SOUND TRANSMISSION THROUGH CROSS-JOINTS IN MULTI-FAMILY HOUSES WITH LIGHTWEIGHT, DOUBLE STRUCTURES AND STEEL SUPPORTING STRUCTURES – MEASUREMENTS

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ABSTRACT
In the Netherlands new building concepts with removable inner walls, floors and installations are developed for multi-family houses. Lightweight, double structures as separating floors and walls and steel structures are applied. In order to fulfil the noise requirements, it is necessary to restrict the sound transmission through cross-joints and steel structures. For a future building, experimental set-ups of the cross-joints have been built (scale 1:1). Vibration reduction indices and other important parameters have been measured in these set-ups. In this paper the experimental set-ups and the measurement results are described. Based on the measurement results the airborne and impact sound insulation between houses is predicted. Another part of this research concerns the making of a FEM model of the cross-joints and is described in a separate paper.

INTRODUCTION

In the Netherlands new building concepts for multi-family houses are developed. The most important characteristic of these concepts is flexibility. Depending on people's needs, multi-family houses, which are built according to these concepts, could be changed relatively easy in future. For example, rooms or eventually houses in these buildings could be made larger or smaller or building service equipment, including pipe systems, could be changed in future. Therefore, walls, floors and installations have to be removable relatively easy. This asks for lightweight, double building structures. In combination with steel supporting structures, this results in lightweight and often time-saving building concepts.
One of the disadvantages of these building concepts is the fact that the cross- and T-joints in these buildings have a limited weight. From a construction point-of-view complete decoupling is not possible in most cases. Often, flexible couplings are not effective because of the limited bending stiffness of the steel elements. In combination with lightweight building structures fixed to the joints, this results in relatively small vibration reduction indices of the cross- and T-joints. However, in order to fulfil the noise requirements, it is necessary to restrict the sound transmission through the joints.
This research consists of several parts. In this research FEM models of some cross-joints have been made in order to predict the vibration reduction indices of some design variants for a future building (see figure 1). The results of that research part are described in a separate paper. Further, some experimental set-ups have been built. In these set-ups the vibration reduction indices have been measured. The research results are described in this paper.

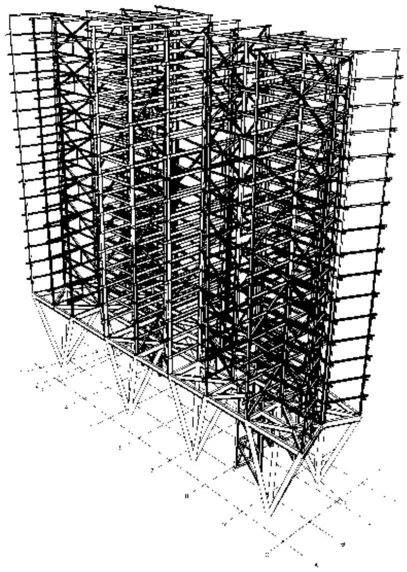

Figure 1 Impression of the considered building

SOUND TRANSMISSION

Figure 2 shows the cross-joint in detail.

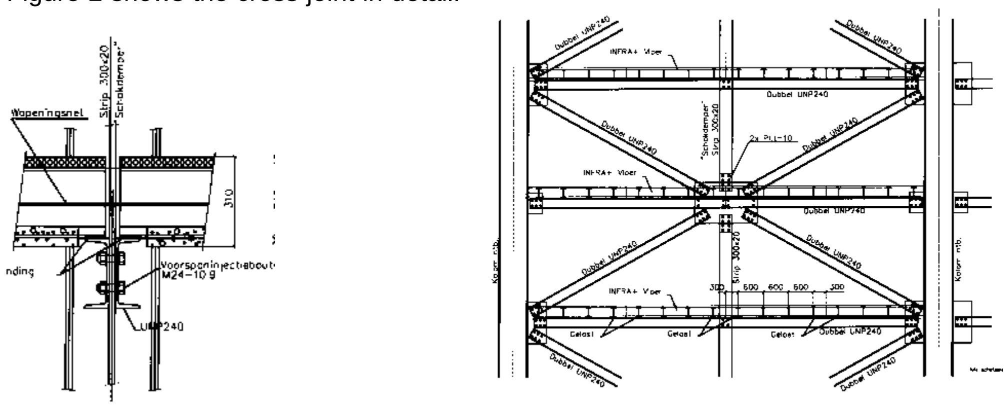

Figure 2 Cross-joint

The lightweight, double walls and floors in this figure are separating structures between apartments in the considered multi-family house. The walls consist of two gypsumboard leaves, which are completely separated from each other. The floors consist of a layer of 70 mm concrete, in which steel IPE beams are imbedded. A 22 mm thick wooden-like floor lays freely on rubber elements on the IPE beams. The cavities in the walls and floors are partially filled with mineralwool. Besides, the cavity in the floor contains both ventilation ducts and sanitary and drinking water pipes.

The airborne sound insulation of the wall and the airborne and impact sound insulation of the floor are high enough to fulfil the noise requirements (direct sound transmission paths).
This research mainly concerns the sound transmission (flanking) from the concrete floor layer in one apartment through the steel supporting structure to the concrete floor layer in another apartment. From a construction point-of-view this floor element has to be connected rigidly with the steel structure at some points. Concerning the vibration reduction indices of the cross-joint, this is the weakest transmission path. This transmission path determines the airborne sound transmission between the apartments. In order to restrict the sound transmission via this path, the cross-joint (especially the steel supporting structure) has been redesigned, based on the research results from the FEM model and from the measurements.

The flanking sound transmission of the other paths (for example from wooded floor to wooden floor or to wall elements in other apartments) is restricted enough by spring-like elements, like rubber, or by complete decoupling (for example of the facade elements).

In the Netherlands the noise requirements, which have to be fulfilled for apartments next to or above each other, roughly correspond to the following values:
- airborne sound insulation: $D_{nT;A} \geq 51$ dB(A);
- impact sound insulation: $L_{nT;A} \leq 59$ dB(A).

At the beginning of the research the airborne sound insulation and impact sound insulation have been estimated, based on the geometry of the considered building design and proposed dimensions and materials of the building structures. From the calculation results minimum values for the vibration reduction index K_{ij} of the weakest transmission path (concrete floor element – steel supporting structure – concrete floor element) have been derived. In order to fulfil the noise requirements, K_{ij} should be at least 13 dB in the 250 Hz 1/1-octave band. Both the FEM calculations and measurements have shown that this octave band determines the airborne sound insulation.

EXPERIMENTAL SET-UPS AND MEASUREMENT METHOD

Vibration reduction indices have been measured in two experimental set-ups as shown in the figures 3 and 4. The main difference between these experimental set-ups is the steel supporting structure.

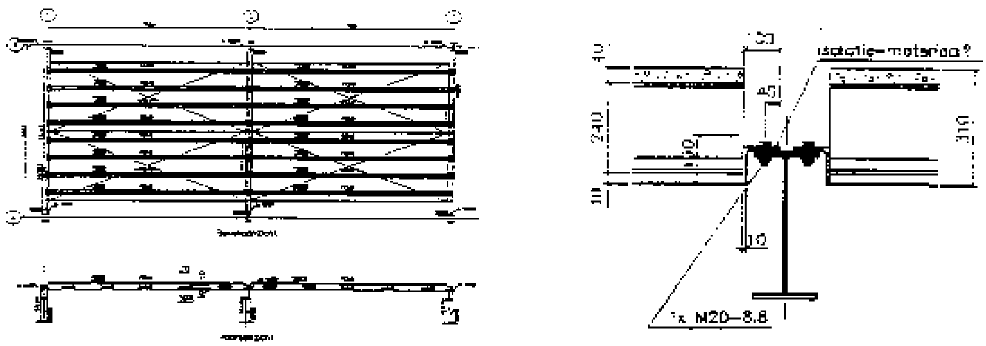

Figure 3 Experimental set-up 1

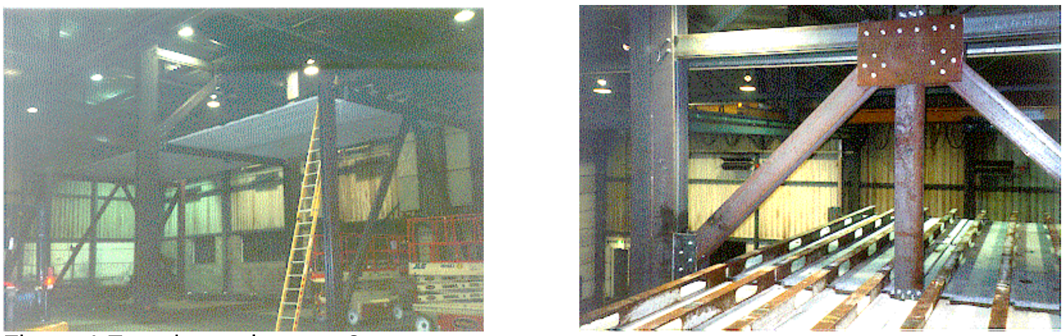
Figure 4 Experimental set-up 2

In the first set-up both floor elements were supported by one common IPE beam. Rubber plates between the floor elements and beam were applied. In this set-up, there was no 'decoupling' by the rubber due to the fact that the bending stiffness of the IPE beam was not high enough. However, from this set-up some valuable data concerning other transmission paths than the one considered in the second set-up have been measured.

In the second set-up, each floor element was supported by a UNP beam. The UNP beams were coupled indirectly by the columns and the steel strip in the mid-joint between the columns. The dimensions of this set-up have been based on the criterion that at least two modes in each

construction element were expected. This set-up was based on the FEM model more or less. In this set-up vibration reduction indices concerning the path floor – steel supporting structure – floor have been measured for two variants of the set-up.
Experimental set-up 2 agrees with the FEM model as described in the other paper. However, there are some important differences between the model and the set-up:

- in the FEM model the floor elements are 'decoupled' by applying rubber plates in the mid-joint between the columns; this is not the case in the experimental set-up;
- in the FEM model the windbracing consists of a double structure of UNP beams, which are 'decoupled' in the mid-joints by applying rubber plates; in the experimental set-up the windbracing consists of a single structure of HEB beams.

The vibration reduction indices have been derived with [1, 2]:

$$K_{ij} = \overline{D_{v,ij}} + 10\lg\frac{l_{ij}}{\sqrt{a_i a_j}};\ \overline{D_{v,ij}} = \frac{D_{v,ij} + D_{v,ji}}{2};\ D_{v,ij} = L_{v,i} - L_{v,j};\ a_i = \frac{2{,}2\pi^2 S_i}{c_o T_{s,i}}\sqrt{\frac{f_{ref}}{f}};\ f_{ref} = 1000\,\mathrm{Hz} \quad (1)$$

One of the floor elements was excited by a tapping machine. The time- and spatial average of the vibration response of both the excited and 'receiving' structures has been measured.
The structural reverberation time of the floor elements has been derived out of the impulse response of the elements at several points after excitation with a hammer. The structural reverberation times have been measured with the computer program Dirac (version 2.5 from Acoustics Engineering, The Netherlands).

MEASUREMENT RESULTS

In experimental set-up 2 measurements have been done for two variants:

- with a coupling of the floor elements in the mid-joint between the columns;
- with a complete separation of the floor elements between the columns.

The measurement results are presented in the figures 5 and 6. Although the second experimental set-up does not agree completely with the FEM model, K_{ij} values as derived from the FEM calculation results are presented in figure 6 also.

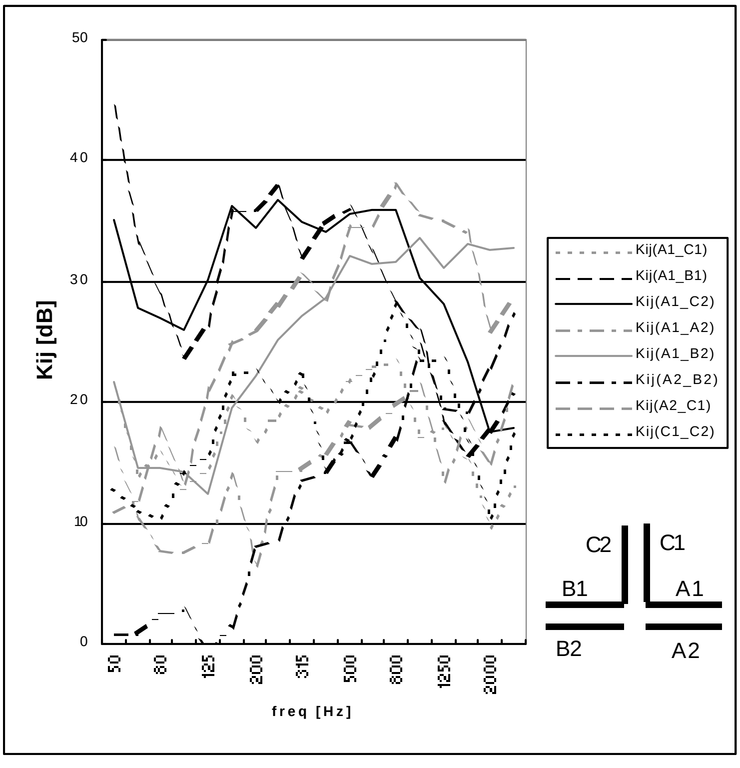

Figure 5 Vibration reduction indices as measured in experimental set-up 1

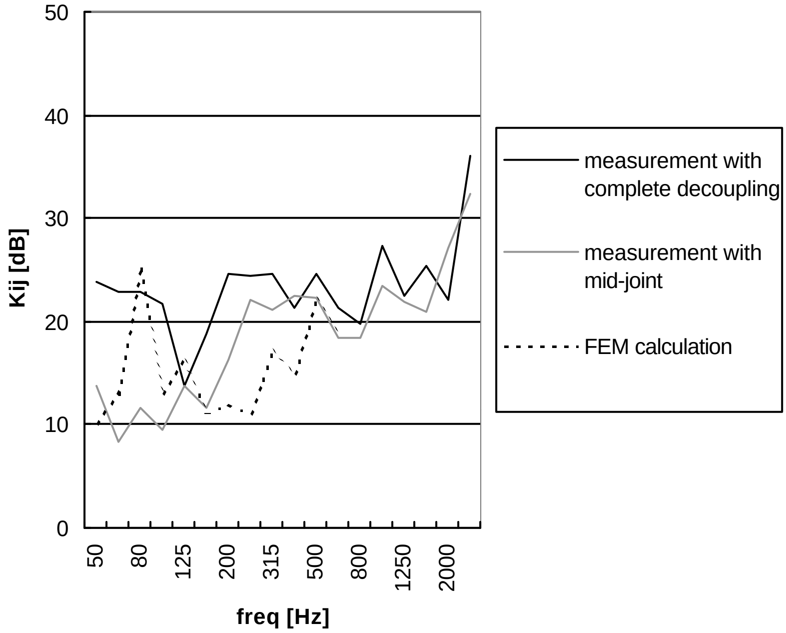

Figure 6 Vibration reduction indices as measured in experimental set-up 2

Figure 5 shows that:
- due to the rubber plates between the wooden-like floor element and the IPE beams the vibration level difference ($D_{v,ij} = L_{v,i} - L_{v,j}$) between the upper (excited) and lower floor element is about 25 dB;
- the vibration reduction index K_{ij} for the transmission between the concrete floor elements is almost zero under 200 Hz; this shows the non-effectiveness of the rubber plates in this case (see above);
- the vibration transmission between the upper floor elements is determined partially by transmission through the joint and partially by transmission via the separating wall; however, these transmissions are smaller for the final design.

Figure 6 shows that:
- the K_{ij} values in the 250 Hz 1/1-bands are lower than 13 dB and therefore not high enough to fulfil the noise requirements;
- complete separation of the floor elements results in much higher K_{ij} values in the 63 Hz, 125 Hz and 250 Hz 1/1-octave bands; the K_{ij} values are higher than 13 dB in this case;
- the FEM model results are conservative, compared to the measurement results: in general the K_{ij} values as derived from the FEM calculation results are smaller than the measured K_{ij} values (maximum deviation 10 dB at 80 Hz and 250 Hz, other frequencies deviation 0-4 dB).

PREDICTION OF AIRBORNE AND IMPACT SOUND INSULATION

Based on the measured and calculated vibration reduction indices and sound insulation of the structures, the airborne sound insulation and impact sound insulation between apartments next to each other have been predicted. The calculations have been performed with the computer program BASaid (version 1.6-1999 from TNO Institute of Applied Physics), according to EN 12354-1 [1] and EN 12354-2 [2].
The calculations have been done for a representative situation in the considered building. It concerns two apartments of 10 x 7 x 2,5 m^3 next to each other. No flanking via facades and inner walls is assumed. The floor elements are completely separated ('decoupled') between the columns, according to variant 2 of experimental set-up 2. Only indirect coupling via the columns and windbracing exists.

The calculation results are:
- airborne sound insulation: $D_{nT;A} > 52$ dB(A);
- impact sound insulation: $L_{nT;A} < 48$ dB(A).

So, with complete separation of the floor elements between the columns, the noise requirements can be fulfilled.

CONCLUSION

In this research the sound transmission through cross-joints in multi-family houses consisting of lightweight building structures and steel supporting structures has been investigated. The research consists of two parts, which are both aimed to determine the vibration reduction indices of the cross-joints. The vibration reduction indices have been calculated based on FEM model calculations (separate paper) and have been measured in experimental set-ups. One of the experimental set-ups agrees more or less with the FEM model, although there are some important differences.

The research has been focussed on the sound transmission of the path floor-joint-floor, because this path determines the airborne sound insulation between two apartments next to each other. No vibration reduction index data concerning this path were available before this research. Based on the research results, the airborne and impact sound insulation between apartments has been predicted for a future building (in the design stage at this moment).

Both the calculations with the FEM model and the measurements in an experimental set-up show that the sound transmission through the considered transmission path can be restricted enough ($K_{ij} \geq 13$ dB for 250 Hz 1/1-octave band). This is the case as long as there are no or effective flexible couplings between the floor elements of separate apartments. Then, the noise requirements can be fulfilled.

In this paper the FEM model and measurement results have been compared. The FEM model results are conservative, compared to the measurement results (maximum deviation 10 dB at 80 Hz and 250 Hz, other frequencies deviation 0-4 dB).

Although there are some deviations between the FEM and measurement results, this research shows that FEM can be applied as a useful ‘design’ tool, in order to predict the sound transmission through cross-joints in the design stage of a future building.

BIBLIOGRAPHICAL REFERENCES

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[2] EN 12354-2, Building Acoustics – Estimation of acoustic performance of buildings from the performance of products – Part 2: Impact sound insulation between rooms, 2000

[3] ISO 3382, Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters, 1995