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FROM CLASSIFICATION TO PREDICTION: APPLYING EN 14366-1 TO FRESHWATER SYSTEMS

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ABSTRACT

Sound emission of and transmission in plumbing systems are currently standardized with different approaches for waste water and fresh water applications. While EN 14366 provides characterization methods for waste water systems that deliver essential input data for the prediction of sound levels in buildings, DIN EN ISO 3822 focuses solely on the classification of individual water appliances, which are the predominant acoustic sources in fresh water installations. However, the methodology outlined in DIN EN ISO 3822 exhibits significant limitations, leading to inconsistencies between different laboratories and focusing solely on classification rather than prediction purposes. This research explores the potential application of EN 14366-1 characterization methods to freshwater systems by experimentally investigating complete installations − including appliances, pipes, and pipe clamps − to assess the necessity of developing a new standard that characterizes entire systems based on the approach used in EN 14366-1.

Keywords: *building acoustics, freshwater, structure-borne sound transmission, sanitary installations, pipe noise*

1. INTRODUCTION

Noise from building equipment is a topic that has been addressed intensely in the last two decades. Numerous case studies on various types of sources to determine the acoustic properties have been performed and led to the development of the test standard EN 15657 in 2009 that has been revised in 2017 to account for all installation conditions [1]. The results according to EN 15657 serve as input data for predictions of the sound propagation in buildings according to EN 12354-5 [2] that was recently revised. The general methods in EN 15657 have been implemented in EN 14366-1 [3] for testing wastewater pipes. While experience with this new standard is gained by numerous laboratories, a current work item of CEN/TC 126 WG7 aims to develop a second part: 14366-2 for water supply installations. The idea is to keep the methods and test facilities the same as for waste water systems and include installations with different components, not only different appliances (e.g. taps or valves), but also different piping configurations and mounting elements. Previously, only the appliances like taps and valves in water supply systems were characterized by EN ISO 3822 which exhibits significant limitations [4]. However, this method only allows the appliances to be categorized into sound classes without delivering input data for predictions. This paper aims to demonstrate the suitability of the methods from EN 14366-1 for the characterization of fresh water pipe systems.

2. TEST SETUP

For the here shown investigations, first, a fresh water system from previous publications [5,6] is used, for which the blocked force has already been determined using the reception plate method by EN 15657. This freshwater system consists of a 1-inch galvanized steel pipe connected to the building via 2 pipe clamps. The test setup on the reception plate is shown in figure 1. The internal noise source of the pipe system is the installation noise standard (INS) by EN ISO 3822, which is a reference source used to characterize appliances like taps and valves. The system is driven by a water supply pump with a controlled flow pressure of 3 bar, leading to a flow rate of 16.4 l/min, mainly determined by the INS. This short pipe section is

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installed on the 2nd floor of an installation test stand shown in figure 3.

Figure 1. Short pipe section from previous investigations on the reception plate [5,6], the same pipe system is investigated in the installation test stand. Blue arrows depict the water flow direction.

In a second step, the system is exchanged for a longer pipe system running through several floors of the installation test stand. This longer pipe is expected to be more building-like than the short pipe section and follows the configuration in EN 14366-1 for testing waste water pipe systems. Schematic sketches of the test setups are shown in figure 2.

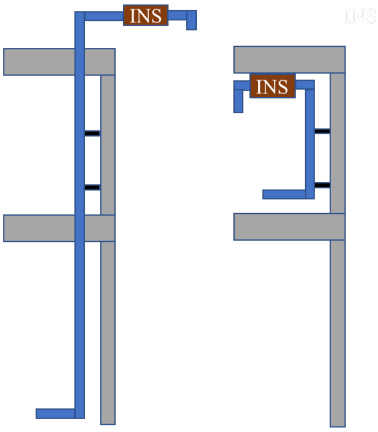

Figure 2. Schematic setup of the pipe systems in the building-like test stand, left: long pipe over several storeys, right: short pipe section within one storey.

3. APPLICATION OF EN 14366-1 TO FRESHWATER PIPES

The concept behind EN 14366-1 is to use a structure-borne sound power substitution method in order to determine the blocked force. Therefore, a calibration source with known power input is needed.

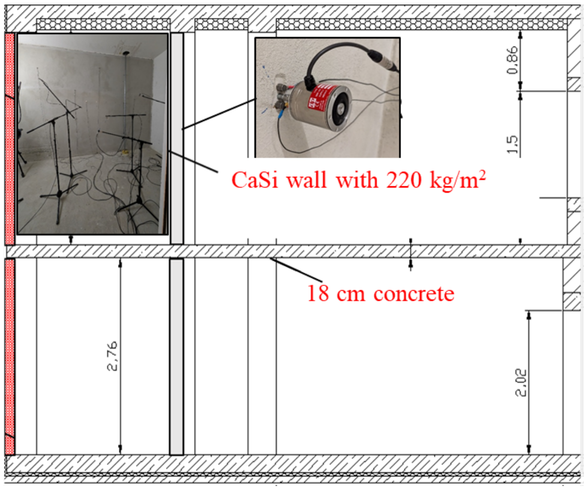

Figure 3. Cross section of the installation test stand. The mean sound pressure level and wall velocity level are measured in the sending room side. The calibration source is mounted on the test wall on the receiving room side.

In this investigation the calibration source is an inertial shaker that is screwed into the threading of the metal expansion anchors in the wall used to mount the pipe clamps of the fresh water pipe. The shaker force is measured via a force transducer while simultaneously the velocity at the contact point is measured via accelerometers. From the cross product of force and velocity at the contact point, the structure-borne sound power of the calibration source is determined. By comparing the response for shaker excitation (mean wall velocity and airborne sound power in the room) to the response for the fresh water pipe system, the source data (blocked force, airborne sound power) of the fresh water pipe system is determined. The wall velocity is captured simultaneously with 6 accelerometers on the test wall and the sound pressure level with 6 microphones in the test room, as shown in figure 3.

Note: So far, the EN 14366-1 (and EN 15657) methods are restricted to stationary excitation. For the characterization of sources with transient excitation (here e.g. closing of a water tap), a new method is explored in [7].

3.1 Structure-borne sound characterization

To determine the structure-borne sound power of the fresh water pipe system, it is assumed that the structure-borne sound power of any source is proportional to the squared mean plate velocity [1]. This leads to the following relation between the structure-borne sound power and mean squared velocity for the source (pipe system) and the calibration source (shaker).

$$\frac{W_{source}}{\langle v_{source}^2 \rangle} = \frac{W_{cal}}{\langle v_{cal}^2 \rangle} \tag{1}$$

As can be seen in figure 4, the mean wall velocity is well above background noise in the investigated frequency range and so is the mean sound pressure level (not shown).

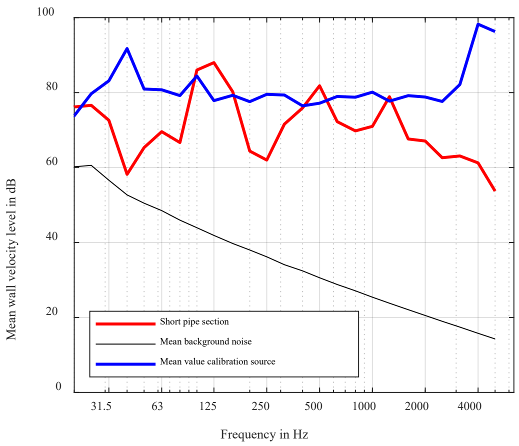

Figure 4. Mean velocity levels on the test wall with the calibration source (blue), with the short pipe section (red) and without excitation (black).

For several contact points j, expressed in levels[1] and rearranged to the structure-borne power of the source, equation (1) becomes:

$$L_{Ws} = 10\lg\left(\sum_j 10^{\frac{L_{Ws,cal,j}}{10}}\right) + L_{\langle v \rangle} - 10\lg\left(\sum_j 10^{\frac{L_{\langle v \rangle,cal,j}}{10}}\right) \tag{2}$$

As can be seen by comparing figure 4 and 5, the difference of structure-borne power levels and wall velocity levels between calibration source and test specimen are equal.

[1] For the calculation of levels, the reference values of EN 14366-1 and EN 15657 are used.

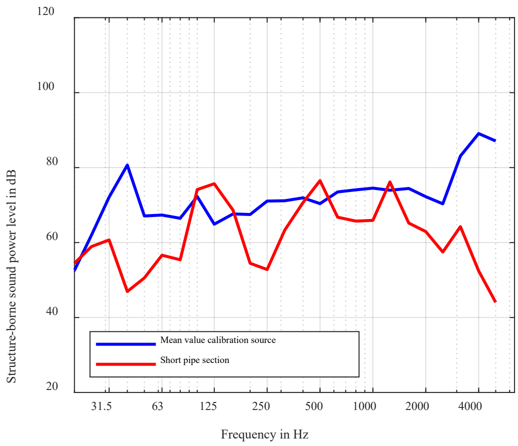

Figure 5. Structure-borne sound power levels of the calibration source (blue) and the short pipe section (red)

Assuming a force source condition, where the receiver mobility Y_R is much lower than the source mobility Y_S, the blocked force level $L_{Fb,eq}$ is calculated using the real part of the equivalent receiver mobility $Y_{R,low,eq}$:

$$L_{Fb,eq} \approx L_{Ws} - 10\lg\left(\frac{\mathrm{Re}\left(Y_{R,low,eq}\right)}{Y_0}\right) \mathrm{dB} \tag{3}$$

The blocked force is independent of the receiving structure and is used as input data for predictions in heavyweight building situations using EN 12354-5, which has already been shown in [6]. For the short pipe section, the blocked force is shown in figure 6.

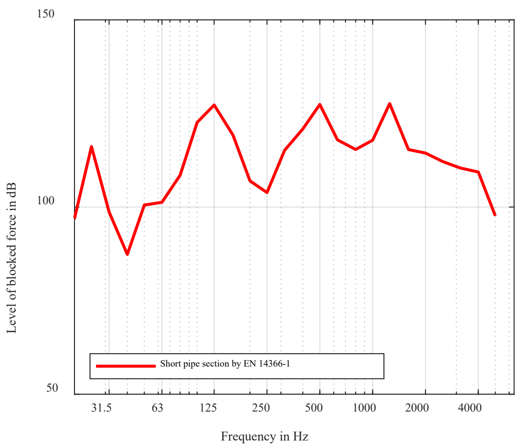

Figure 6. Blocked force of the short pipe section determined according to EN 14366-1

3.2 Airborne sound characterization

To determine the airborne sound power of the test specimen, first the mean total sound pressure level $L_{p,total}$ is measured in the test room. With the reverberation time and the volume of the test room, the normalized total sound pressure level $L_{n,total}$ is calculated.

$$L_{n,total} = L_{p,total} - 10\lg(T_R) + 10\lg\left(\frac{0{,}16V}{10}\right) \quad (4)$$

The total airborne sound power $L_{Wa,total}$ in the test room is:

$$L_{Wa,total} = L_{n,total} + 4\text{ dB} \quad (5)$$

Since the fresh water system is a combined structure-borne and airborne sound source, the total airborne sound power in the room $L_{Wa,total}$ is a combination of direct radiation of airborne sound by the pipe L_{Wa} together with the airborne sound radiation of the wall $L_{Wa,struc}$ due to structure-borne excitation of the wall at the pipe contacts. Therefore, the airborne sound power of the pipe system itself can be separated using:

$$L_{Wa} = 10\lg\left(10^{\frac{L_{Wa,total}}{10}} - 10^{\frac{L_{Wa,struc}}{10}}\right) \quad (6)$$

To determine the airborne sound due to structure-borne excitation $L_{Wa,struc}$, the structure-borne sound power level of the calibration source $L_{Ws,cal}$ is compared to the structure-borne sound power level L_{Ws} of the test specimen. With the difference between those two and the radiated airborne sound power level $L_{Wa,struc,cal}$ radiated by the structure-borne excitation of the calibration source, calculated using equations (4) and (5), the radiated airborne sound power level of the wall $L_{Wa,struc}$ can be determined:

$$L_{Wa,struc} = 10\lg\left(\sum_j 10^{\frac{L_{Wa,struc,cal,j}}{10}}\right) + L_{Ws} - 10\lg\left(\sum_j 10^{\frac{L_{Ws,cal,j}}{10}}\right) \quad (7)$$

The separation according to equation (6) is only applicable if $L_{Wa,total}$ is greater than $L_{Wa,struc}$. As seen in figure 7, the radiation of the wall due to structure-borne excitation is dominant up to 600 Hz. This is already a hint that for the prediction of the sound transmission in a real building, airborne sound radiation of the pipe is negligible compared to structure-borne sound transmission.

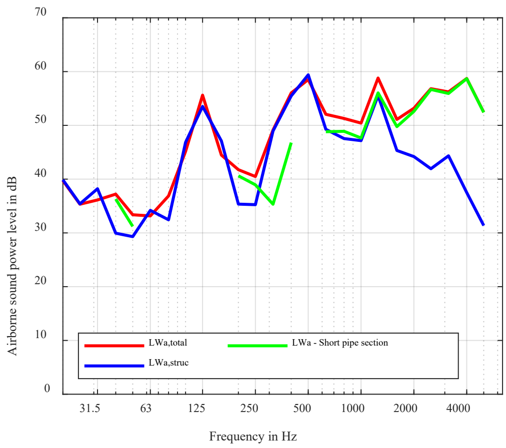

Figure 7. Separation of total airborne sound power (red) of the short pipe section into shares of wall (blue) and pipe (green).

It should be noted that for the short pipe section, the airborne sound in the room is influenced by the noise of water running out of the pipe system and into and through a drainage pipe without any connection to the wall. The radiation by the fresh water pipe itself could then be even lower than shown here.

3.3 Source mobility

To assess the validity of the force source condition, the equivalent source mobility Y_S is determined according to EN 14366-1 indirectly from the equivalent free velocity $v_{f,eq}$ of the contact points when the pipe is disconnected from the test wall and the beforehand measured equivalent blocked force of the pipe system:

$$|Y_{S,eq}|^2 = 10^{\frac{L_{vf,eq} - L_{Fb,eq}}{10}} \cdot 10^{-6} \quad (8)$$

The equivalent free velocity level of the pipe can be calculated by energetically summing up the free velocity levels at each contact point:

$$L_{vf,eq} = 10\lg\left(\sum_j 10^{\frac{L_{vf,j}}{10}}\right) \quad (9)$$

For comparison, the source mobility has also been determined directly by impact hammer excitation at each contact point while keeping the accelerometer at the same position as for the free velocity measurement , see figure 8. The equivalent magnitude of source mobility is then the arithmetic average of the measured mobilities at each contact point.

Figure 8. Direct measurement of source mobility at a contact point (threaded rod) of the pipe system.

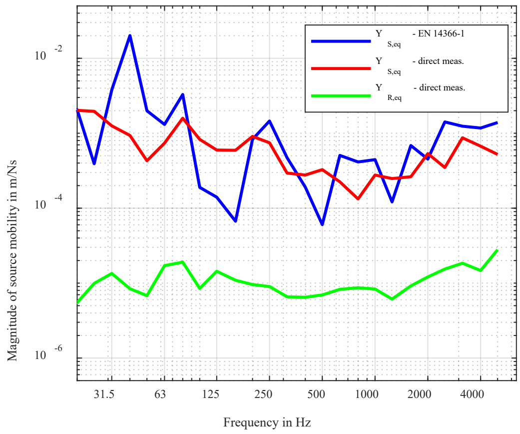

Figure 9. Mean mobility of the test wall (green) and the short pipe section (red) directly measured and the equal mobility of the short pipe section by the standardized method (blue).

Figure 9 shows the measured mobilities of source and receiver together with the source mobility determined by the EN 14366-1 method. Because the source mobility is much higher than the receiver mobility, the force source condition holds true, even though the agreement between the source mobility methods is not perfect.

4. PREDIICTION

With the blocked force from equation (3), predictions of the normalized sound pressure level in a receiving room due to structure-borne excitation of the fresh water pipe system can be made according to DIN EN 12354-5 [2] using

$$L'_{ne,s} = L'_n + L_{Fb,eq} - L_{Fb,eq,stm} \quad (10)$$

where L'_n is the apparent impact sound pressure level of the wall caused by the ISO tapping machine and $L_{Fb,eq,stm}$ is the blocked force of the ISO tapping machine. The apparent impact sound pressure level L'_n can either be calculated using EN 12354-2 [9] or measured using the normalized spatial average transmission function $D_{TF,av,n}$ from ISO 10848-1 [8]. The determination of L'_n using transfer functions has been implemented in the recently published EN 17823 [10] and can be calculated according to

$$L'_n = D_{TF,av,n} + L_{Ws,stm} \quad (11)$$

where $L_{Ws,stm}$ is the structure-borne sound power of the ISO tapping machine calculated using its blocked force $L_{Fb,eq,stm}$ and the equivalent mobility of the test wall $Y_{R,low,eq}$:

$$L_{Ws,stm} = L_{Fb,eq,stm} + 10\lg\left(\mathrm{Re}\left\{\frac{Y_{R,low,eq}}{Y_0}\right\}\right) \quad (12)$$

The normalized spatial average transfer function $D_{TF,av,n}$ by ISO 10848-1 is determined from the spatial average transfer function $D_{TF,av}$ which is the energetical average of the transfer functions $D_{TF,k}$ between structure-borne sound power and sound pressure level in the test room for each excitation position k:

$$D_{TF,k} = L_{p,cal,k} - L_{Ws,cal,k} \quad (13)$$

$$D_{TF,av} = 10\,lg\left(\sum_j 10^{\frac{D_{TF,j}}{10}}\right) \quad (14)$$

$$D_{TF,av,n} = D_{TF,av} + 10\,lg\left(\frac{A}{A_0}\right) \quad (15)$$

It should be noted that, since a force source condition is assumed for equation (12), the same evaluations could be made using directly measured forces instead of using the structure-borne sound power W_s of the calibration source. Since the mobility of the test wall still has to be determined to check if the force source condition holds true, no measurement effort can be saved.

The apparent impact sound pressure level of the test wall in the installation test stand using the two methods are shown in figure 10.

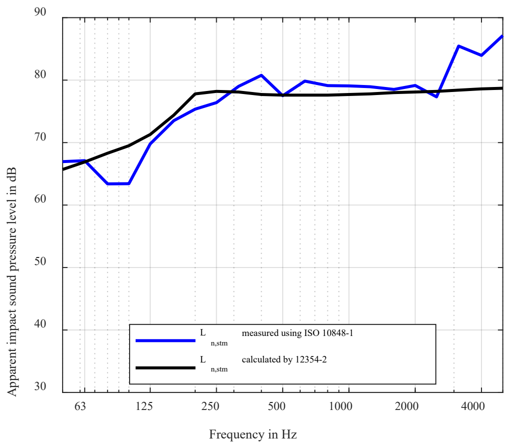

Figure 10. Apparent impact sound pressure level calculated by EN 12354-2 and measured using transfer functions from ISO 10848-1.

EN 14366-1 already uses a similar approach with transfer functions for the determination of the radiated airborne sound power of the wall due to structure-borne excitation $L_{Wa,struc}$ of the fresh water pipe system, compare equations (4), (5) and (7). The main difference is the determination of the average transfer function $D_{TF,av}$. While the ISO 10848-1 averages the transfer functions themselves (see equation (14)), EN 14366-1 sums the power input at all contact points and the mean sound pressure levels caused by each power input. The average transfer function EN 14366-1 implicitly uses is:

$$D_{TF,av,EN14366} = 10\lg\left(\sum_j 10^{\frac{L_{p,cal,j}}{10}}\right) - 10\lg\left(\sum_j 10^{\frac{L_{Ws,cal,j}}{10}}\right) \quad (16)$$

If the power input is the same for each contact point the two methods deliver the same results. If the power input at any contact point is much higher than at other contact points, which is easily possible for impact hammer excitation, the resulting average transfer function from equation (16) is dominated by the result of that point. For the investigations made here, there are only minor differences caused by the inconsistent determination of average transfer functions, because the shaker delivers nearly identical structure-borne excitation at each contact point and the individual transfer functions of each point also only show small deviations.

The predicted normalized sound pressure levels in the receiving room of the installation test stand using equation (10) with calculated and by ISO 10848-1 determined apparent impact sound pressure levels are shown in figure 11. The by EN 14366-1 predicted normalized sound pressure levels $L_{n,struc} = L_{Wa,struc} - 4$ dB, compare equation (5), shows small deviations to the prediction with the transfer function from ISO 10848-1, which is only due to the different averaging, see equations (13) (14) and (16). The measured and predicted sound pressure level in the receiving room is in good agreement for all prediction methods.

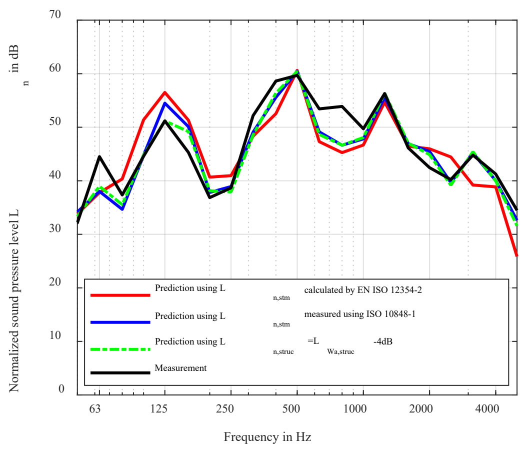

Figure 11. Normalized sound pressure level in the receiving room caused by the short pipe section excited by the INS.

5. COMPARISONS

To validate the blocked force determined by EN 14366-1 a comparison with the results on the reception plate by EN 15657 [5] is made in figure 12. The results show good agreement between the two methods from 50 Hz upwards. This shows, that the EN 14366-1 method is suitable to characterize fresh water pipe systems as structure-borne sound sources.

For the long pipe section, the blocked force of the pipe system is much lower than for the short pipe section. Such large differences were not expected, since in previous studies on the reception plate [5], only minor variations of the blocked force with respect to the pipe geometry were found.

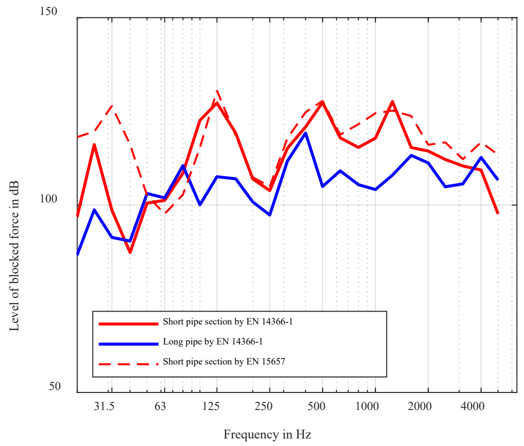

Figure 12. Blocked force of the long pipe (blue) and the short pipe section (red) by EN 14366-1 method in comparison with the blocked force of the short pipe section on the reception plate by EN 15657 (red dashed).

In the previous investigations on the reception plate [5], it has been shown that the insertion loss is independent of the excitation of the pipe but dependent on the specific combination of pipe and pipe clamp. To verify these results, the long pipe system is mounted with pipe clamps with a rubber inlay. The influence of the pipe clamp inlay on the blocked force is shown in following figure.

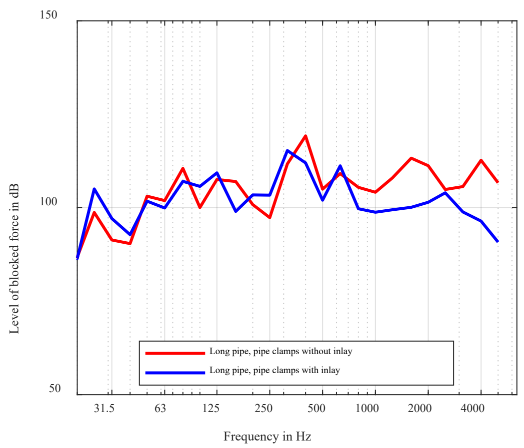

Figure 13. Effect of a rubber inlay in the pipe clamps of the long pipe.

The effect of the inlay in the pipe clamp on the blocked force is limited to the high frequency range above 600 Hz, except for the 3150 Hz 3rd-octave band. Below 600 Hz, the resilient inlay has only a minor effect. The difference in blocked force level will lead to the same difference in sound pressure level in the receiving room, which effectively is the insertion loss, displayed in figure 14. To evaluate the validity of this result, the insertion loss determined on the reception plate for the small pipe section with the same pipe clamps [5] is also shown.

The insertion loss of the pipe clamps determined via the EN 14366-1 methods for the long pipe system show the same trend as for the short pipe section characterized on the reception plate. This approves the expectation from previous investigations that the insertion loss of pipe clamps has a minor dependency of the geometry of the pipe but is heavily dependent on the combination of pipe and pipe clamp.

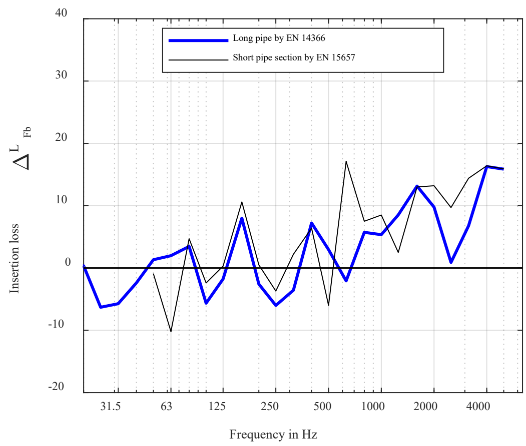

Figure 14. Insertion loss of the pipe clamp with a resilient inlay determined by the blocked force for the long pipe system by EN 14366-1 and for the short pipe section by EN 15657 at the reception plate.

6. CONCLUSIONS

It was shown that the methods of EN 14366-1 are in principle suitable for characterizing fresh water pipe systems. The blocked forces determined for the short pipe section according to EN 14366-1 are in good agreement with the results from measurements on the reception plate method according to EN 15657. The airborne sound power can also be determined in accordance with EN 14366-1, however the valid frequency range is limited here as the structure-borne sound component dominates up to 600 Hz.

The source quantities free velocity and mobility can also be determined using the methods in EN 14366-1.

The blocked force for the long pipe is significantly lower than for the short pipe section, which was not expected from previous investigations. This indicates that the pipe length has a relevant effect that has to be investigated in further detail. The consequence so far is that a laboratory test set-up needs to be as building-like as possible which requires an installation over more than one storey as for waste water pipe systems.

7. ACKNOWLEDGMENTS

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