Characterisation of a Wooden Stair as Structure-borne Sound Source

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Introduction

A characterisation of lightweight stairs as structure-borne sound sources is needed to predict the sound transmission in building situations. An approach is followed where a stair is treated as an active component, in a similar manner to that used for vibrating machines (Figure 1) [1]. For a given external excitation e.g. by the tapping machine or a walking person the characterisation is obtained from the measured contact free velocity and mobility. A characterisation based on measurements is practical since the vibration behaviour is complicated which was already shown in [2]. The system under investigation is a straight wooden stair with stringboard rigidly point connected (Figure 2) to a single-leaf receiver wall (24 cm CaSi, density 2000 kg/m^3) which is a typical separating wall in dwellings. To make sure that excitation of the wall results only from transmission through this wall contact the stair is resiliently supported on the ceilings.

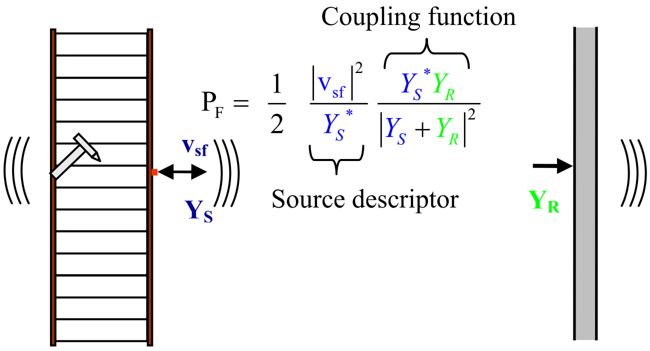

Figure 1: stair as active component – source descriptor concept

Predominant component of excitation

Before the characterisation as illustrated above was applied the predominant components of excitation were identified in the installed condition by means of a reciprocal method [3]. The force perpendicular to the wall and the two moments around the axes in plane of the wall were considered (Figure 2). A shaker attached to a central step (Figure 4) was used for the excitation of the stair. As a result the force perpendicular to the wall was clearly identified to be the predominant component in the case considered. This finding allows a significant simplification regarding the characterisation and prediction of the sound transmission into a receiving room using EN 12354 since only the translational z-component (perpendicular to the wall) has to be taken into account. A general statement about the role of forces and moments for all types of stairs cannot be deduced from this case study. It is however indicated that moment excitation is not as important as it could have been assumed regarding the screwed connection as a lever.

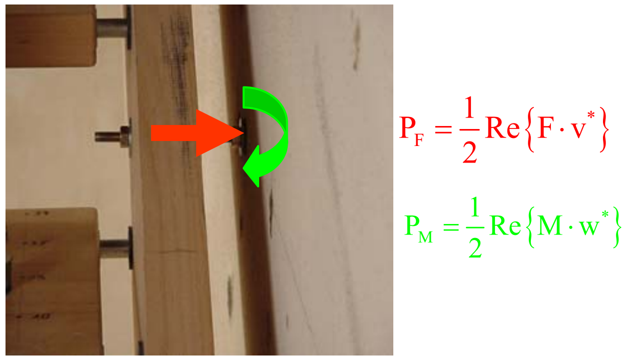

Figure 2: excitation of the wall by forces and moments

Characterisation by free velocity and mobility

The translational contact free velocity and mobility were measured for the z-component (perpendicular to the wall). Figure 3 shows the contact mobility of the stair to be significantly higher than the contact mobility of the wall. Mobility matching only occurs in the very low frequency range near the fundamental wall mode. In general the stair constitutes a force source and thus the blocked force can equally be used to fully characterise the stair system. It can be assumed that this finding still holds true for other lightweight stair systems (e.g. steel-wood constructions) since the variations in mass are not significant and also the variation of wall mobilities tends to be small due to requirements on the sound insulation of separating walls. The blocked force can be used as input quantity for the prediction of the sound transmission in buildings according to 12354-2 [4].

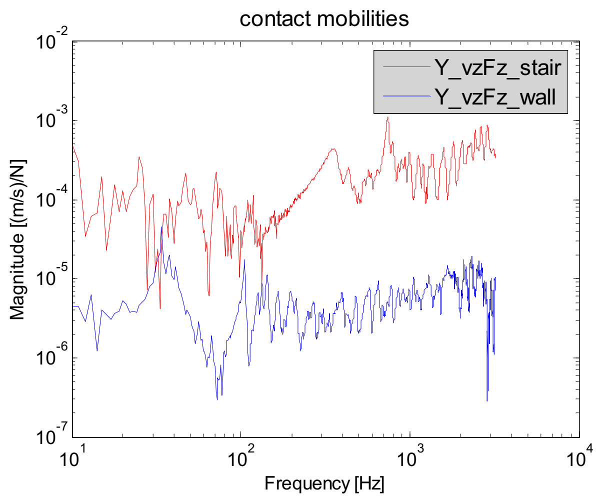

Figure 3: contact mobilities of stair and wall

The contact free velocity was measured for excitation of the stair at the same position as in the former experiment (Figure 4) and afterwards for the tapping machine situated on the central step near the wall contact.

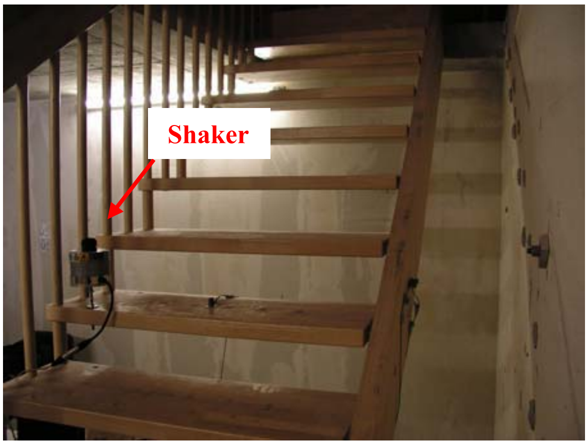

Figure 4: setup for free velocity measurement

From this data the power imparted to the wall was predicted as narrow band values and finally converted into 3rd octave band values. Figure 5 shows the comparison of the predicted power to the "in-situ" power obtained by the reciprocal method. The agreement is very good in the relevant frequency range up to 1 kHz. Thus it can be stated that the free velocity and mobility method is applicable to characterise stair systems as building elements.

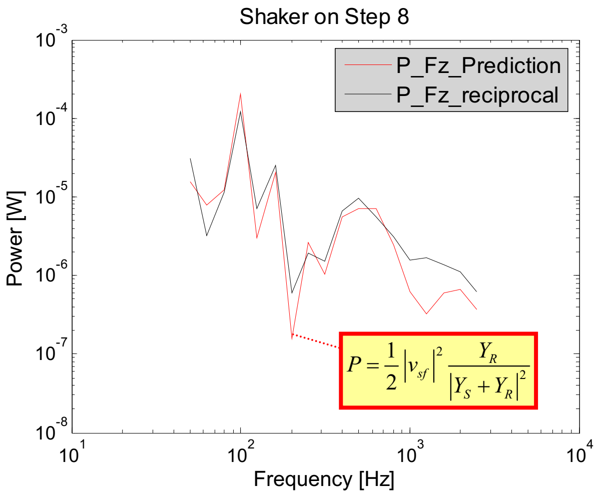

Figure 5: predicted and "in-situ" measured power transmission for excitation of the stair with a shaker

Reception plate method

The free velocity and mobility method is precise but on the other hand time consuming and complicated especially regarding multiple contacts where the interaction between contact points has to be considered. In addition handling of the data is complicated since complex narrow band values are required. For this reason the so-called reception plate method is investigated. The method was initially developed for the simplified characterisation of service equipment like for example sanitary installations. The power emitted by the source can be estimated from the spatial average velocity, loss factor and mass of the plate. In [5] it is shown that this method is appropriate when the reception plate is a free plate with known mass. In the case considered the stair wall is not a free plate but connected to the surrounding walls and ceilings. However the method was applied for the excitation of the stair by the tapping machine. In Figure 6 the "in-situ" power from the reception plate method is compared with the prediction from mobility and free velocity.

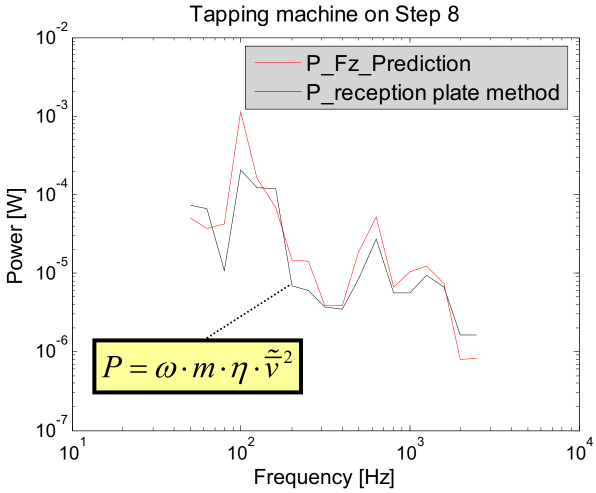

Figure 6: predicted and "in-situ" measured power transmission for excitation of the stair with the tapping machine

The agreement is promising but it is found that the reception plate method tends to underestimate the power going into the wall. This could be due to the sampling of the point velocities, measurement of the loss factor or estimation of the mass. A detailed investigation is currently in progress.

Summary

Different measurement methods were investigated in order to characterise stair systems as structure-borne sound sources. The stair is treated as an active element with respect to an arbitrary external excitation e.g. by the tapping machine or a walking person. A precise characterisation is obtained from the free velocity and mobility. The reception plate method can be used for a simplified characterisation. From these methods input data appropriated for the prediction of the sound transmission of stairs in buildings is obtained [4]. The proceeding is simplified by the fact that stairs constitute force sources when attached to separating walls.

References

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