Measuring the Insertion Loss of Water Drainage Pipe Enclosures

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MEASURING THE INSERTION LOSS OF WATER DRAINAGE PIPE ENCLOSURES

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ABSTRACT

To protect building occupants from water drainage noises, piping systems are often installed inside enclosures, or technical shafts. The noise generated by the pipe can be characterized in the laboratory according to EN 14366 (currently under revision). This standard method is based on a steady-state excitation using a controlled water flow. Measurements are done successively with the pipe connected and disconnected from the supporting wall in order to separate airborne and structure-borne noise contributions. However, the current version of EN 14366 does not cover noise mitigation measures. Therefore, years ago, CSTB developed a method to measure the insertion loss of pipe enclosures. This method uses broadband noise generated by a loudspeaker instead of a water flow, the pipe being disconnected from the supporting wall. Now, the characterization of mitigation measures is part of the scope of the ongoing revision of EN 14366, along with important changes in performance indicators and measurement methods. This study aims at comparing the new method proposed for standardization to the historical CSTB method. Measurements are done on different pipe enclosures made of plasterboard on steel frame. The influence of the excitation (water flow at different rates or loudspeaker) and of the contact condition (pipe attached or detached) is investigated. Experimental results are presented and discussed.

1. INTRODUCTION

Water drainage pipes are regularly designated as annoying sources of noise by building occupants. In order to meet performance requirements in terms of sound pressure levels generated on site, design studies can rely on predictions using the model defined in EN 12354-5 [1]. Such predictions use airborne and structure-borne sound characteristics from drainage pipes that can be measured in the laboratory following EN 14366 [2]. With this method, the airborne and structure-borne sound characteristics of the piping system are determined using sound pressure measurements in two test rooms separated by the supporting wall. The total sound field in the first room, where the pipe is installed, is composed of both airborne sound and structure-borne sound. In the adjacent room, only structure-borne sound is supposed to be radiated.

However, the current version of this standard does not consider the commonly used mitigation measures such as resilient mountings, pipe linings or enclosures. Therefore, CSTB proposed a method derived from EN 14366 to determine the insertion loss of pipe enclosures but uses a loudspeaker for the acoustic excitation instead of a constant water flow. This method has been used for years to characterize enclosures used on the French market and take them into account in predictions.

Recently, a revision of EN 14366 was initiated by CEN/TC126/WG7. Along with significant changes in the measurement procedure and in the expression of the results, this revision aims at providing a standard method for the characterization of mitigation measures.

In 2018, experimental work was conducted to assess the impacts of this revision on the determination of the structure-borne sound characteristics of piping systems [3]. Airborne sound and the characterization of mitigation measures were out of this study's scope.

Therefore, the present study is focused on the laboratory characterization of pipe enclosures. It aims at:

- Providing experimental background for the future standard and proposing modifications if necessary;
- Check the relevance of performance values measured with the historical CSTB implemented method to determine whether new characterizations will be needed once the revised standard is available.

First, this paper gives a brief description of both methods, starting with the measurement procedures and followed by the determination of single number quantities used to express the performance. Then, both methods are applied to 3 different pipe enclosures. The measured performances are presented and discussed.

2. MEASUREMENT PROCEDURES

2.1 CSTB method

The characterization method for pipe enclosures proposed by CSTB is based on the current EN 14366 standard, where two main performance indicators can be determined for a given piping system under different water flow rates: the airborne normalized sound pressure level L_{an} and the characteristic structure-borne sound pressure level L_{sc}. These quantities are derived from the sound pressure levels measured in two test rooms.

Assuming that pipe enclosures modify the airborne sound characteristics of the system but not its structure-borne sound characteristics, the insertion loss of the enclosure can be determined with the pipe being disconnected from the test wall. It is defined as follows for each one-third octave band.

$$IL = L_{an} - L_{an,enclosed} \quad (1)$$

In Eqn. (1), L_{an} and $L_{an,enclosed}$ are the airborne normalized sound pressure levels of the bare pipe and of the pipe with the enclosure, respectively.

However, when measuring airborne sound according to EN 14366, the excitation is a controlled water flow inside the pipe, which sometimes results in low L_{an} values at certain frequency bands, depending on the piping system and on the water flow rate. This prevents a true determination of the enclosure's insertion loss. In order to increase the signal-to-noise ratio, the CSTB method replaces the water flow excitation by a loudspeaker placed at the input of the pipe and playing broadband noise.

One drawback of this method is that different experimental setups are necessary to characterize a piping system alone (using the water flow, the pipe being connected to the test wall) and the same piping system associated to one or several enclosures (using the loudspeaker, the pipe being disconnected from the test wall).

2.2 New method proposed for standardization

In the draft prEN 14366 standard under preparation, only one test room is necessary to characterize piping systems. The total sound power level in the test room $L_{Wa,total}$ due to the water flow is derived from sound pressure measurements according to EN ISO 10140-3 [4]. Then, the sound power level $L_{Wa,struc}$ due to structure-borne sound is derived from the space-average vibration velocity of the supporting wall using a power substitution method according to EN 15657 [5]. This requires calibrating the test facilities according to EN ISO 10848-1 [6] using a source of known structure-borne sound power. This calibration step can be performed once and checked periodically. Finally, the airborne sound power contribution is calculated as follows.

$$L_{Wa} = 10\lg\left(10^{\frac{L_{Wa,total}}{10}} - 10^{\frac{L_{Wa,struc}}{10}}\right) \quad (2)$$

With this method, the airborne sound characteristic L_{Wa} can be determined in one-third octave bands under different water flow rates. The characterization procedure for the enclosure requires to disconnect the pipe from the test wall and perform two series of measurements. The first series, with the bare pipe, yield an airborne sound power spectrum L_{Wa}. The second series, with the enclosure built around the pipe, yield another spectrum $L_{Wa,enclosed}$. The frequency-dependent insertion loss D_{Wa} of the enclosure is the difference between these two results.

$$D_{Wa} = L_{Wa} - L_{Wa,enclosed} \quad (3)$$

Note that, with this method, the near-field acoustic excitation is considered as a part of the structure-borne sound contribution. Therefore, even though the pipe is disconnected from the test wall, the structure-borne sound contribution is measured with and without the enclosure to allow the use of Eqn. (2).

According to prEN 14366, the highest water flow rate specified by the standard must be used to characterize pipe enclosures. This value depends on the internal diameter of the pipe. The performance determined for this flow rate is assumed to remain valid for lower rates.

However, with the enclosure, the total sound pressure level in the test room may be too close to background noise. If necessary, the draft standard allows to use a loudspeaker instead of the water flow to improve the signal-to-noise ratio, leading to an approach close to the CSTB method.

Otherwise, this method has the advantage of keeping the same experimental setup to characterize piping systems or enclosures.

3. SINGLE NUMBER QUANTITIES

3.1 CSTB method

In the method used at CSTB, a single number quantity noted ΔL_{an} is calculated from the frequency-dependent performance values as follows.

First, the airborne sound pressure spectrum of a reference drainage pipe, represented in Fig. 1, is considered. Note that it is defined from 100 Hz to 5000 Hz.

The sound pressure level of this reference pipe with the enclosure is obtained by subtracting its insertion loss at each frequency band.

$$L_{an,ref,enclosed,i} = L_{an,ref,i} - IL \quad (4)$$

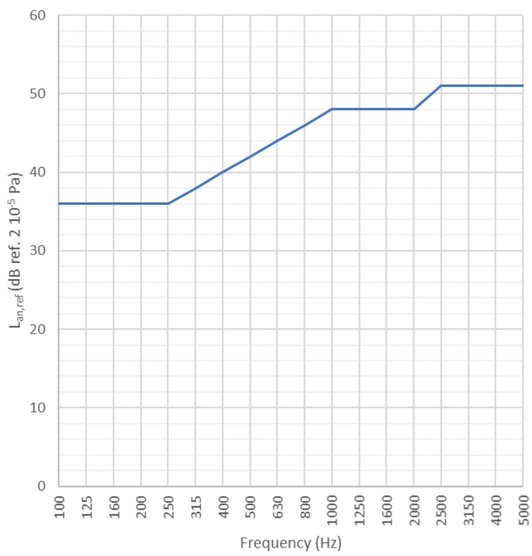

Figure 1. Reference airborne sound pressure spectrum of a drainage pipe without enclosure.

Then, the A-weighted overall level with the enclosure $L_{an,ref,enclosed,A}$ is calculated, while the overall level of the bare reference pipe $L_{an,ref,A}$ is equal to 60 dB(A).

Finally, the single number quantity expressing the performance of the enclosure is the difference between the A-weighted sound pressure levels.

$$\Delta L_{an} = L_{an,ref,A} - L_{an,ref,enclosed,A} \qquad (5)$$

3.2 New method proposed for standardization

In the draft prEN 14366 standard, the single quantity is defined in a similar way but from A-weighted sound power levels, and without the use of a reference spectrum for the bare pipe.

$$D_{Wa,A} = L_{Wa,A} - L_{Wa,enclosed,A} \qquad (6)$$

Plus, this method covers a wider frequency range, starting at 50 Hz.

4. PERFORMANCE MEASUREMENTS ON REAL SYSTEMS

In this section, the acoustic performances of three pipe enclosures are measured considering different methods:

- The historical CSTB method based on sound pressure levels, using a loudspeaker to generate sound in the pipe;
- The new method proposed for standardization based on sound power levels, using a constant water flow to generate noise in the pipe.

The piping system inside the shaft remains the same for all measurements. It uses a vertical plastic pipe with a nominal diameter of 110 mm.

The maximum water flow rate for this diameter is 4 L/s. However, in this work, measurements according to the new method were mistakenly performed under the flow rates of 1, 2 and 3 L/s only. Variants were considered with the pipe connected to the test wall.

Results for each enclosure are presented below.

4.1 Enclosure A

The pipe enclosure considered here is a single BA18 gypsum board mounted on a metal frame. The insertion loss of this system is shown in Fig. 2. The single number quantities associated to each method are represented in Fig. 3.

An important observation is that many values are missing with the new method proposed in prEN 14366. This happens even more often for low water flow rates or when the pipe is attached to the test wall, with no result available below 400 Hz. Such problems occur when the total sound power level in the test room $L_{Wa,total}$ is equal or lower than the evaluated structure-borne contribution $L_{Wa,struc}$. This situation has no physical meaning and prevents from using Eqn. (2). Considering that the measurement of $L_{Wa,total}$ is rather straightforward, these errors might come from the determination of the structure-borne contribution. This issue will be discussed in Section 5.

At frequency bands where results can be determined, the different methods agree rather well, except some values at 200, 250 and 630 Hz. The water flow rate in the pipe seems to have a limited influence on the insertion loss values, although using the higher flow rates allows to use Eqn. (2) on a wider frequency range.

The calculation of the single number quantities is of course affected by the lack of frequency-dependent values mentioned above. However, this issue is compensated by the application of A-weighting, where the medium and high frequency content matters most. Therefore, single number quantities calculated from the available values are in reasonable agreement, with a 2 dB(A) spread. Considering the new characterization method with water flowing at 3 L/s (pipe connected or disconnected) gives an insertion loss D_{Wa} of 22 dB(A), while the CSTB method with the loudspeaker gives a ΔL_{an} value of 21 dB(A).

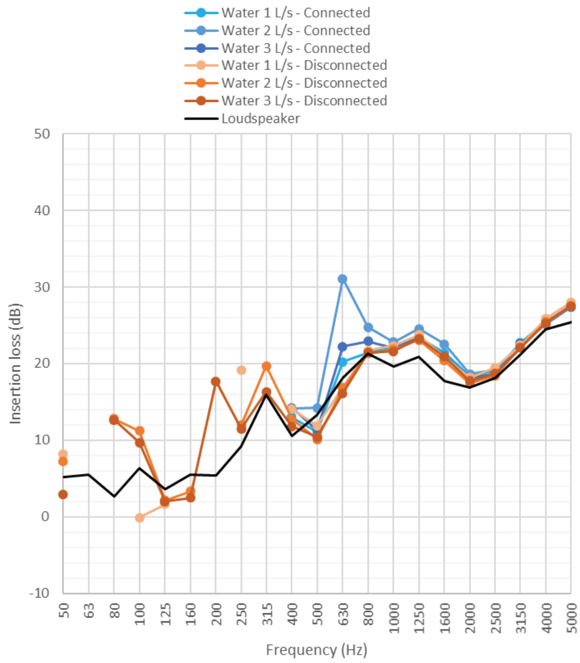

Figure 2. Measured insertion loss spectra of enclosure A.

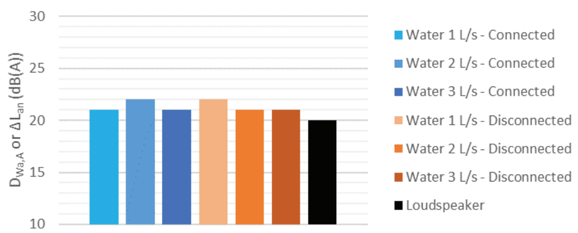

Figure 3. Insertion loss of the enclosure A expressed as single number quantity in dB(A).

4.2 Enclosure B

The pipe enclosure considered here is a single BA18 gypsum board mounted on a metal frame, with 45 mm of mineral wool on the inner side. The insertion loss of this system is shown in Fig. 4. The single number quantities associated to each method are represented in Fig. 5.

Similar observations as for the previous enclosure can be made: the new method often fails to produce insertion loss values in the low frequency range, but the available values are in reasonable agreement with the results of the loudspeaker method. Larger discrepancies are obtained when the water flow rate is low or when the pipe is connected to the test wall.

With the pipe disconnected from the wall and a water flow rate of 2 or 3 L/s, a single number quantity D_{Wa} of 31 dB(A) is obtained, equal to the ΔL_{an} value obtained with the loudspeaker. With a water flow and the pipe connected to the test wall, D_{Wa} values are significantly higher.

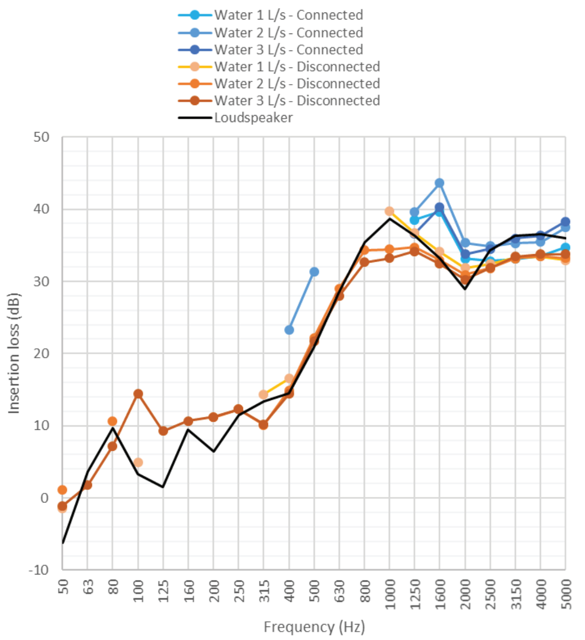

Figure 4. Measured insertion loss spectra of enclosure B.

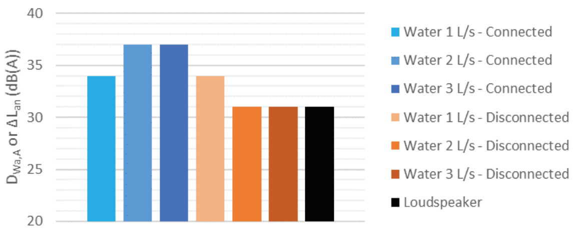

Figure 5. Insertion loss of the enclosure B expressed as single number quantity in dB(A).

4.3 Enclosure C

The pipe enclosure considered here is a double-leaf system composed of BA13 and BA18 gypsum boards screwed together, mounted on a metal frame, with 45 mm of mineral wool on the inner side. The insertion loss of this system is shown in Fig. 6. The single number quantities associated to each method are represented in Fig. 7.

Similar observations as for the two previous enclosures can be made: the new method often fails to produce insertion loss values in the low frequency range, but the available values are in reasonable agreement with the results of the loudspeaker method. Larger discrepancies are obtained when the water flow rate is low.

With the pipe disconnected from the wall, the single number quantity D_{Wa} is 36-37 dB(A), while the CSTB method with the loudspeaker gives a ΔL_{an} value of 35 dB(A). With a water flow and the pipe connected to the test wall, D_{Wa} values range between 34 and 38 dB(A).

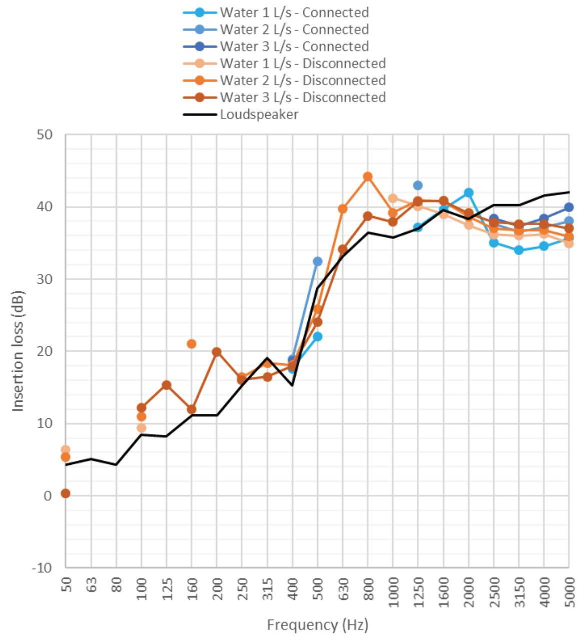

Figure 6. Measured insertion loss spectra of enclosure C.

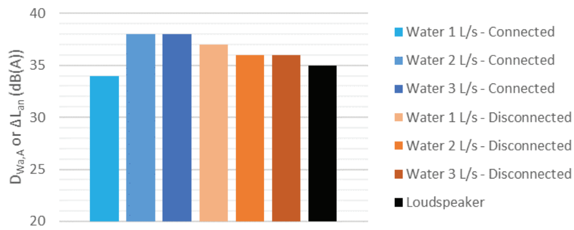

Figure 7. Insertion loss of the enclosure C expressed as single number quantity in dB(A).

5. DISCUSSION AND RECOMMENDATIONS

The main difficulty observed during this experiment lies in the calculation of the airborne sound power of the piping system using Eqn. (2). Indeed, in many cases, the structure-borne contribution – estimated from the vibration of the test wall – is greater than the total sound measured in the test room. This is particularly true in the presence of a pipe enclosure, when the total sound in the test room is low.

The method used to determine this total sound power level from sound pressure level measurements is quite common and can be considered as robust. Therefore, it seems more likely that the structure-borne contribution is overestimated.

This could be explained by different reasons. The estimation method itself involves several steps (pre-calibration of the test facilities, measurement of the wall vibration velocity with the water flow and conversion into a radiated sound power using the substitution method) which can result in uncertainty accumulation. Plus, measurements of the wall vibration velocity can be affected by some near-field acoustic excitation from the pipe – even when it is disconnected – or by the background noise of the measuring equipment. To investigate the latter factor, the raw vibration velocity levels can be observed. The space-average velocity level of the test wall is represented in Fig. 8 in the absence of an enclosure and in Fig. 9 with enclosure C. The following observations can be made:

- The results are very similar with and without the enclosure;
- When the pipe is connected to the test wall, the vibration velocity emerges from background noise, even for the lower water flow rate, and increases with increasing flow rate;
- When the pipe is disconnected, only background noise is measured, regardless of the flow rate. No effect of a near-field acoustic excitation can be detected from these measurements. This remains true even when the sound field is constrained by the enclosure.

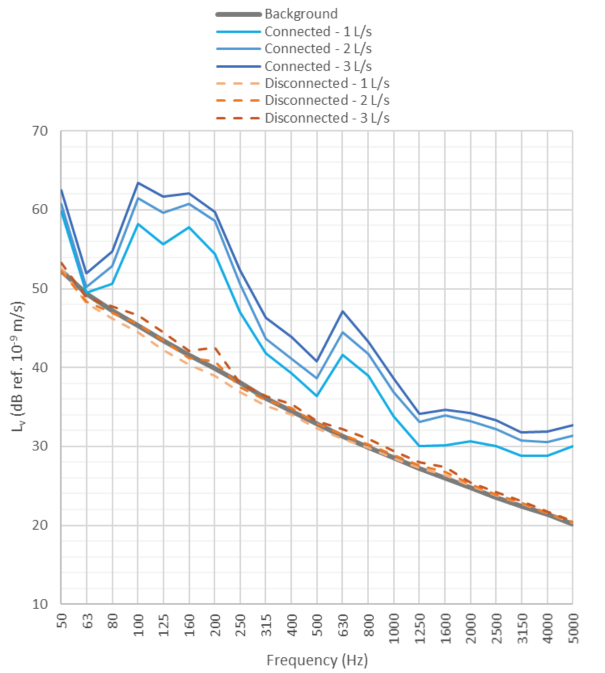

Figure 8. Space-average vibration velocity level of the test wall, uncorrected from background noise, for the bare pipe.

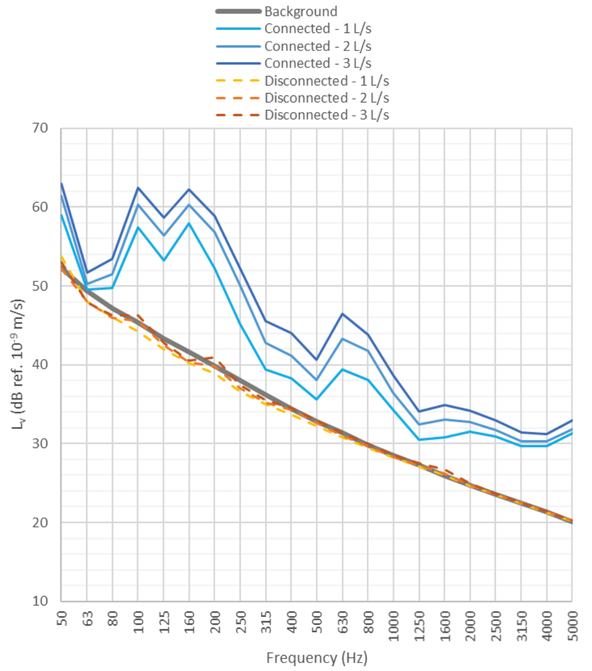

Figure 9. Space-average vibration velocity level of the test wall, uncorrected from background noise, for the pipe equipped with enclosure C.

When applying the measurement procedure described in Section 2.2 (the pipe being disconnected), this background velocity level is used to calculate a – virtually – radiated sound power level, represented in Fig. 10. The corresponding overall value is 21 dB(A).

Note that Eqn. (2) is applicable only if the total sound power level measured in the test room is much greater than this limit, which can be considered as a laboratory limit. Unfortunately, this condition was rarely met during this study, even with enclosure A. Therefore, the background vibration level seems to be the reason why many performance values cannot be determined with the new method. It should be noticed that CSTB laboratory used to perform these measurements is not decoupled from its environment and might suffer from this condition with regards to background vibration levels. However, very similar background vibration levels were observed in another laboratory, as shown in Fig. 11.

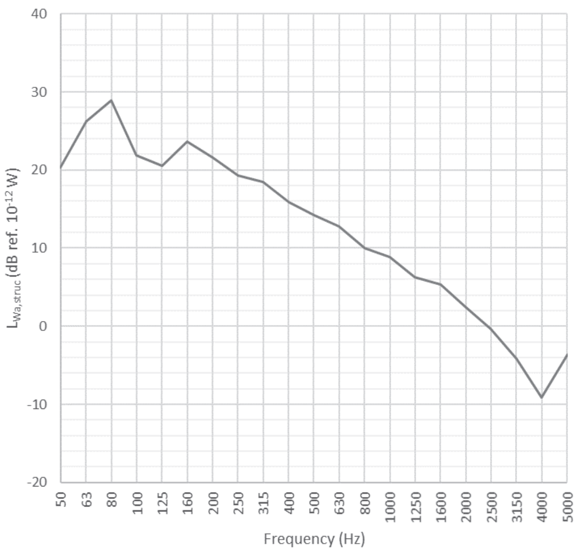

Figure 10. Minimum measurable values for the structure-borne contribution to the total sound power level.

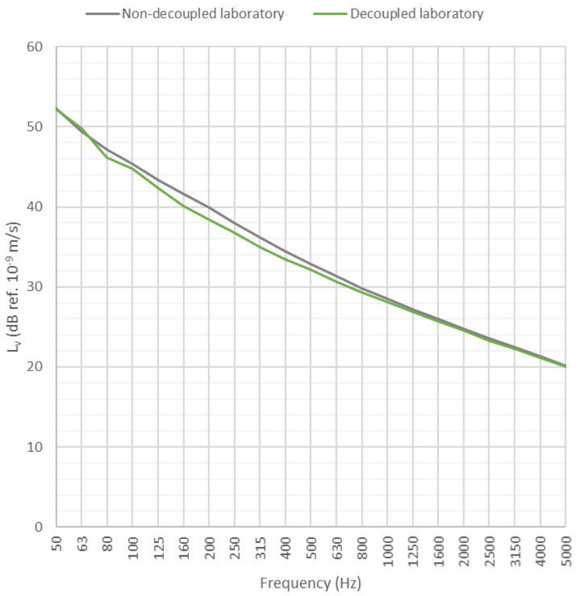

Figure 11. Influence of laboratory decoupling on background vibration levels.

It should be stressed out that applying the highest flow rate of 4 L/s, as proposed in prEN 14366, may solve the problem by increasing the total sound pressure power radiated in the test room, without modifying the structure-borne contribution. However, further experimental work is needed to confirm it.

If problems still occur with the highest flow rate, then the following recommendations can be made:

- The vibration measuring equipment should be carefully chosen to ensure the lowest possible background level. The revised standard should include specifications on this point;
- The water flow should be replaced by a loudspeaker emitting broadband noise to increase the total sound level in the test room, while the structure-borne contribution would remain minimal;
- Otherwise, the characterization method for pipe enclosures should be modified to neglect the structure-borne contribution, provided that the pipe is properly decoupled from the laboratory structure.

The prEN 14366 should also alert on the fact that the evaluation of the airborne sound power contribution can be impossible in some cases and propose corrective approaches. The laboratory conditions should also be questioned with regards to background vibration levels.

These conclusions and recommendations will be shared with standardization group CEN/TC126/WG7 in charge of revising the measurement standard.

The results presented in this study also show that the future standard method for characterizing pipe enclosures should provide similar performance values as those obtained with the historical CSTB method. Therefore, enclosure performances evaluated from past characterizations should remain relevant for use in acoustic predictions or for comparing products.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] *EN 12354-5 – Building acoustics – Estimation of acoustic performance of building from the performance of elements – Part 5: Sound levels due to the service equipment*, 2013 (under revision).

[2] *EN 14366 – Laboratory measurement of noise from waste water equipment*, 2005 (under revision).

[3] S. Bailhache, S. Colin, P. Ducruet and C. Guigou-Carter: "Characterization of a water drainage pipe using the EN 14366 and EN 15657 methods", *Proc. Euronoise*, 2018.

[4] *EN ISO 10140-3 – Acoustics – Laboratory measurement of sound insulation of building elements – Part 3: Measurement of impact sound insulation*, 2013.

[5] *EN 15657 – Acoustic properties of building elements and of buildings – Laboratory measurement of structure-borne sound from building service equipment for all installation conditions,* 2017.

[6] *EN ISO 10848-1 – Acoustics – Laboratory measurement of the flanking transmissions of airborne and impact sound between adjoining rooms – Part 1: Frame document,* 2017.