Study of the Influence of Adjacent Elements on the Sound Level Decay of Heavy Building Structures by means of Transient SEA

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Introduction

The loss factor is an important acoustic property of building elements. The sound reduction and the vibration level difference depend strongly on this quantity. The loss factor of a structure is commonly determined by measuring the level decay (e.g. T_{20} evaluating the decay between -5 dB and -25 dB) on the structure. But most building structures are rigidly connected to adjacent elements and therefore will be an exchange of energy between these elements. The level decay on these coupled building structures is similar to the level decay of rooms with coupled volumes. And the level decay of coupled air volumes must not be a straight line. A change in the gradient of the decay curve will indicate a difference in energy losses.

To investigate the loss factor and the decay of energy e.g. into the adjacent building elements a statistical energy analysis (SEA) model is used. This model is extended to a Transient Statistical Energy Analysis (TSEA) model according to Kling [1]. With this TSEA the decay of coupled building structures can be examined. With this analysis the observed total loss factor of the structure is time dependant.

TSEA

The decay process of the Transient SEA is based on the classical SEA method. The classical SEA method calculates the energy E on each subsystem considering the different loss factors η (η_i: total loss factor; η_{ij}: coupling loss factor calculated from the Transmission loss τ according to Craik [2]) and the power input on the right hand side of the equation.

By switching off power input P_{in} into the system, the energy levels of all subsystems begin to decrease. The rate of change of energy is set equal to the power losses of the element. Therefore in equation (1) the input power on the right hand side is replaced by the power losses.

$$\begin{bmatrix} -\eta_1 & \cdots & \eta_{N1} \\ \vdots & \ddots & \vdots \\ \eta_{1N} & \cdots & -\eta_N \end{bmatrix} \cdot \omega \begin{bmatrix} E(t)_1 \\ \vdots \\ E(t)_N \end{bmatrix} = \begin{bmatrix} P_{loss}(t)_1 \\ \vdots \\ P_{loss}(t)_N \end{bmatrix} \qquad (1)$$

After calculating the power loss a new energy distribution can be calculated by subtracting the power lost in a small time interval (e.g. Δt=0,1 [ms]) from the energy on the element. With this new energy distribution the energy balance of the system is calculated for each time step. This results in a decay curve for each subsystem. It is assumed that the energy exchange between the plates happens in each time interval.

In figure 1 the energy level decay at f = 1000 Hz of the partition wall between two rooms with several flanking plates is shown. The partition wall is excited with a stationary source and the source is switched off at t = 0. The change of the gradient of the decay curve can be illustrated by an observed transient loss factor. This loss factor describes the energy decay of the subsystem.

$$\eta_{loss,i}(t) = \eta_i - \sum_{j(j\neq i)} \eta_{ji} \frac{E_j(t)}{E_i(t)} \qquad (2)$$

In general the transient loss factor $\eta_{loss,i}$ (t) is smaller than a loss factor obtained under stationary conditions η_i. In general its this stationary loss factor η_i which we are interested in, because this loss factor describes the amount of energy lost under stationary conditions which we have when we measure sound insulation or the power input into a structure. The smaller transient loss factor can be explained by change of the energy ratio $E_j(t)/E_i(t)$ in eq. 2. The net power flow from the excited element into the adjacent elements decreases when the the level difference between the excited element and the adjacent elements decreases.

Figure 2 shows the corresponding transient loss factor $\eta_{loss,i}$ (t) calculated from the decay curve (Figure 1) of an excited subsystem. The loss factor decreases during the decay.

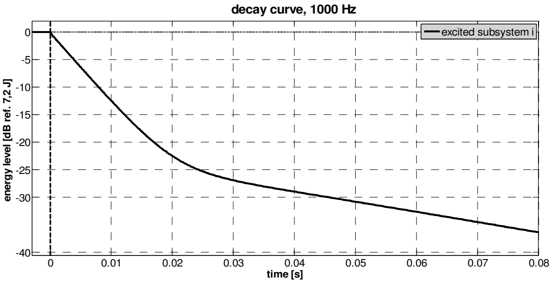

Figure 1. Decay curve of an excited building element integrated in a system

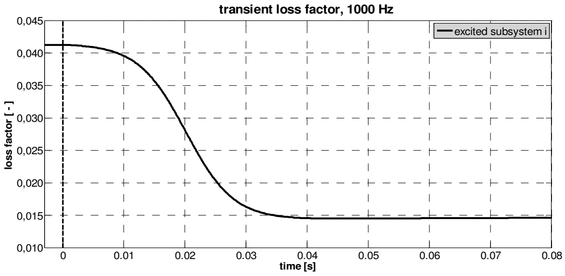

Figure 2. Corresponding transient loss factor of the decay curve in Figure 1

Simulation

For the first investigations three different systems, starting with a T – joint, a double room situation and a three storey building situation shown in figure 3 have been simulated. By changing parameters like material properties and thickness, the acoustical behaviour of the excited wall changes in each situation and the level decay and loss factor are examined.

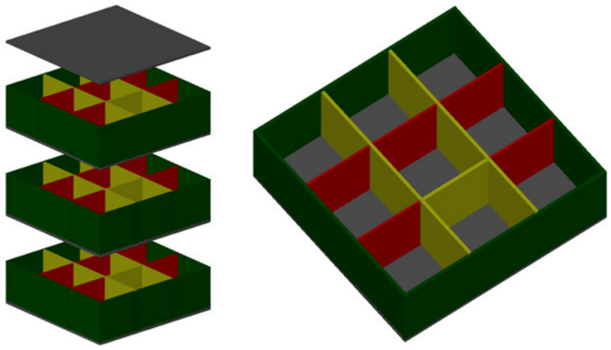

Figure 3: Model of the building situation, red: Lightweight concrete d = 11,5 cm, green: calcium silicate (CaSi: ρ = 1.4 kg/dm³) d = 17,5 cm, yellow: CaSi (ρ = 2.0 kg/dm³) d = 24 cm, grey: concrete d=20 cm.

This model covers a building which consists of three floors and squared plates made of different materials and thicknesses. The investigations have been carried out on the separating wall of the second floor. The adjacent elements are partitions between rooms (lightweight concrete) or partitions between dwellings (calcium silicate walls).

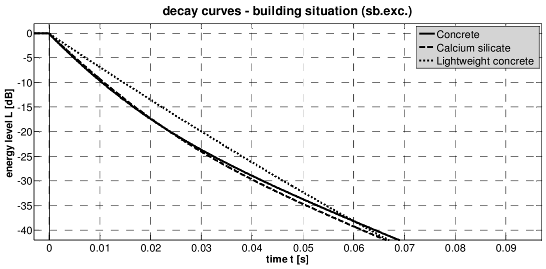

Figure 4. Decay curves for different partitions in a building situation using structure-borne excitation.

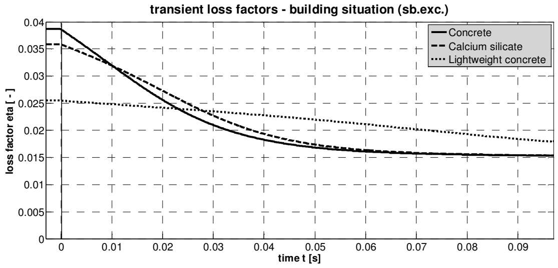

Figure 5. Transient loss factor for different partitions in a building situation using structure-borne excitation.

In figure 4 the decay of the different partition walls is shown. The change in the decay of the heavy partitions is more distinct whereas the curve of the lightweight concrete partition is more linear. This seems due to the fact that the lightweight concrete wall has higher vibration level differences and therefore smaller energy losses into the adjacent elements. Due to the minor transmission loss the energy level decays slowly and continuously.

The high loss factor of the heavy partitions in figure 5 is based on the large number of building elements in the system. Most of the adjacent elements have a similar mass per area (m'' > 300 kg/m²) like the excited structure whereby a high distribution of energy occurs. In general, the loss factor for each partition devolves into an averaged internal loss factor of the system. The non linearity of these decay curves indicates that the evaluated reverberation time can vary significantly dependant on the loss behaviour of the investigated partition and its surrounding elements.

Summary

By using the Transient SEA approach (TSEA) the influence of adjacent subsystems on the decay process has been investigated. The observed loss factor of the excited element coupled to the surrounding elements decreases after the source is switched off. The energy level differences between the excited element and the adjacent structures determine the level decay.

Measurements of the structural reverberation time using the slope of the decay curve will therefore underestimate the total loss factor. The difference depends on the energy level difference between the excited plate and the adjacent plates. If the energy levels on the surrounding plates are much lower e.g. the excited plate has a smaller surface mass, then the decay starts with a constant slope. After this first drop in level decay the gradient of the level decay gets smaller due to a smaller energy flow from the excited element to the adjacent structures. In this case the measured loss factor T_{20} corresponds to the total loss factor during stationary excitation. If surface mass of all the plates is the same, the level difference between excited and adjacent building elements is small. The change in energy levels due to the switch off of the source leads to a rapid change in energy losses. In this case the decay curve sags and the measured loss factor is much smaller than for stationary excitation. If the investigated building consists of a large number of elements, the energy flow from the excited element into the adjacent elements becomes more dominant. In this case the measured and stationary loss factors are quit similar.

References

[1] Kling, Christoph: Investigations into Damping in Building Acoustics by Use of Downscaled Models; Dissertation RWTH Aachen; Logos Verlag Berlin, 2008

[2] Craik, Robert J.M.: Sound Transmission through Buildings using Statistical Energy Analysis; Gower Publishing Ltd., 1996