Laboratory characterisation and prediction of structure-borne sound transmission of sanitary installations in heavyweight buildings

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Summary

Sound transmission from sanitary installation systems can be a significant source of annoyance in buildings. Typical constructions are pre-wall installations that contain the sanitary equipment such as washbasin, toilet and fresh- and waste-water pipes. Structure-borne sound due to operation of the sanitary equipment is transmitted into the pre-wall and from there through the mounting points into the installation wall (separating wall) and flanking elements that subsequently radiate sound into adjacent rooms. At present the possibilities to predict the sound levels due to sanitary installation systems especially for transient excitation are limited. For this reason it is essential that there are validated approaches to characterise the pre-wall installation in order to be able to incorporate these data in prediction models. For this paper, investigations were carried out on a pre-wall installation that was installed onto a reception plate in order to characterise the structure-borne sound power using EN 15657-1 and to obtain input data for the EN 12354-5 prediction model. For this purpose, stationary and transient excitations due to operation of sanitary equipment were investigated and the prediction model used to predict the sound transmission in a building-like test rig for comparison with in-situ measurements.

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1. Introduction

Noise from sanitary equipment can be a significant problem in buildings. A complaint by inhabitants often gives rise to on-site measurements and if it turns out that requirements are not met, it is not always clear who is responsible. One reason for this is that at present there are limited possibilities to predict the sound levels due to sanitary installation systems especially for transient excitation e.g. toilet flush. As part of a research project [1], investigations are being carried out using the reception plate test rig and the building-like test rig of the Stuttgart University of Applied Sciences. The aim is the characterisation of a sanitary installation system as structure-borne sound source with the reception plate method according to EN 15657-1 [2] to obtain input data for the prediction model EN 12354-5 [3]. The characterisation has been carried out with respect to different 'operating conditions' with steady-state sources (washbasin tap, bathtub tap and shower) and transient sources (toilet flush). In a previous paper, investigations with steady-state operating sanitary equipment were outlined [4]. This paper focuses on transient excitation by the flushing toilet. Rules for the application of the reception plate method are proposed for the characterisation of transient sources. The source data obtained will be used to predict the sound transmission for a building situation. In this situation an additional influence of the wastewater pipe on the structure-borne sound transmission is observed.

2. Sanitary installation system

Modern installations combine the sanitary equipment such as washbasin, toilet and fresh and waste water pipes into a 'sanitary installation wall' as shown in Figure 1.

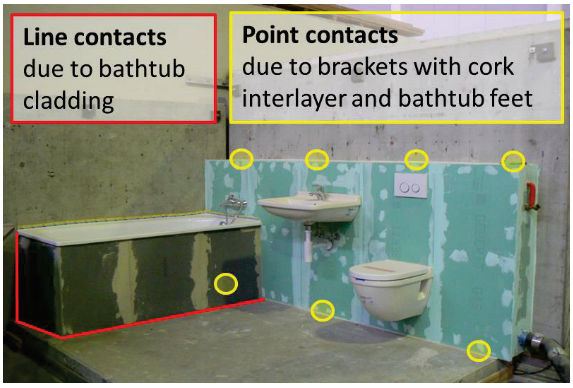

Figure 1. Sanitary installation system on the reception plate test rig (installed without a typical installation shaft for the waste water pipe as needed in practice).

The main components of the system are the load bearing frame, installation components (fresh and waste water pipes, sanitary equipment) and plasterboard panels. The plasterboard panels and mounting points are decoupled by an elastic interlayer. In operation, structure-borne sound from the sanitary equipment is transmitted simultaneously into wall(s) and floor via the mounting points of the sanitary installation wall as indicated in Figure 2. In buildings, installation noise is generally measured according to EN ISO 10052 [5]. DIN 4109-11 [6] also needs to be considered in Germany. These measurements can be carried out only in a finished building or in an installation test rig in a laboratory. This means that a specific result is only determined for a specific building or test rig situation. How well these results are applicable to other building situations remains unanswered. Limited optimisations of the installation system are possible after the mounting of the system. The aim of the project [1] is to predict sound transmission from such systems in advance. For the prediction of the sound transmission in buildings with EN 12354-5 [3] the structure-borne sound power input into the wall and floor is required.

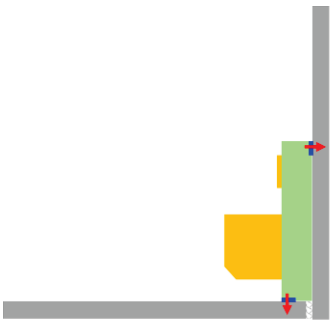

Figure 2. Power injection from the sanitary installation system (green) into the floor and wall from the toilet in operation.

The sound transmission begins with a manual push of the toilet flushing button that opens a valve to let water run out of the cistern, in and out of the toilet bowl and through the waste water pipe to the outlet. This is followed by the refilling process of the cistern. Figure 3 shows a typical time variation of the velocity level for one operating cycle.

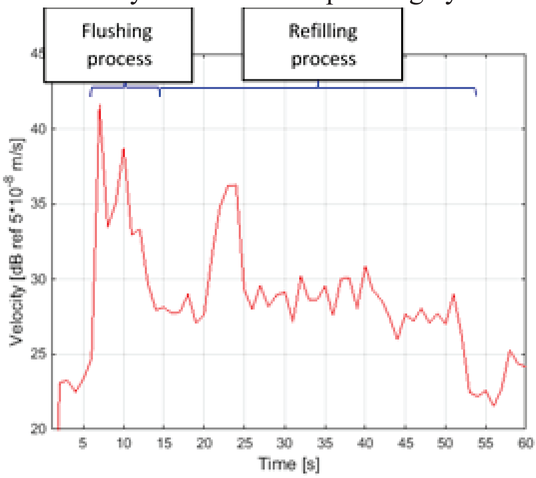

Figure 3. Time varying velocity level (spatial average for 12 accelerometer positions) on the horizontal reception plate during the toilet flushing cycle.

Several difficulties arise from this time-varying signal for the characterisation of the power output, in particular the evaluation of a representative frequency spectrum that is required as input in EN 12354-5 [3]. In addition, the building regulations for installation noise in Germany, Switzerland and Austria [7-9] refer to L_{AFmax} (maximum A-weighted sound pressure level with time weighting "Fast"). Although Transient SEA [10] provides a time domain prediction model capable of predicting maximum levels it is significantly more complex than EN 12354-5 [3]. It would therefore be advantageous to adapt the general procedure that is used for steady-state sources; this is considered in this paper.

3. Reception plate method

3.1 Steady-state operating conditions

The reception plate method described in EN 15657-1 [2] assumes that (a) when a vibrating source is connected to a simple plate structure, under steady-state conditions, the source power equals the plate power and (b) the plate is energized into bending vibration only. This method enables a practical characterisation of structure-borne sound sources with any number of contact points and geometry. The reception plate power W_{rec} into reception plate i is:

$$W_{\text{rec,i}} = \omega \cdot m_{\text{i}} \cdot \bar{\tilde{v}}_{\text{i}}^{2} \cdot \eta_{\text{i}} \quad (1)$$

where ω is the angular frequency, m_{i} the plate mass, $\bar{\tilde{v}}_{\text{i}}^{2}$ the spatial average velocity and η_{i} the total loss factor of the plate [11].

In order to correct the reception plate power for the properties of the finite reception plate, in particular its modal behavior, the characteristic power is used as independent source quantity:

$$W_{\text{char,i}} = W_{\text{rec,i}} \cdot \frac{Y_{\infty,\text{rec}}}{\text{Re}\{\bar{Y}_{\text{rec,i}}\}} \quad (2)$$

where $\bar{Y}_{\text{rec,i}}$ is the spatial average point mobility of the laboratory reception plate at the contacts with the source. $Y_{\infty,\text{rec}}$ is the characteristic reception plate mobility, which is the mobility of a plate of the same material and thickness as the reception plate, but which is of infinite extent.

To provide input data for EN 12354-5 [3] the characteristic power can be transformed into the installed power for real floors and walls according to (3).

$$W_{\text{inst,i}} = W_{\text{char,i}} \cdot \frac{Y_{\infty,\text{inst,i}}}{Y_{\infty,\text{rec}}} \quad (3)$$

3.2 Time varying operating conditions

In EN 15657-1 [2] a measurement procedure for sources with time-varying operating conditions is not defined. Hence the following procedure was applied for the toilet flush. For a measurement time greater than one operating cycle, the short term equivalent velocity was measured for discrete time intervals. This yields a time-varying frequency spectrum of the spatial-average velocity as shown in Figure 4.

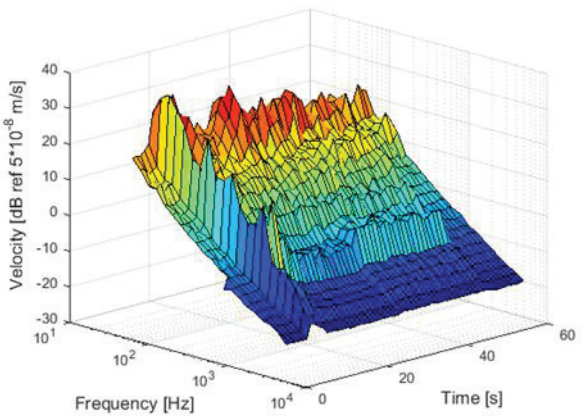

Figure 4. Short L_{eq} velocity levels on the horizontal plate during the toilet operating cycle (Figure 3).

Frequency spectra can be evaluated during different parts of the operating cycle of the source which can be critical for national requirements. For example, the German standard DIN 4109 [7] states that “temporary peaks that occur at actuation should not be considered” when installation noise is measured and rated in buildings. For this reason the engineer ignores the first peak in Figure 3 when assessing whether the requirement of $L_{\text{AFmax,n}} \leq 30$ dB is met. Accordingly the first peak could be ignored in the characterisation (and for the prediction) as well. In other countries such as Switzerland the frequency spectrum corresponding to the highest peak of the toilet operating cycle is considered when characterising the source. This procedure is applied here for the investigations on the reception plate test rig. In Figure 5 the characteristic powers into the horizontal and vertical plate are compared. Both power spectra show a similar characteristic with the maximum values occurring below 100 Hz and a decrease in level with increasing frequency. The structure-borne sound transmission into the wall and floor is equally strong.

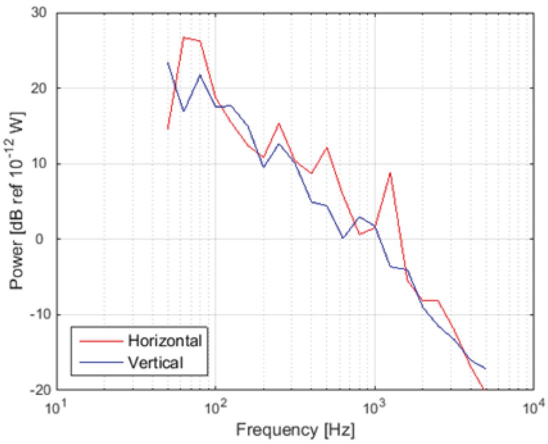

Figure 5. Characteristic power of the highest peak during the operating cycle into the horizontal and vertical reception plates.

4. Comparison of sanitary components

Characteristic powers of all investigated sanitary components are compared in Figure 6 for horizontal and in Figure 7 for vertical transmission. The bathtub shower is the strongest source for floor excitation, whereas the toilet flush is the strongest for wall excitation.

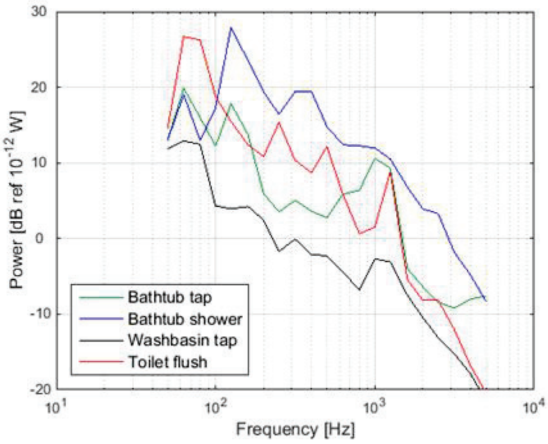

Figure 6. Characteristic power of components of the sanitary installation system into the horizontal reception plate.

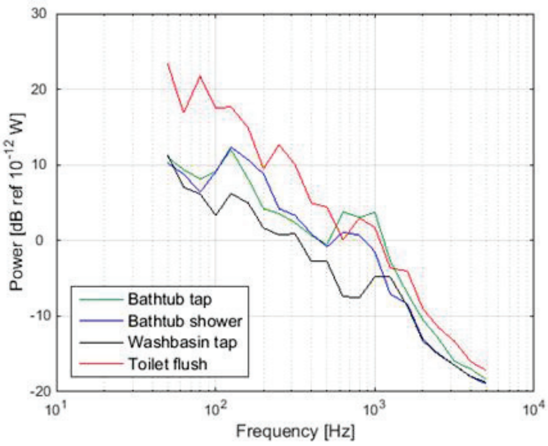

Figure 7. Characteristic power of components of the sanitary installation system into the vertical reception plate.

5. Investigations in building-like test rig

A similar sanitary installation system has been installed in a building-like situation but with an installation shaft containing a waste water pipe like in buildings (Figure 8 and 9). The wall is made of gypsum blocks which are decoupled from the adjacent walls and floors by elastic interlayer. The floor is made of reinforced concrete.

Note that for the validation of the prediction model in EN 12354-5 [3], only the sanitary installation system without the installation shaft containing the waste water pipe was investigated on the reception plate test rig. The characterisation of the waste water system with the installation shaft is not technically feasible.

Figure 8. Sanitary installation system in a building-like test rig with additional installation shaft enclosing the waste water pipe.

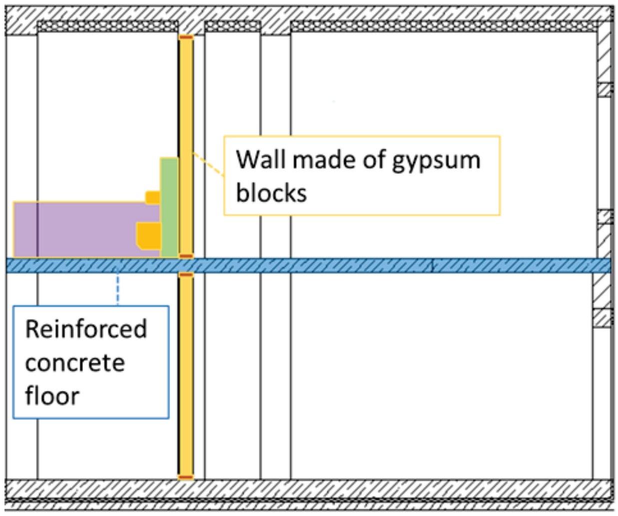

Figure 9. Vertical section of building-like test rig with sanitary installation system (green) connected to the installation wall made of 10 cm thick gypsum blocks with density 1200 kg/m^3, decoupled on all sides, and to the floor made of 18 cm thick reinforced concrete.

The sound transmission of the sanitary installation system in the building-like test rig was first investigated in a configuration with a low noise water drain that was realized by a flexible hose that has no connections to the installation walls. In Figure 10 is shown the time varying sound pressure level (according to EN ISO 10052 [5]) in the receiving room for diagonal transmission during a toilet flushing cycle.

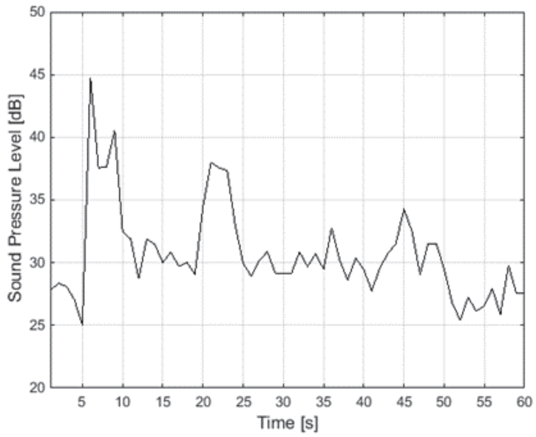

Figure 10. Time varying sound pressure level in the receiving room for diagonal transmission for a toilet flushing cycle.

The curve shape of the time signal is similar to that measured on the reception plate (Figure 3). The contribution of wall and floor to the overall transmission was investigated by measurements of short L_{eq} velocity levels on the radiating surfaces in the receiving room. The radiated sound pressure levels of wall and floor were estimated from:

$$L_{p,i} = L_{v,i} \cdot 10\,\lg(\sigma_i) + 10\,\lg\left(\frac{S_i}{A}\right) + 6\text{ dB} \qquad (4)$$

where $L_{v,i}$ is the velocity level, σ_i the radiation efficiency (assumed to σ_i = 1), S_i the area of the radiating surface and A is the equivalent absorption area in the receiving room.

In Figure 11 the frequency spectra from analysis of the first peak are compared. The radiation into the receiving room is clearly dominated by the floor. Due to the effective decoupling of the installation wall there is no significant structure-borne sound transmission from the floor into the wall and from the upper to the lower installation wall.

In buildings the waste water pipe (inside the installation shaft) is usually fixed to the installation walls (separating walls). Therefore measurements were also carried out in a configuration with the waste water pipes fixed with two pipe brackets on each installation wall.

In Figure 12 the radiated sound pressure levels of the wall and the floor are compared, in addition the curves from Figure 11 are shown. Due to the fixation of the waste water pipe the radiation of the installation wall is up to 20 dB higher and now dominates the overall sound transmission for $f > 500$ Hz. The sound transmission into the floor is also increased for $f < 315$ Hz. It is assumed that the water impact on the 90° angle of the waste water pipe in the ground level results in a higher vibration of the pipe and pre wall and thus a higher sound transmission into the floor. From these results it can be stated that in buildings both, the sanitary installation system and the waste water system, have an effect on the sound transmission. Both ‘sources’ must be considered separately for characterisation and prediction (waste water systems can be characterized according to EN 14366 [12]).

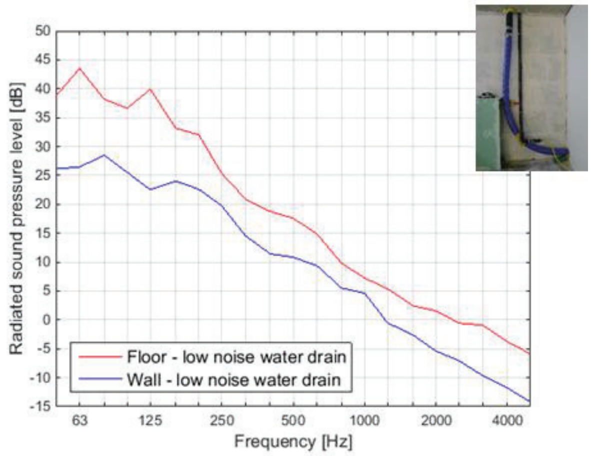

Figure 11. Estimated sound pressure levels in the receiving room for diagonal transmission from radiation of the floor and the wall – low noise water drain.

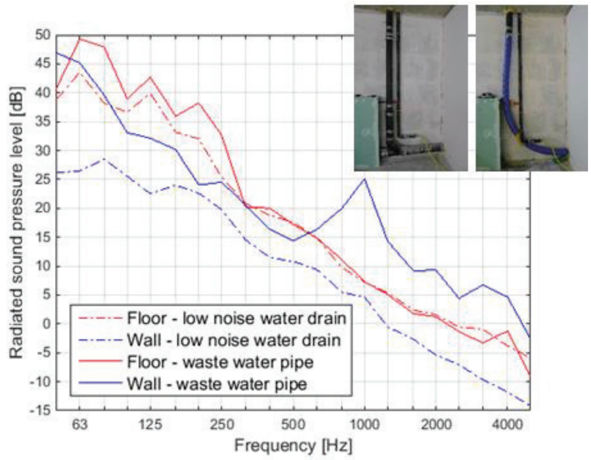

Figure 12. Estimated sound pressure levels in the receiving room for diagonal transmission from radiation of the floor and the wall – waste water pipe system.

6. Conclusions

The reception plate method can be used for the characterisation of complex sanitary installation systems. The power inputs into horizontal and vertical reception plates can be measured independently and used for the prediction of the structure-borne sound transmission in buildings. So far the method according to EN 15657-1 [2] was restricted to stationary operating sources. In this paper the method has been extended for the characterisation of time-varying sources on example of a flushing toilet. The approach is to measure short term equivalent velocity for discrete time intervals to capture different parts of the operation cycle of the source. From this, the relevant frequency spectrum needs to be extracted (e.g. with respect to national requirements).

The sanitary installation system has been installed and tested on laboratory reception plates and in a building-like test rig. Considering all investigated sanitary components (bathtub tap and shower, washbasin tap and toilet flush) the bathtub shower, as well as the actuation and the discharge of water of the toilet flush are the strongest sources of the sanitary installation system.

Investigations in a building-like test rig have shown that besides the sanitary system, the waste water system can have a relevant effect on the sound transmission. Both 'sources' must be considered separately for characterisation and prediction.

In the next step the in-situ measurements in the building-like situation will be compared with the prediction according to EN 12354-5 [3].

Acknowledgement

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