of the method to measurement position was investigated by measuring the wall/floor junction using three sets of accelerometer positions. In Set 1 the accelerometers were randomly located on both the wall and subfloor. (The positions are shown in Figure 1 by the triangles on the wall and the circles on the subfloor). In Set 2 the accelerometers on the subfloor were moved toward the wall and located 0.25±0.07 m from the wall/floor joint (and are shown by the squares in Figure 1). The wall positions were unchanged. In Set 3 both the wall and subfloor accelerometers were located 0.25±0.07 m from the wall/floor joint. (The accelerometer positions on the wall are indicated by the pentagonal symbols in Figure 1).

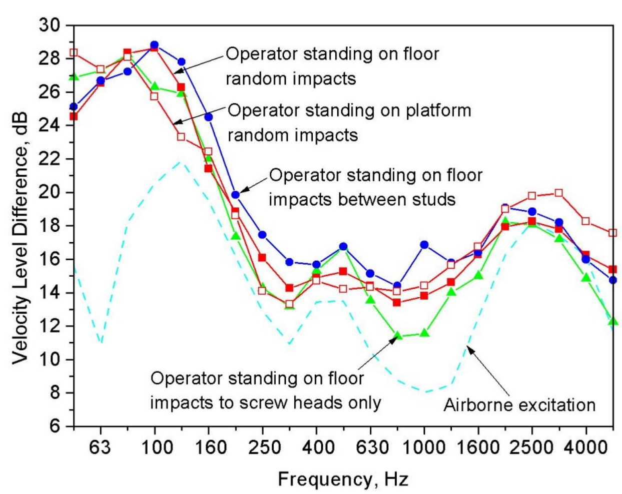
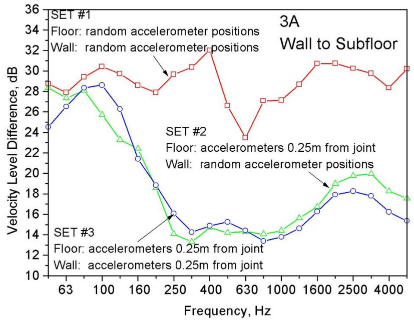
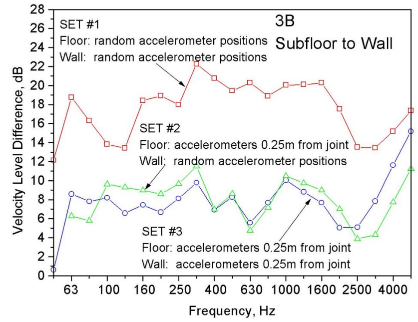


Figure 2: Measured velocity level difference between a gypsum board wall and the subfloor as a function of different excitation methods; the accelerometer positions were the same for all measurements.

Comparing Set 1 and Set 2 data of Figure 3 it can be seen that the measured velocity level difference is very sensitive to the location of the accelerometers on the subfloor. The change in VLD was greater than



(a): Wall to subfloor.



(b): Subfloor to wall.

Figure 3: Measured velocity level difference in the two directions using different accelerometer positions.

10 dB for frequencies greater than 200 Hz. However, comparing the data of Sets 2 and 3, it can be seen that there was virtually no change in the measured VLD as a result of moving the wall accelerometers close to the wall/floor joint.

The apparent insensitivity of the measured VLD's to the position of the accelerometers on the wall suggests that the vibration field resulting from excitation (either by impacts or by the junction) should be reasonably uniform and probably satisfies assumptions 1, 2 and 3, (i.e., the field is reasonably diffuse). Conversely, the marked drop in the measured VLD when the positions on the floor are moved closer to the wall/floor joint suggests that the vibration field is highly attenuated as it propagates in the subfloor. Strong attenuation with distance is inconsistent with the field being diffuse and the surface behaving as a single subsystem. This violates all the assumptions and is the subject of the next section.

4 - SURFACE VIBRATION RESPONSE

To investigate the vibration response of the wall and floor surfaces, draw-away measurements of surface acceleration were made along a line perpendicular to the joint. For measurements on the floor, an ISO tapping machine was used as the source. The source is shown in Figure 1 by the large solid rectangle on the floor while the positions of the accelerometers are shown by the series of open squares containing crosses.

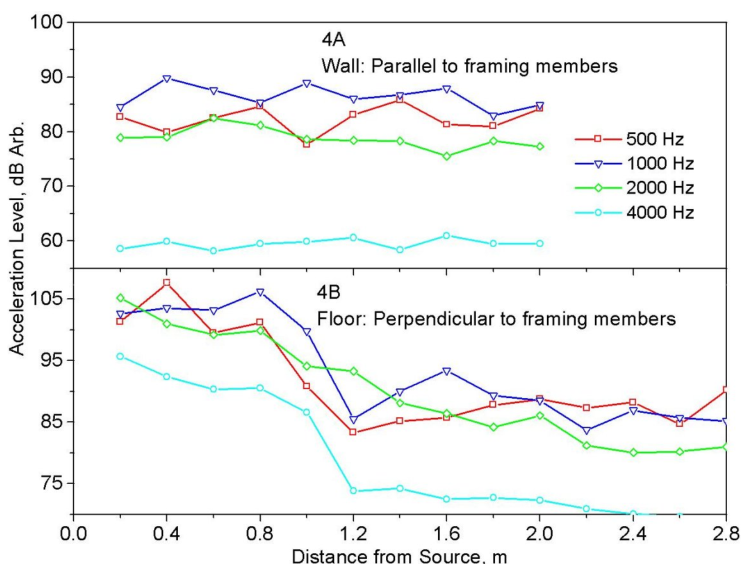


Figure 4: Measured surface velocity as a function of distance from the source for the gypsum board wall and the wood joist floor; the captions in the top right-hand corners indicate the surface and the direction of propagation with respect to the framing members.

Examining the acceleration levels with distance on the subfloor shown in Figure 4B, it is evident that the vibration response is not uniform as there are two distinct regimes. One close to the source where there is strong localization of energy and one further away where the level decreases with distance. The transition between the two regions occurs 1.2 m from the source where there is a butt joint in the subfloor sheathing (as shown in Figure 1). Obviously the discontinuity in the vibration levels at a butt joint between the subfloor panels precludes treating the floor surface as a single subsystem. In addition to the attenuation due to the butt joints, there is also a general reduction of vibration level with distance implying that the field is not diffuse and that an individual subfloor panel is not a homogenous and isotropic.

A similar investigation was done for the gypsum board wall. An ISO tapping machine excited the subfloor close to the wall/floor joint and the resulting velocity was measured from the bottom to the top of the wall along a line located midway between the studs. The measured levels are shown in Figure 4A and do not exhibit a strong attenuation with distance away from the joint. This is consistent with measured VLD being reasonably insensitive to the location of the accelerometers on the wall surface as shown in Figure 3.

5 - DISCUSSION AND CONCLUSIONS

The measured VLD's shown in Figure 3 are the result of two attenuation mechanisms: the wall/floor junction and losses in the measurement surfaces. The additional attenuation in the surfaces will tend to increase the measured VLD. Inspection of Figure 1 indicates that when the floor is the receive surface the vibration energy must propagate across a butt joint to get to eight of the ten Set 1 accelerometer positions. This explains the very high VLD's from the wall to the floor. Conversely, when measuring from the floor to the wall, random impacts from the hammer will be located such that the vibration energy can propagate to eight of the ten accelerometers without encountering a butt joint, however, to reach the wall/floor joint the energy must propagate across a butt joint. Again, the VLD will be overestimated due to the butt joint(s).

The unwanted attenuation of the subfloor butt joint(s) can be eliminated if all the accelerometers are placed between the wall/floor joint and the first butt joint (e.g., using Set 2 or 3 positions). This removes one attenuation mechanism but leaves propagation losses within an individual subfloor panel. Figure 4B indicates that for an accelerometer located between 0.8 and 1.0 m from the joint under test there could be as much as 5-10 dB of attenuation. Propagation losses are thought to be due primarily to the series of periodic plate beam junctions and can be minimized by placing the accelerometers in the first sub-panel. However, this might introduce an unwanted near-field contribution from the junction. By placing all the accelerometers in the first sub-panel one is, in essence, defining this a separate subsystem; one which is typically 0.4m wide and very much larger in the other dimension. Despite the moderate damping the modal overlap will be low because of the small area.

One further difficulty occurs in determining the effective mass of the surface. The mass of the sheathing may actually be less than that of the framing to which they are attached. It is not clear how to treat the mass of the framing members. Further work is needed to determine a suitable in-situ test method for lightweight framed constructions and how the measured VLD relate to power balance models.

REFERENCES

1. **R.J.M. Craik**, *Sound transmission through buildings using statistical energy analysis*, Gower Publishing, Aldershot, England, 1996

2. *Estimation of acoustic perfomance of buildings from the performance of elements. Part 1: Airborne sound insulation between rooms*, prEN 12354-1, 1999

3. **R.J.M Craik**, The measurement of structure borne sound transmission using impulsive source, *Applied Acoustics*, Vol. 15, pp. 355-361, 1981

4. **Draft prEN 10848-1**, *Laboratory measurement of the flanking transmission of airborne and impact noise between adjoining rooms. Pt. 1: Frame document*

5. **T.R.T. Nightingale, Ivan Bosmans**, Vibration response of wood frame building elements, *Journal of Building Acoustics*, Vol. 6, pp. 269-288