Aspects of the measurement of K_{ij} at junctions of lightweight assembled structures

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Introduction

The EN 12354-1/2:2000 is a valuable tool for the prediction of airborne and structure-borne sound transmission in buildings. But unfortunately, the methods mostly are applied only to homogeneous monolithic building elements ('heavy' elements, e.g. masonry, concrete), since a great knowledge was obtained over application and determination of input data for the model in recent years.

Less research was done regarding lightweight assembled building elements (e.g. double leaf framed gypsum board walls), even though they become more important in modern buildings due to their advantages, like their small weight and thickness as well as the fast mounting and the greater flexibility of the created rooms.

Further regularly fundamental mistakes are made in research projects that are done particularly on the measurement of the vibration reduction index K_{ij} at this type of elements, since measurement methods were applied identically as to junctions of 'heavy' structures.

Review of EN 12354

Basic Equations of EN 12354

In the model also transmission that occurs over 1st order flanking paths are taken into account besides the direct sound transmission. The flanking sound reduction index R_{ij} for airborne sound transmission between adjacent rooms over the elements denoted by subscript i and j is calculated out of the sound reduction indices R_i, R_j for direct resonant transmission through the elements, the improvements of the sound reduction index by additional layers ΔR_i, ΔR_j, the direction averaged velocity level difference $\overline{D_{v,ij}}$ and the area of the surfaces of the elements S. Subscript s denotes the separating element and *situ* the particular situation.

$$R_{ij} = \frac{R_{i,situ} + R_{j,situ}}{2} + \Delta R_{i,situ} + \Delta R_{j,situ} + \overline{D_{v,ij,situ}} + 10\lg\frac{S_S}{\sqrt{S_i S_j}} \quad (1)$$

$\overline{D_{v,ij,situ}}$ is determined from the vibration reduction index K_{ij} which is normalized and independent of the dimensions of the elements.

$$\overline{D_{v,ij,situ}} = K_{ij} - 10\lg\frac{l_{ij}}{\sqrt{a_{i,situ}\, a_{j,situ}}}, \quad a_{i,situ} = \frac{2{,}2\pi^2 S_i}{c_0 T_{s,i,situ}}\sqrt{\frac{f_{ref}}{f}} \quad (2)$$

K_{ij} depends only on junction details and frequency to derive the level difference. It has to be adjusted to the length of the junction l_{ij} and the equivalent absorption lengths $a_{i,situ}$ and $a_{j,situ}$ that contain the surface area S and structural reverberation time T_s of the element, sound speed in air c_0, centre band frequency f, and reference frequency f_{ref} = 1000 Hz. With the structural reverberation time T_s losses that occur across the non-regarded junctions and cannot be neglected are taken into account for weakly damped 'heavy' structures. The equivalent absorption length is set numerical equal to the surface area S of the element, in cases, where those losses are not significant or exceeded by the great internal damping.

Measurement of K_{ij} according to prEN ISO 10848-1/3:2001

Indirect Measurement of K_{ij}

The normalized sound pressure level difference $D_{n,ij}$ is measured between two rooms with only one dominating transmission path through the elements i and j. Thus the junction is mounted in an enclosure with a high sound insulation (Figure 1) and shielding must be applied to avoid excitation or radiation of non-regarded surfaces of the specimen.

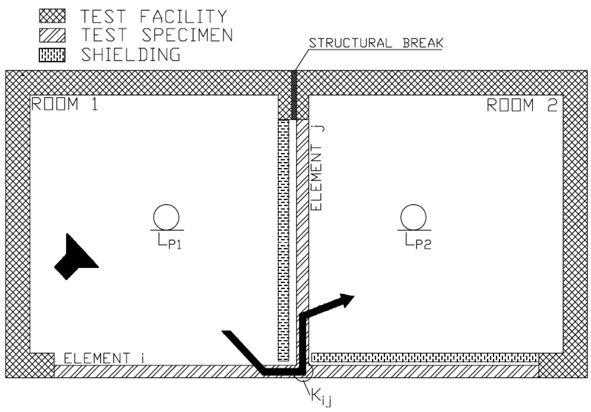

Figure 1: Test set-up for indirect measurement of K_{ij}

The K_{ij} is found by performing the reverse procedure to the prediction, taking the properties of the set-up into account.

$$K_{ij} = D_{n,ij} + \frac{R_i + R_j}{2} - 5\lg\frac{a_i a_j}{l_{ij}^2} + 5\lg\frac{S_i S_j}{S_S^2} \quad (3)$$

The advantage of this method is that it is practicable for all types of building elements, but on the other hand a special test facility is required.

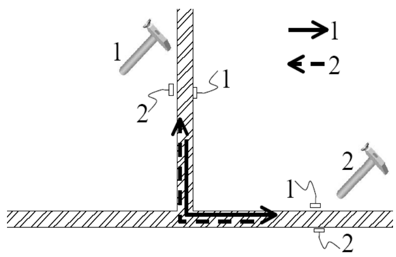

Figure 2: Test set-up for direct measurement of Kij

Direct Measurement of K_{ij}

The test set-up for this method is shown in Figure 2. The direction averaged velocity level difference $\overline{D_{v,ij}}$ is measured directly on the elements and K_{ij} found using equation 2.

In this case no test facility is required, but unfortunately the method seems to be only practicable for junctions of 'heavy' building elements until now.

Physical Interpretation of K_{ij}

Recently Nightingale et al. [1] showed that the expression of the EN 12354 for the sound transmission through a 1st order flanking path of homogeneous monolithic elements is identical to the one derived by the power balance model 'Statistical Energy Analysis' (SEA). K_{ij} is equivalent to the 'Coupling Loss Factor' of SEA that governs the power flow between two simple coupled sub-systems.
A comparable interpretation for K_{ij} of lightweight assembled elements is not found and proved yet.

Derivation of Expressions

Sound transmission over a 1st order path in one direction can be expressed in terms of incident and radiated sound power of the surfaces (s. Figure 3) [2]. The radiated sound power W_{rad} can be expressed in terms of the time and space averaged surface velocity $\langle v^2 \rangle$, the specific acoustic impedance $\rho_0 c_0$, the area of radiating surface S and its radiation coefficient σ.

$$W_{rad} = \rho_0 c_0 \sigma S \langle v^2 \rangle \tag{4}$$

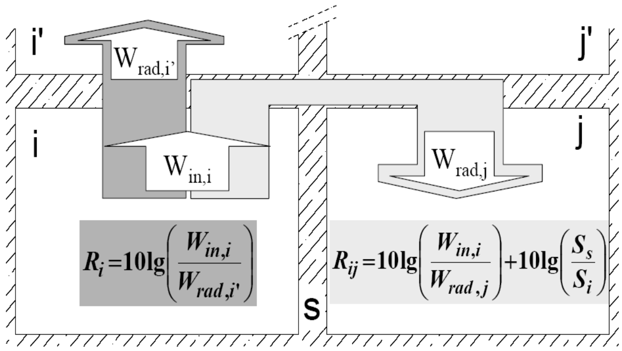

Figure 3: Flanking transmission in one direction

The unknown incident sound power $W_{in,i}$ can be replaced in the flanking sound reduction index R_{ij} in terms of the direct sound reduction index R_i and radiated sound power can be substituted by equation 4 and leads to equation 5.

$$R_{ij} = R_i + 10\lg\left(\frac{\sigma_{i'} S_{i'} \langle v_{i'}^2 \rangle}{\sigma_j S_j \langle v_j^2 \rangle}\right) + 10\lg\left(\frac{S_s}{S_i}\right) \tag{5}$$

Applying the reciprocity relationship of direction independence of the sound reduction index and averaging R_{ij} and R_{ji} we finally obtain equation 6.

$$R_{ij} = \frac{R_i + R_j}{2} + 5\lg\left(\frac{\sigma_{i'} \langle v_{i'}^2 \rangle}{\sigma_j \langle v_j^2 \rangle}\right) + 5\lg\left(\frac{\sigma_{j'} \langle v_{j'}^2 \rangle}{\sigma_i \langle v_i^2 \rangle}\right) + 10\lg\left(\frac{S_s}{\sqrt{S_j S_i}}\right) \tag{6}$$

Homogeneous Monolithic versus Lightweight Assembled Structures

K_{ij} is based on the 2nd and 3rd term of the right hand side of equation 6, thus only those terms will be regarded in the following. For 'heavy' elements the equation can be further simplified, since the critical frequency is usually low and radiation coefficients are almost equal in the regarded frequency range. Regarding in this range a thin homogeneous weakly damped plate also the number of modes in a frequency band is high. The vibration response of the plate is uniform and the velocity is at every point on the surfaces of a element almost equal to the space averaged velocity that is further proportional to the kinetic energy of the element. The radiation coefficients as well as the particular surface of the element, where the velocity is measured, can be neglected.

Regarding lightweight assembled structures, like double leaf framed walls, conditions are more complicated. The critical frequency is usually above the regarded frequency range. Regarding R_i, R_j and σ it must be differentiated between forced and resonant transmission, resp. radiation. The average velocity is different on every leaf of the element and therefore the velocity of particular surfaces must be taken into account at the measurement of K_{ij}. Further, due to the low modal density, the high internal damping, the not uniform mass load and many discontinuities velocity varies strongly over each surface.
All in all, a statement over the conserved kinetic energy of an element can not be made with the given information. Thus, K_{ij} is the difference of the directly and via the flanking path transmitted power rather than the difference of kinetic energy of coupled elements.

Conclusions for Measurement of K_{ij}

It was shown that the physical interpretation of K_{ij} as quantity that governs power flow between two elements at junctions of homogeneous monolithic elements does not hold for lightweight assembled elements. Even though the EN 12354 model generally is valid for all types of structures, most of the conditions for its application and the determination of input data are based on this interpretation.
The meaning of K_{ij} of junctions of lightweight assembled structures is not fully understood yet, but nevertheless the indirect method seems to be reliable for its determination. Due to the reverse application of the same expressions as for the prediction, the quantity K_{ij} is used as 'Black-Box', in which also the influence of other parameters than those that are important for 'heavy' elements are automatically included.
Before the direct measurement method can be applied to junctions of lightweight assembled elements, the existing conditions for 'heavy' structures have to be reviewed regarding assembled elements as well as the influence of other parameters has to be determined. As shown above it must be pointed out that contrary to 'heavy' elements the velocity level difference must be measured between particular surfaces of framed double leaf structures.

References

[1] Expressions for 1st order flanking paths in homogenous isotropic and lightly damped buildings. T. Nightingale et al., Acta Acustica united with Acustica 89 (2003), 110-112

[2] Calculation of the sound transmission between dwellings by partitions and flanking structures. E. Gerretsen, Applied Acoustics (1979), 413-433