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APPROACH FOR A NEW LABORATORY METHOD TO DETERMINE NOISE FROM WASTE WATER INSTALLATIONS

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ABSTRACT

EN 14366:2004 [1] describes the laboratory measurement procedure to determine noise from waste water installations. This standard procedure requires a test-rig comprising two rooms: a source room to determine the airborne sound and a receiving room to indirectly determine the structure-borne sound by measuring the sound pressure. This paper proposes a method to determine the airborne and the structure-borne sound directly on a power basis without the need for any room. The waste-water installation is attached to a vertical reception plate according to EN 15657:2017 [2]. The structure-borne sound power can be determined straight-forward using the reception plate method or the power substitution method. This quantity can directly be used as input data for the prediction model described in EN 12354-5 [3]. The airborne component is measured using sound intensity based on the procedures described in ISO 9614 [4]. This quantity is therefore also measured directly on a power basis that can be used as input data for prediction. The paper presents preliminary results from a case study on the application of the proposed method [5].

1. INTRODUCTION

The latest version, EN 14366:2004+A1:2019 [6] contains the amendment A1 which states, that the results determined with this standard can be used to compare products. However the results can not be transferred to the building situation easily. In order to provide input data for prediction, the standard is currently under revision.

This paper does not intend to propose another method for the current revision. The intention is to apply and investigate different measurement techniques in order to characterize the airborne and structure-borne sound power of a waste water pipe system directly and in parallel.

Therefore the following research questions are investigated: Concerning airborne sound intensity measurements, the measurement procedure is investigated. Therefore intensity scans are compared with discrete measurements. The measurement distance and additional measures, such as absorption material opposite the pipe is considered. An important question concerns the definition of the measurement surface around the pipe. This paper investigates var-

ious possibilities. Concerning structure-borne sound measurements, the signal-to-noise ratio was evaluated for the heavy concrete reception plate using ICP transducers with a sensitivity of $\approx 100 \text{ mV}/(\text{m s}^2)$. In addition the excitation of the plate by the nearfield radiated from the pipe (see [7]) was considered using shielding by a reflector between the reception plate and the pipe.

2. TERMS AND DEFINITIONS

From measurements of the sound intensity in front of the pipe and the spatial average velocity on the reception plate, the airborne sound power and the structure-borne sound power can be determined straight-forward using the following equations:

The airborne sound power level, L_{W_a} , is determined using the measured spatial average sound intensity level, L_I , across a specified area, S ($S_0 = 1 \text{ m}^2$).

$$L_{W_a} = L_I + 10 \lg \left(\frac{S}{S_0} \right) \quad (1)$$

The structure-borne sound power level, L_{W_s} , is determined using the reception plate method according to EN 15657:2017.

$$L_{W_s} = 10 \lg \left(2\pi\eta \frac{f}{f_0} \frac{m}{m_0} \frac{S}{S_0} \right) \text{ dB} + L_v - 60 \text{ dB} \quad (2)$$

Where L_v is the spatial average velocity level on the reception plate, m is the surface density, η the total loss factor of the plate and S the plate surface.

f_0 , m_0 and S_0 are the reference values 1 Hz, 1 kg/m² and 1 m².

3. LABORATORY MOCK-UP

The mock-up is installed in the *roteg* laboratory at Rosenheim Technical University of Applied Sciences. The installation of the waste water pipe system basically follows the standard configuration given in EN 14366. However no room at all is used (see Figure 1). The pipe is connected to a vertical reception plate with two clamps (see Figure 2). The clamps are made from two pieces that are connected with screws at both sides. The screws were fastened using a torque wrench to provide a reproducible tightening torque. The metal clamps are provided with a thin layer

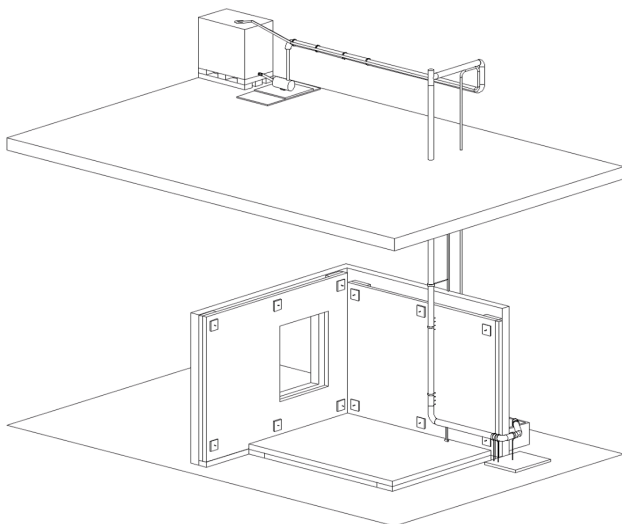


Figure 1: 3D sketch that shows the whole test mock-up.

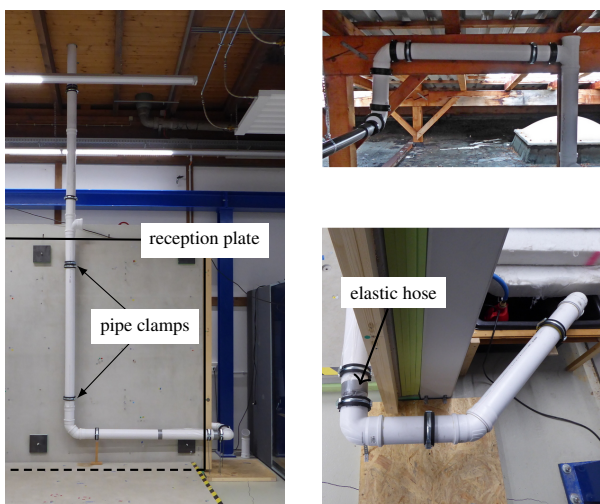


Figure 2: Test mock-up of waste water pipe. Left: vertical section and reception plate. Right top: Set-up at top of mock up before the vertical section. Right bottom: bends to direct the water into the tank behind the reception plate.

of rubber to avoid direct contact to the pipe. The types of clamps can be considered as low budget clamps. There are more sophisticated products on the market.

The falling height, h , is ≈ 5.8 m. At the top a horizontal section is installed as described in EN 14366 (see Figures 1 and 2, top right). The fresh water used for the measurements is provided in a tank at the top of the mock-up. A pump is used to provide the water flow down the waste water pipe. The pump can be adjusted to provide a specific flow rate in the pipe. At the bottom the water is collected in another tank behind the reception plate test rig, equipped with another pump to get the water up for the next measurement. After the bend at the bottom of the vertical pipe section, there is a horizontal section of ≈ 1.4 m. Before other bends are used to direct the water into the tank behind the test-rig, the pipe is isolated using a hose (see Figure 2, bottom right).



Figure 3: Left: Additional absorption opposite the pipe. Right: Asymmetrically positioned reflector behind the tube made from 25 mm OSB boards.

For the investigation of different strategies to define the measurement surface for sound intensity measurements, Figure 3 (Right) shows the vertical pipe section with and without reflector. The triangle-shaped reflector between the pipe and the plate gives a plane measurement surface. For the measurements without reflector a cuboid frame was used as measurement surface, Figure 4. The frames were placed without direct contact neither to the vertical reception plate nor the wastewater pipe. In Figure 3 (left) additional absorption material can be seen that was used with the aim to increase the quality of intensity measurements. The material that was used is polyester fibre. The depth of the layer was ≈ 1 m. The height was adjusted to the measurement area required for the intensity measurements. The width was ≈ 2 m. This means that there was ≈ 1 m of absorption material to the left and right of the centre line of the pipe. For the sound intensity measurements, an additional layer of ≈ 10 cm of polyester fibre was applied to the bend and the horizontal section of the pipe system (see Figure 3). In the construction of the reflector an 25 mm horizontally mounted OSB-board was used to separate the bend at the bottom from the vertical pipe with the aim to reduce the influence of the radiated sound from this bend. For the structure-borne sound measurements no additional polyester fibre was applied to the bend and the horizontal section of the pipe.

As this paper investigates measurement procedures rather than absolute values of different pipe systems, the absolute flow rate was not considered to be of importance yet. However it was guaranteed to have a rather constant flow rate to compare measurement procedures. The main flow rate considered in this paper was $\approx (2.98 \pm 0.06)$ l/s. All tests were carried out from the same pipe system. The only variation was to open the clamps for some measurements to investigate the behaviour without clamps and to investigate whether nearfield excitation of the reception plate takes place.

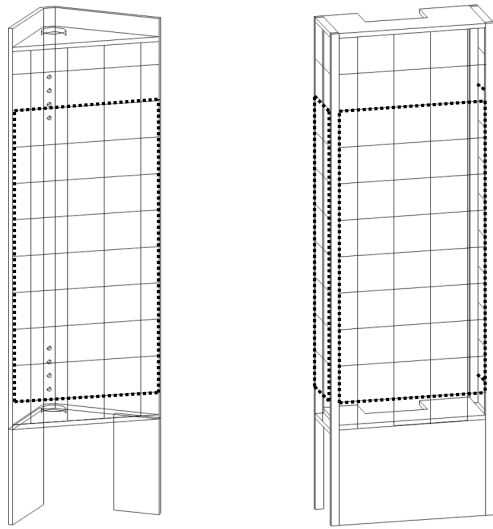


Figure 4: Measuring frames with and without reflector. The dotted rectangles indicate the area for intensity measurements at discrete points shown in Figure 10. It indicates also the area used for intensity scans. The front measuring surfaces have the same size.

4. SOUND INTENSITY MEASUREMENTS

The measurement time corresponds to the requirements according to DIN EN ISO 9614-1:2009 and [4]. For scans 20 s were used and for discrete measurements 10 s.

Figures 5, 6, 7 and 9 show results for sound intensity scans across the dotted rectangle indicated in Figure 4. Figures 8 and 10 show results from discrete measurements. Except Figure 7 all presented measurements were carried out with a measurement distance of 40 cm between the centre of the two probe microphones and a plane at the front boundary of the waste water pipe.

4.1 Results

A variation of the flow rate is shown in Figure 5 for: 1.01/s, 2.01/s, 3.01/s and 4.01/s using the scanning procedure.

All flow rates show a logical rank order except the low frequency range below 100 Hz. With increasing flow rate the increase of intensity levels becomes smaller. The level in the 160 Hz one-third octave band for 2.01/s can be considered as an outlier.

Figure 6 shows the intensity levels with open and closed pipe clamps starting with a flow rate of 3.01/s. The results are compared with the background noise intensity (without water flow) to indicate the signal-to-noise-ratio.

The minimum ratio of 20 dB, required by DIN EN ISO 9614-1:2009-11, is not met for closed clamps in three one-third octave bands at low frequencies. The sound intensity levels without clamps are lower compared to closed clamps particularly in one-third octave bands up to 315 Hz.

Figure 7 compares the F_{pI} -indices for different measurement distances in octave bands. The averaged results

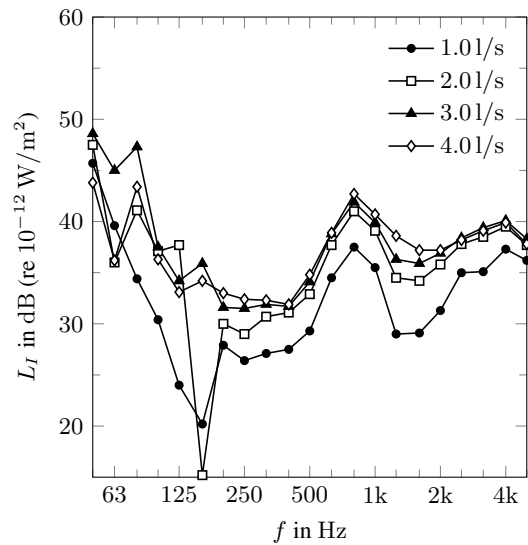


Figure 5: Sound intensity levels for scans with different flow rates. Measurements with closed pipe clamps and without a reflector between reception plate and pipe.

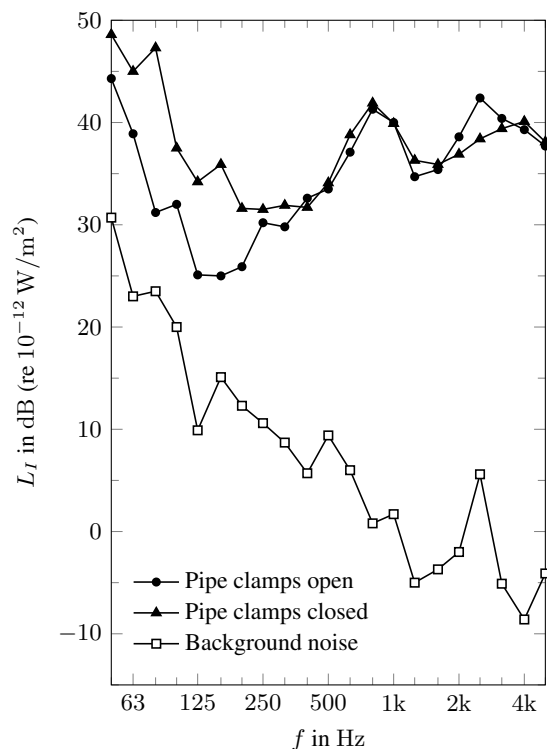


Figure 6: Signal-to-noise-ratio for 3.01/s. Comparison of pipe system connected and disconnected from the reception plate. Scan measurements without using a reflector.

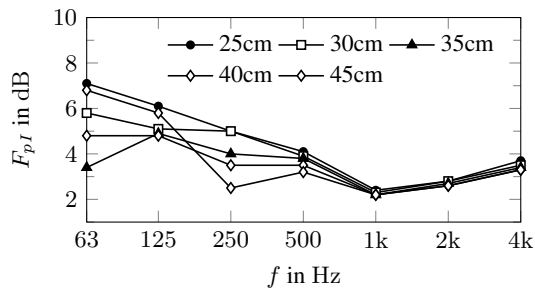


Figure 7: F_{pI} -indices for measurements at different distances from the pipe with closed clamps.

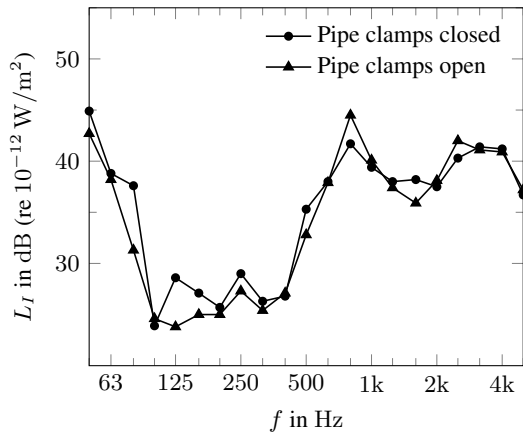


Figure 8: Sound intensity levels for a discrete measurement point with closed and open pipe clamps.

are shown for eight flow rates (0.51 l/s to 4.01 l/s, in steps of 0.51 l/s).

The measurements were carried out using the scanning procedure. No reflector was used and only the front surface was considered.

The F_{pI} -index is <10 dB for all measurement distances. The highest F_{pI} -index occurs in the 63 Hz octave band for 25 cm measurement distance. With increasing measurement distance a slight reduction of the F_{pI} -indices can be observed. The lowest F_{pI} -indices are obtained for 40 cm. Above 500 Hz there is no influence of the measurement distance on F_{pI} -index. Based on these results, all further comparisons were made with 40 cm.

Another comparison was made with open and closed pipe clamps without reflector. The intensity levels were measured at a discrete measurement point in the middle of the pipe at a height of 127.5 cm (measured from the horizontal reception plate) without reflector. The measurement distance was 40 cm.

Figure 8 shows that the measurement results with closed clamps are above the intensity levels with open clamps at one-third octave bands below 500 Hz. Particularly at 80 Hz and 125 Hz, differences of about 5 dB are apparent.

Figure 9 considers the application of absorption material opposite to the measurement object as indicated in Figure 3 (left).

The averaged sound intensity levels were measured by scanning the front surface without reflector. Figure 9

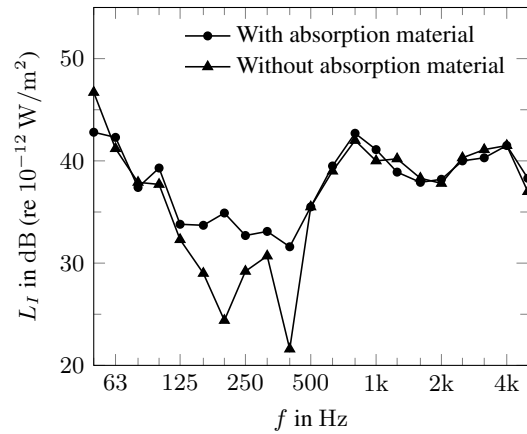


Figure 9: Sound intensity levels for scan measurements with and without additional absorption material.

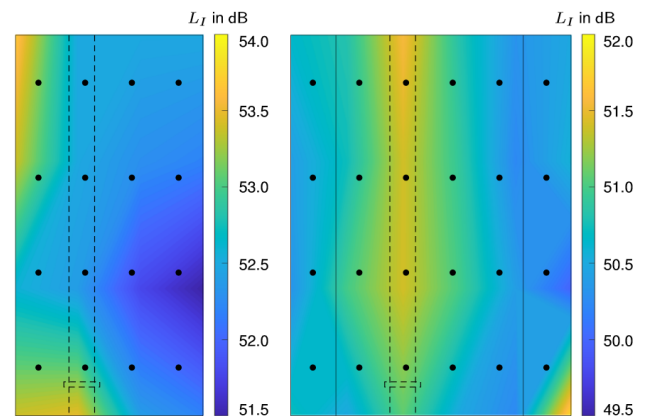


Figure 10: A-weighted sum average sound intensity levels with standard deviation for discrete measurements at 16 points on a measuring surface in front of a reflector (left), shown by the dotted rectangle in Figure 4. Average sound intensity levels with standard deviation for discrete measurements at 24 points on a measuring surface without a reflector (right), shown with two unfolded measuring surfaces. Left: $L_{Wa} = 53.7$ dB(A). Right: $L_{Wa} = 54.1$ dB(A)

shows that the absorption material cause an increase in the average sound intensity levels, especially in the mid frequency range from 125 Hz to 400 Hz.

The average difference in this range is about 5 dB, with the largest deviations of about 10 dB in the 200 Hz and 400 Hz one-third octave band. However the use of absorption material opposite the measurement object is considered to improve the measurements (see [8]).

The two contour plots in Figure 10 show the A-weighted sum average sound intensity levels at 16 and 24 discrete measurement points. The measurement points are spaced 20 cm horizontally and 40 cm vertically. With the reflector the considered area is 1.28 m^2 and for the cuboid it is 2.32 m^2 . The wastewater pipe is located right behind the second column of the grid. Again the measurement distance was 40 cm.

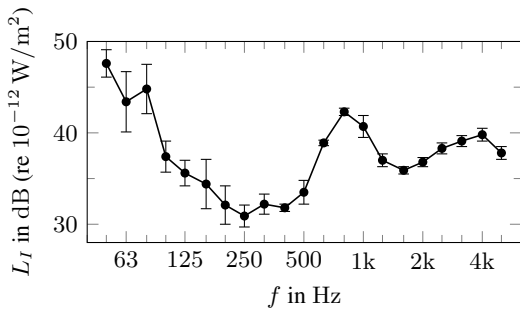


Figure 11: Sound intensity levels with standard deviation for five scan measurements without reflector.

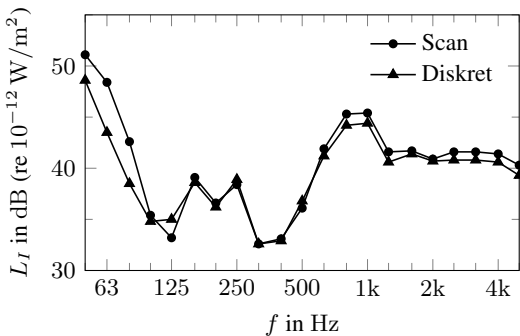


Figure 12: Sound intensity levels for scan and discrete measurements with reflector.

In the left contourplot in Figure 10 the summed and A-weighted sound intensity levels range from 51.5 dB to approximately 54.0 dB, while the levels in the right contourplot are in the range from 50.0 dB to 51.5 dB. With the reflector, the sound intensity levels tend to be higher on the left side of the pipe than on the right. For the cuboid (i.e. no reflector), it is clearly indicated that the highest sum levels occur right in front of the pipe.

The summed and A-weighted sound intensity levels for the entire measuring surface is 52.6 dB in the left contourplot, 50.4 dB in the right contourplot. Using equation (1) and the surface areas mentioned above, the A-weighted airborne sound power level is 53.7 dB for the reflector and 54.1 dB for the cuboid (i.e. no reflector).

To investigate the repeatability of the scan measurements, five similar scans were performed across a grid with 40 cm spacing on the front surface of the symmetrical cuboid boxframe. Figure 11 shows the averaged sound intensity levels and the corresponding standard deviations for the five scans. Figure 11 shows that the average standard deviation from 50 Hz to 200 Hz is approximately 2 dB and from 315 Hz is less than 1 dB.

The average difference between scanning and discrete measurements in Figure 12 with reflector is 1.0 dB across the considered frequency range. The largest level differences occur mainly in the low frequency range. At 63 Hz it is 5 dB.

4.2 Discussion

The results in Figure 6 indicate that the signal-to-noise-ratio for the measured sound intensity levels is lower at low frequencies. In contrast to the lower flow rates, the intensity levels for 3.0 l/s are at least 20 dB above background noise intensity in the frequency range from 50 Hz to 5 kHz except three one-third octave bands at low frequencies.

Not one of the tested measurement distances shows F_{pI} -indices >10 dB in the frequency range from 50 Hz to 5 kHz. At high frequencies the measurement distance has no significant influence on the F_{pI} -index. Although the F_{pI} -index is low for all considered distances, the results indicate that distances between 35 cm to 40 cm provide the best (lowest) F_{pI} -indices. Sound intensity levels are higher with closed clamps than with open clamps as shown in Figure 8. This can be expected due to a mechanical discontinuity in the pipe caused by the clamp with the effect of enhanced radiation. At 125 Hz and 250 Hz the closed clamps influence the intensity. Five repeated scans without reflector show good repeatability (standard deviation <2 dB) despite manual operation of the probe and provide good agreement at high frequencies (standard deviation <1 dB). A slight spatial variation of the intensity levels could be determined with discrete measurements. The average levels are within ± 3 dB for the measurement area defined by the OSB reflector.

The positioning of absorption material at a 60 cm distance from the outer edge of the pipe has a positive effect on the sound intensity especially in the medium-frequency range from 125 Hz to 400 Hz and is recommended in any case [8]. If scanning and discrete measurements are compared, the scans with the reflector tend to yield the highest intensity levels, with the time required for measurement being the lowest overall in this measurement configuration. The comparison of the results obtained with the reflector and with the cuboid boxframe shows that the obtained sound power level is almost the same for both with a difference of <0.5 dB in the A-weighted sum. Although this is a promising results, it is not yet possible to give a clear answer whether the reflector gives the correct absolute airborne sound power. This can be validated conclusively by comparison with results from diffuse field measurements according to EN 14366.

5. STRUCTURE-BORNE SOUND MEASUREMENTS

5.1 Results

To determine the structure-borne sound power of the pipe, the spatial average velocity level on the reception plate needs to be measured. The absolute power is not considered yet, but strategies and investigation in measuring the spatial average velocity. In this case study ICP accelerometers with a sensitivity of ≈ 100 mV/(m/s²) were used. The measurement points were randomly distributed over the reception plate. Basically, the minimum distance between the sensors was kept at 0.5 m according to [2]. The measurement positions are shown in Figure 13.

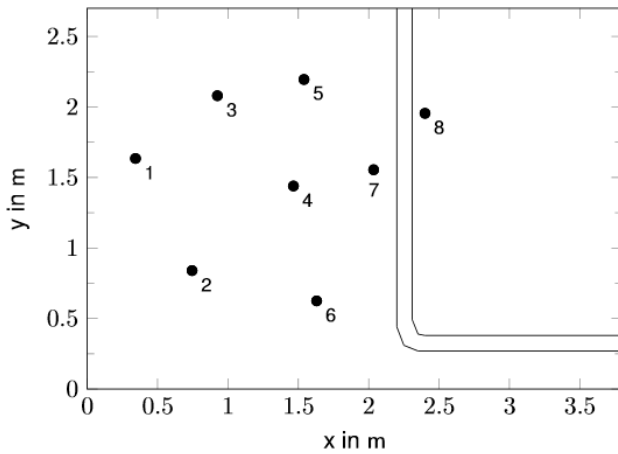


Figure 13: Measuring points across the vertical reception plate.

The velocity levels were measured for different flow rates. Figure 14 shows the results measured with closed pipe clamps, Figure 15 shows the results measured with open pipe clamps.

To check the available signal, the signal-to-noise ratio for the pipe system connected with two closed clamps to the reception plate is shown in Figure 16 for a flow rate of 3.01/s. It can be seen that the signal-to-noise ratio is >10 dB for the majority of one-third octave bands.

Figure 17 shows spatial average velocity levels on the plate for the pipe disconnected from the plate with and without the OSB reflector (i.e. only airborne excitation considered). The measured data is compared against the background noise level. The figure shows that the signal-to-noise ratio is <2 dB for the majority of presented frequency bands except the 63 Hz and 80 Hz one-third octave bands.

Figure 18 shows spatial average velocity levels on the reception plate for the pipe connected to the plate (closed clamps). Results are compared with reflector, with reflector and additional shielding of the bend (see Figure 20) and without reflector. It can be seen that the influence of the OSB reflector is <2 dB for the entire frequency range from 50 Hz to 5000 Hz.

5.2 Discussion

In this case study the pipe system delivered enough signal to measure vibration levels on the heavy 10 cm reception plate across the frequency range from 50 Hz to 5000 Hz with the equipment used.

The measured velocity levels are mainly caused by the structural contact via the two clamps. Measurements with open clamps showed vibration levels very close to background noise. Only at very low frequencies and in the 4000 Hz one-third-octave band there was signal on the plate although the pipe was decoupled. At low frequencies this could be due to stripes of resilient material that were necessary to avoid direct contact. These are shown in Figure 19. As the stripes had a thickness of only a few mm there is potential structural coupling at low frequencies.

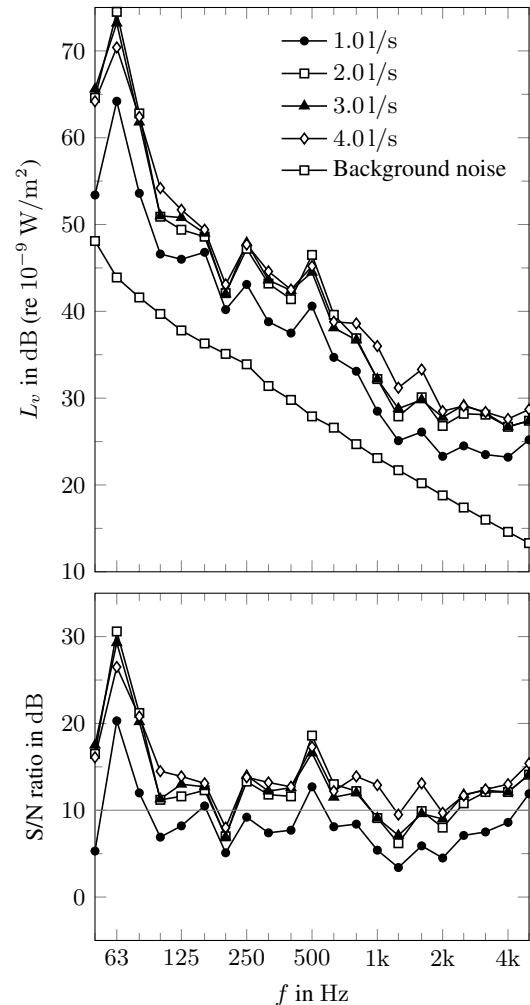


Figure 14: Signal-to-noise-ratio shown for the pipe system connected with two clamps to the reception plate. A spatial average of eight positions in the centre area of the plate with standard deviation is shown using the same positions.

The influence of near-field excitation was investigated further by removing the OSB reflector with closed clamps. The measurement was carried out with an additional OSB board between the bend and the reception plate to shield radiation at this point (see Figure 18). The results however do not show a significant difference with or without the reflector or the reflector in combination with the additional shielding at the bend (see Figure 20).

6. CONCLUSIONS

This study showed investigations on the determination of the airborne and structure-borne sound power of waste water pipes. The aim was on the application of measurement methods to directly determine the power in a direct measurement using sound intensity and the spatial average velocity on a reception plate. From these two quantities the airborne and structure-borne power can be determined straight-forward using equations (1) and (2).

Whereas the measurement procedure for structure-borne sound is already clearly defined in [2], the measure-

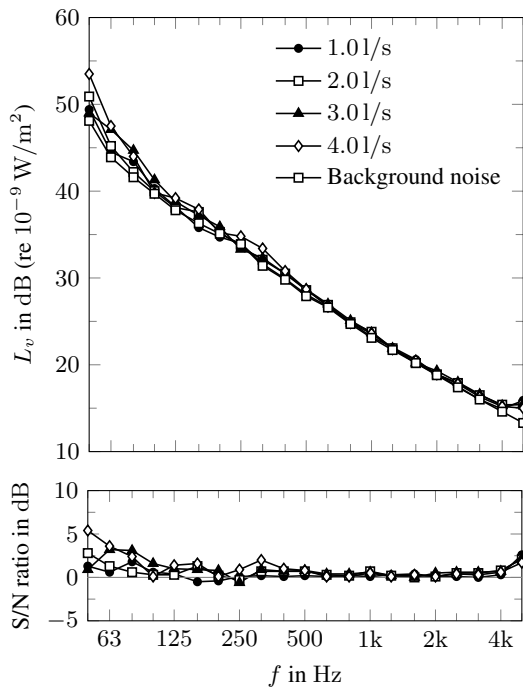


Figure 15: Signal-to-noise-ratio shown for the pipe system connected with two clamps to the reception plate. A spatial average of eight positions in the centre area of the plate with standard deviation is shown using the same positions.

ment of the airborne sound power of the pipe using sound intensity requires investigations. This paper showed possible procedures considering the improvement of the measurement quality and definitions of measurement surfaces.

It can be shown that the quality of intensity measurements is good for a waste water pipe system attached to a vertical reception plate. Not much improvement of the room such as additional absorption material is required. N.b. the measurements were carried out in a large space. To-date no clear guideline on the measurement procedure can be given. Although the considered strategies show the following advantages: A reflector in the shape of a triangle defines a plane measurement area. It could be shown that the sum intensity levels across this area differ by less than 3 dB although the pipe covers less than 15% of the area. Measurements without a reflector showed very similar results in terms of the A-weighted sum sound power, with <0.5 dB difference between both methods. Further measurements and validations with diffuse field measurements are required to validate the procedure.

The structure-borne sound measurements used the reception plate method by measuring spatial average velocities on a 10 cm vertical reception plate. This case study showed that a waste water pipe system delivers enough signal above background. Investigation on nearfield excitation showed that the structure-borne excitation via the clamps dominates.

For both, airborne and structure-borne sound, validations with measurements in the test-rig described in [1] are required to prove the possibility to apply the proposed methods.

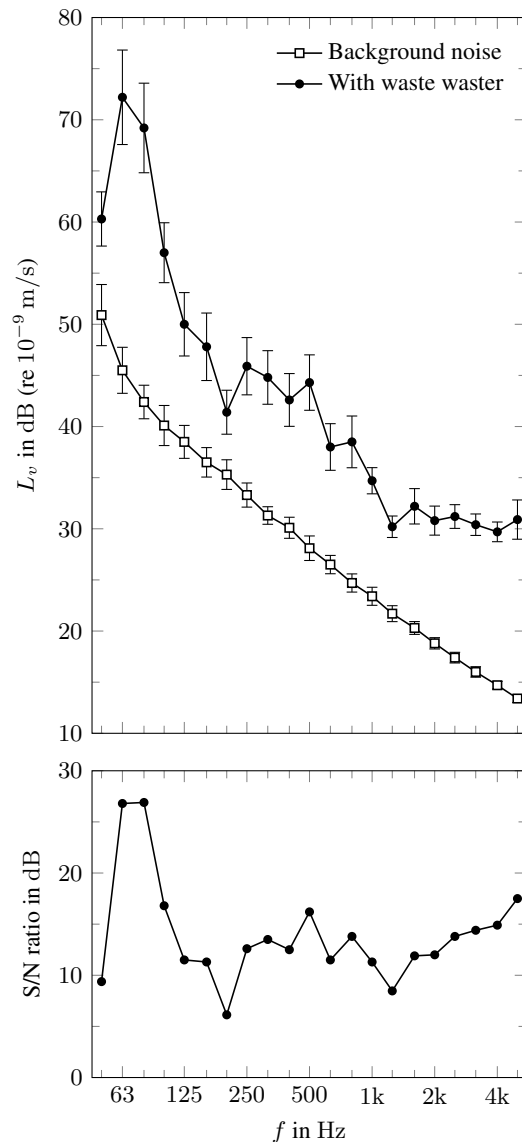


Figure 16: Signal-to-noise-ratio shown for the pipe system connected with two clamps to the reception plate. A spatial average of eight positions in the centre area of the plate with standard deviation is shown using the same positions.

7. ACKNOWLEDGEMENTS

The authors are grateful to Müller-BBM Vibroacoustic Systems GmbH for their support with measurement equipment.

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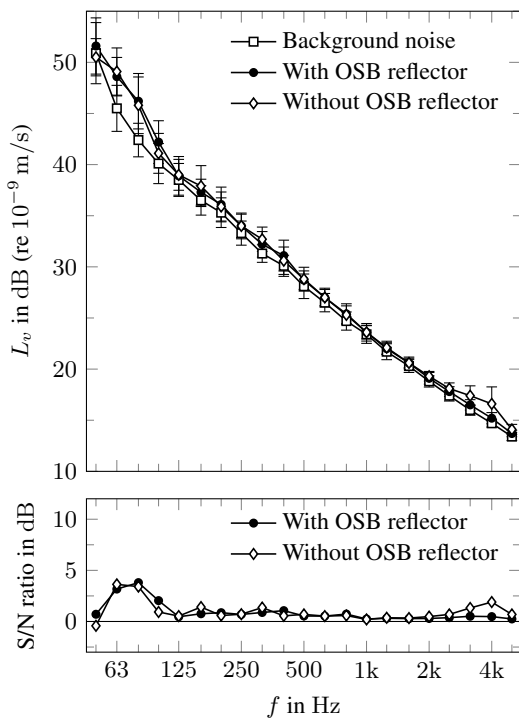


Figure 17: Signal-to-noise-ratio shown for the pipe system disconnected from the reception plate (clamps open). Comparison: with and without the OSB reflector as shown in Figure 3

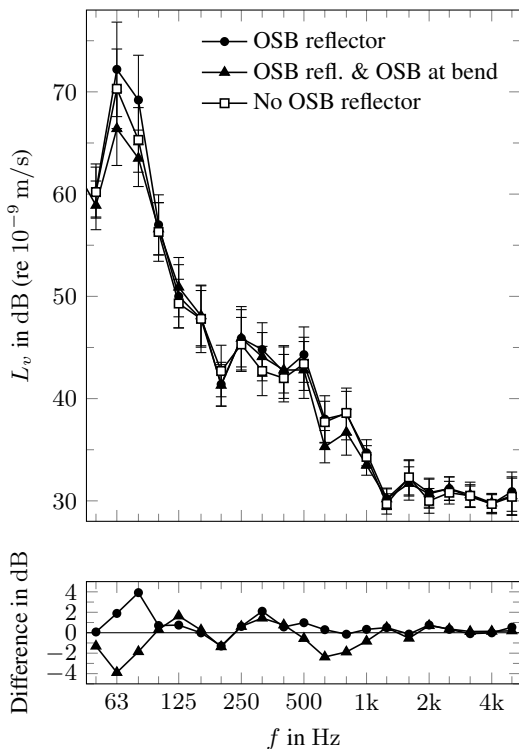


Figure 18: Spatial average velocity level on reception plate with waste water in pipe system and closed clamps. Data with OSB reflector (Figure 3 right) and OSB reflector with additional OSB at bend (Figure 20 right) normalized to data without any shielding.



Figure 19: Detail of open clamps: Additional resilient material used to avoid contact with open clamp or OSB reflector.



Figure 20: Bend at bottom without (left) and with additional 25 mm OSB shielding (right). Note: Care was taken to have no contact between OSB plates and pipe or reception plate.

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