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VIBRATION REDUCTION INDEX KIJ, A NEW QUANTITY FOR SOUND TRANSMISSION AT JUNCTIONS OF BUILDING ELEMENTS

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1. INTRODUCTION

The airborne and impact sound insulation between rooms depends not only on the acoustic performance of the building elements, like walls and floors, but also on the acoustic performance of the junctions between these elements. To express the acoustic performance of elements well known quantities are used, the sound reduction index R and the impact sound pressure level L_n, and for these measurement methods are normalized [1], though not completely without shortcomings [2]. However, for the acoustic performance of junctions neither a practical quantity nor accepted measurement methods is available. In order to develop normalized prediction models for the sound transmission in buildings this problem was adressed and a new quantity was introduced to specify the acoustic performance of junctions of building elements [3, 4]. This quantity, the vibration reduction index K_{ij}, is suitable for developing normalized measurement methods and facilities.

2. SOUND TRANSMISSION AT JUNCTIONS

Flanking transmission

The sound transmission between rooms can be predicted by considering transmission paths from an element in the source room to an element in the receiving room. The total transmission follows from the summation over all transmission paths or at least summation over the most important ones. In principle this is the same as applying SEA to the whole system of the two rooms. The transmission of airborne sound or impact sound via one path from element i to element j can then be written as [3, 4]:

$$R_{ij} = \frac{R_i + R_j}{2} + \frac{D_{v,ij} + D_{v,ji}}{2} + 10\lg\frac{S_s}{\sqrt{S_i S_j}}$$
$$L_{n,ij} = L_{n,i} + \frac{R_i - R_j}{2} - \frac{D_{v,ij} + D_{v,ji}}{2} - 10\lg\sqrt{\frac{S_i}{S_j}} \qquad (1)$$

The elements involved in the transmission are characterised by their sound reduction index R, the normalized impact sound pressure level L_n and the areas S. The transmission over the junction is characterised by the vibration level difference between the elements D_v.

Junctions

However, the level difference over the junction depends on the actual situation as does the sound pressure level difference D_p between rooms. A more invariable quantity would be the structural reduction index R_s, an equivalent to the sound reduction index R_a for airborne sound. These quantities are related to the measurable level differences as follows:

$$R_a = D_{p,12} + 10\lg\frac{(\rho_o c_o)_2}{(\rho_o c_o)_1} + 10\lg\frac{S_{12}}{A_2}$$
$$R_s = D_{v,12} + 10\lg\frac{(m' c_B)_1}{(m' c_B)_2} + 10\lg\frac{l_{12}}{a_2} \qquad (2)$$

Instead of the common area and the absorption area, the common length l_{12} and the absorption length a appear. The absorption length depends on the structural reverberation time T_s:

$$a = \frac{2,2\pi^2 S}{c_o T_s}\sqrt{\frac{f_c}{f}} \qquad (3)$$

The terms $\rho_o c_o$ and $m'c_B$ relate to the wave impedance resp. in the rooms and in the elements (m' is the surface maas and c_B the bending wave velocity). For airborne sound this term cancels, but not for structure-borne sound. However, applying reciprocity it follows that:

$$R_{a,12} = R_{a,21}$$
$$R_{s,12} + 10\lg c_{B1} = R_{s,21} + 10\lg c_{B2} \qquad (4)$$

For airborne sound transmission this is sometimes applied to improve the accuracy of measurement results. The sound reduction index is determined as the arithmetical average of measurements in two directions, or:

$$R_a = \frac{R_{a,12} + R_{a,21}}{2} = \frac{D_{p,12} + D_{p,21}}{2} + 10\lg\frac{S_{12}}{\sqrt{A_1 A_2}} \quad (5)$$

If we apply eq. 4 for structure-borne sound to eq. 3 we can deduce a simular relation:

$$\frac{R_{a,12} + R_{a,21}}{2} = \frac{D_{v,12} + D_{v,21}}{2} + 10\lg\frac{l_{12}}{\sqrt{a_1 a_2}} \quad (6)$$

By always measuring the vibration level difference always for the two directions and using eq. 6 determination or estimation of the term (m' c_B) in eq. 2 is avoided, making the determination easier and more general. According to eq. 3 the absorption length contains also contains the critical frequency; this could easily be estimated for homogeneous elements but not so in general. To avoid this problem the critical frequency in eq. 3 is replaced by a fixed reference frequency (f_{ref}) and a is then denoted as the equivalent absorption length. For well-dampened constructions, like light weight double elements, the structural reverberation time is hard to determine but luckily also not relevant. The dampening is only determined by the element itself, not by the surrounding constructions and is thus invariant between laboratory and the different field situations. In that case eq. 6 gives the appropriate quantity to characterise the junction if the value for the equivalent absorption length is taken as numerically equal to the area of the construction [5] or in fact the area of the part of the construction over which the average velocity level is determined [5]. The new quantity according to eq. 6 to characterise the sound tranmsission at junctions of elements i and j is denoted as K_{ij} and called vibration reduction index:

$$K_{ij} = \frac{D_{v,ij} + D_{v,ji}}{2} + 10\lg\frac{l}{\sqrt{a_i a_j}} \; ; \; a = \frac{2,2\pi^2 S}{c_o T_s}\sqrt{\frac{f_{ref}}{f}} \quad \text{or} \quad a = S \quad (7)$$

with f_{ref} = 1000 Hz. Eq. 7 can be applied to determine K_{ij} as characteristic for a junction, for instance in a test set-up. In a given field situation eq. 7 can be used the other way around to determine the flanking transmission in combination with eq. 1 by estimating the absorption length in that field situation. Since eq. 7 is thus used twice, the reference frequency cancels anyway in determining the flanking transmission.

Homogeneous elements. The vibration reduction index for homogeneous elements is also easily deduced from theoretical values for the bending wave power transmission factor γ by:

$$K_{ij} = -10\lg\gamma_{ij}\sqrt{\frac{f_{ref}}{f_{c,j}}} = -10\lg\gamma_{ji}\sqrt{\frac{f_{ref}}{f_{c,i}}} \qquad (8)$$

Light weight, damped elements. For light weight, damped elements the equivalent absorption length is numerically equal to S and eq. 1 can be re-written as:

$$\begin{aligned} R_{ij} &= \frac{R_i + R_j}{2} + K_{ij} + 10\lg\frac{S_s}{l_{ij}} \\ L_{n,ij} &= L_{n,i} + \frac{R_i - R_j}{2} - K_{ij} - 10\lg\frac{S_i}{l_{ij}} \end{aligned} \qquad (9)$$

Thus for this type of elements the flanking transmission in the field is no longer dependent on the area of the elements, but just on the length over which these are coupled. As a first approximation this could be used for all types of elements.

Measurement methods

Thus the vibration reduction index K_{ij} according to eq. 7 is suited for characterising the transmission over junctions between various elements. Measurement methods can be specified to determine this quantity for junctions in special (laboratory) measurement facilities and under certain restrictions probably also in field situations [6]. This is a task taken up by CEN/TC126 [7]. The normalization term in eq. 7 is in buildings roughly equal to - 5 dB on average. This can be used in the mean time to translate available field data on the vibration level difference D_v into values for K_{ij}. Further research is needed, especially to determine the necessary conditions for the measurements and the measurement set-up in order to get reliable and reproducible results.

3. MEASUREMENT RESULTS

Some results are given of prelimary measurments of the vibration reduction index according to eq. 7. The vibration reduction index can be measured by structural excitation of an element and measuring the average velocity level of the excited and the receiving element. In figure 1 an example is given for the transmission between two ground level concrete floors over a junction with a brick work partition wall. The excitation has been done in three different ways: by the tapping machine, by hammering with a plastic hammer in a small area and by dropping a plastic ball several times from a specified height on three positions. The velocity level is measured on several points on the floors. With the tapping machine the equivalent velocity level is measured successively on the two floors, with the hammer the equivalent velocity level is measured over several hammer blows, simulteneously on the two floors.

With the falling ball the maximum velocity level is measured with integration time 'F" succesively on the two floors.
The results are compared with calculations based on older empirical data [3]. As can be seen the results do not differ much between the different measurement methods on these rather heavy constructions. The measured results are also reasonably in accordance with the calculated values.

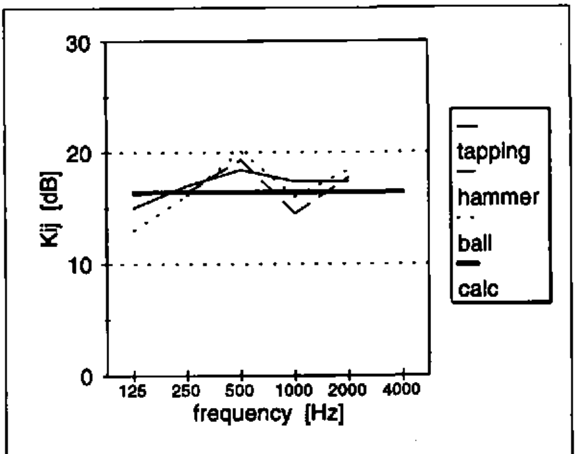

Fig. 1 K_{ij} for a junction between concrete floors and a brick work partition wall; several measurement methods and a calculated value.

In figure 2 an example is given of a cross-junction between profiled steel floor and wall elements, before and after the receiving element was covered by a gypsum board floating floor.

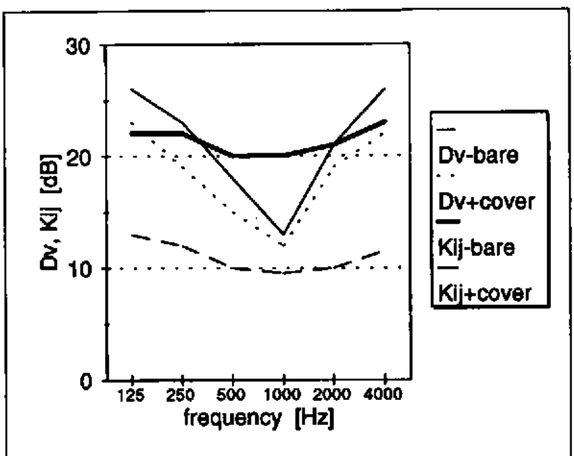

Fig. 2 D_v and K_{ij} for a bare or covered cross-junction between profiled steel elements.

The addition of the floating floor greatly influenced the structural reverberation time of the steel construction. This is reflected in the rather large difference between the vibration level difference (D_v) for the two situations. The difference in the vibration reduction index K_{ij} for the two situation is much smaller, except for the 1kHz octave band. The reasons for the low values in this band for the floor with covering are not really clear.

Figure 3 gives an example for the junction between a brick wall partition and a facade cavity wall of brick work inside and outside. Clearly the transmission to the wall is dominated by the inner leaf and is as a homogeneous T-junction. For the transmission from facade to facade the cavity and outer leaf are more important, hence the increase with frequency.

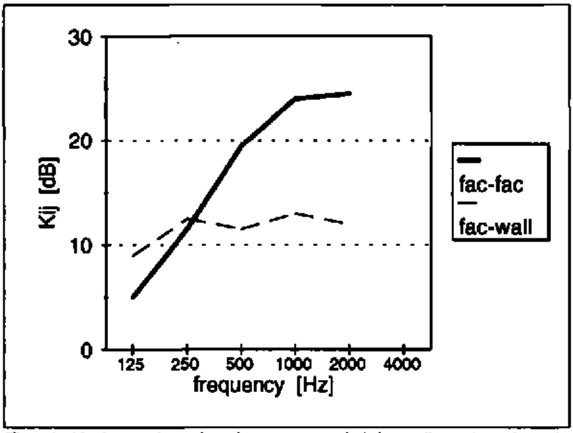

Fig. 3 K_{ij} for a junction between a brick wall and a facade cavity wall.

4. CONCLUSIONS

The vibration reduction index K_{ij} is defined in such a way that it can characterise the sound transmission at junctions between various types of building elements, it is independent of the situation (dimensions and surroundings of the elements involved) and it can be determined from measurable quantities. Some first measurement results show that potentially different measurement methods could be used to specify standardized methods.

References

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