Noise from Waste Water pipes above a Suspended Ceiling

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Summary
The estimation of sound levels due to waste water installations in buildings is a complex task. Insight in both the sound radiation of the installation and the sound reduction of the building is necessary to make a reliable prediction. An investigation was carried out to the noise from waste water pipes mounted in the plenum above a suspended ceiling. Aim of the research is to get a better understanding in the sound pressure level to be expected in a room due to a toilet flushing (and a steady flow of tap water). The noise is generated by the flow and fall of water in the piping system and radiates airborne sound in the plenum. This airborne sound is transmitted to the receiving room via the suspended ceiling. The resulting sound pressure level in the receiving room depends on the acoustical quality of both the piping system as the suspended ceiling. The measurement results given in this paper can be used to the estimation of the airborne sound pressure level.
Key words: Waste water pipes, suspended ceiling.

1. Introduction

The estimation of sound levels due to waste water installations in buildings is a complex task. Insight in both the sound radiation of the installation and the sound reduction of the building is necessary to make a reliable prediction.
A waste water piping system is composed of any combination of straight pipes with tees, bends, joints and inlets. The noise is generated by the flow and fall of water in the piping system. In the present case the noise radiation is studied when the piping system is horizontal mounted in the plenum above a suspended ceiling. This is a common situation in civic and commercial buildings.
In Peutz' Laboratory for Acoustics a measurement set-up was build up with a waste water piping system using 3 different materials and a suspended ceiling underneath. The following issues are investigated:

1. The radiation of the waste water installation itself with different pipe materials and different flow rates;
2. Insulation measures to the bare pipes, such as a cladding system and an enclosure;
3. The influence of the suspended ceiling system.

The sound absorption, measured according to the reverberation room method, and the room-to-room sound insulation of a suspended ceiling are well known acoustic parameters. Most of the ceiling panel manufacturers can give this information about their products. The relation between the direct sound insulation of the combination of the ceiling tile and the suspension system to the room-to-room sound insulation of the complete suspended ceiling is described in [1]. In the present case the sound transmission in the opposite direction, from the plenum via the suspended ceiling into the receiving room, is studied.
Laboratory measurements have been performed with different ceiling panel materials mounted at different ceiling heights to determine the insertion loss. The full test results are presented in report [2]. In this paper the results of the investigation will be summarized and discussed.

2. Laboratory measurement set-up

The measurements are performed in a measurement set-up based on the standard EN 14366 [3]. The piping system is mounted inside the test room as shown in figure 1 and 2.
A steady flow of tap water is applied with an adjustable flow rate between 0,5 l/s and 4,0 l/s.

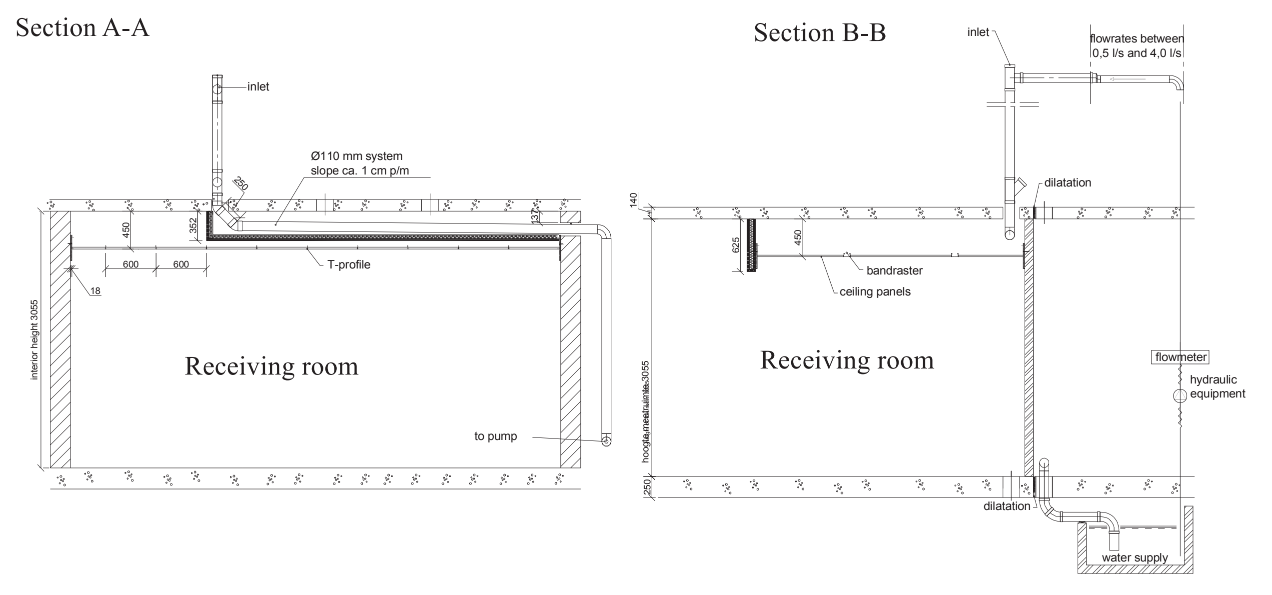

Figure 1. Vertical sections of the measurement set-up.

Figure 2. Photo of the measurement set-up.

The investigated pipe systems materials can be divided in the following three different types (see figure 3):

- lightweight plastic (PVC)
- low noise (heavyweight) plastic
- cast iron

The dimensions and weight of the pipe materials are also given in figure 3.

Notice that the intersection between the vertical and the horizontal pipe is mounted in a 45° bend / 250 mm straight pipe / 45° bend. This is the recommended mounting method according to the manufactures of the piping systems to become a smooth transition of the water flow from the vertical into the horizontal pipe.

The pipes are mounted using pipe clamps with noise insulating lining to the overlying concrete ceiling to minimize structure-borne sound transmission.

Variant 1

type:	lightweight plastic (PVC)
mass:	1,2 kg/m[1]
inner diameter:	103 mm
outer diameter:	110 mm

Variant 2

type:	heavyweight plastic (low noise)
mass:	3,5 kg/m[1]
inner diameter:	98 mm
outer diameter:	110 mm

Variant 3

type:	cast iron
weight:	8,5 kg/m[1]
inner diameter:	103 mm
outer diameter:	110 mm

Figure 3. Investigated materials of the piping systems.

3. Measuring Method

With the hydraulic system of the laboratory a steady flow of tap water is pumped up to the room above the test room. The water is applied to the inlet point, which is a part of the tested piping system. At the basement the water is gathered in a container. The measurements are performed at the constant flow rates of: 0,5 l/s; 1 l/s; 2 l/s; 3 l/s and 4 l/s. These flow rates are controlled and kept constant at the stated values during the measuring time. In the receiving room the sound, generated by the flow and fall of the water and radiated by the piping, is measured using a microphone mounted on a rotating beam in order to measure the sound level averaged over time and space. From the measured reverberation time and the sound pressure level (SPL), the airborne SPL normalized to an equivalent absorption area of 10 m², in decibels, is calculated according to equation 1.

$$L_{an} = L_t + 10\ lg\ \frac{A}{A_0} \qquad (1)$$

in which:

L_t = the average SPL in the receiving room [dB]
A = the equivalent sound absorption of the receiving room [m²]
A_0 = the reference sound absorption (= 10 m²)

The measurements have been carried out with a bandwidth of 1/3 octave. From these values the octave-band levels have been calculated as well as the "A-weighted airborne sound pressure level $L_{a,A}$ in decibels".

3.1. Measurement results

The results of the measurements presented as $L_{a,A}$ at the stated flow rates for the 3 piping system materials are given in figure 4.

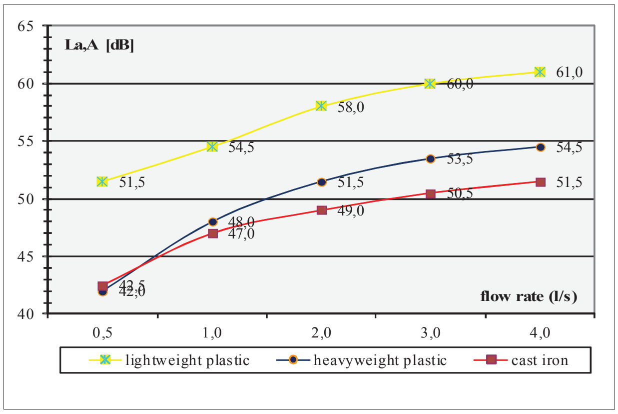

Figure 4. Measured sound pressure level at the tested flow rates for 3 piping system materials.

The radiated SPL at a flow rate of 3,0 l/s is for lightweight plastic piping system 60 dB(A). Due to the higher surface weight, a lower level of 53,5 dB(A) is measured with the heavyweight plastic system. The cast iron system appears to be the most silent piping system with a radiated sound pressure level of 50,5 dB(A) at 3,0 l/s.
The measurements with a steady flow of tap water are performed according to the standard [3].

In practice, with a real toilet flushing, the water flow rate and thus the SPL will vary in time.
To obtain more insight in the relation between practice and laboratory, additional measurements are performed with a real toilet flushing. The in time varying SPL in the receiving room is determined as maximum level $L_{a,A}$ using time weighting Slow (S) and time weighting Fast (F). These measurements are performed in 11 different measurement set-ups with different piping materials and different suspended ceilings. Aim of these measurements is to see which SPL with a constant flow rate fits at best with the SPL during a real toilet flushing. From the results, given in figure 5, the following conclusions can be drawn:

- the maximum SPL in Fast due to a toilet flushing is in average 3 dB(A) higher compared to the maximum SPL in Slow;
- The difference in SPL caused by a steady flow rate of 2,0 l/s and the maximum SPL in Slow is in average 1,3 dB(A);
- The measured SPL in Fast fits with a average difference of 0,3 dB(A) at best with a constant flow rate of 3,0 l/s. Therefore this flow rate is chosen as the nominal flow rate.

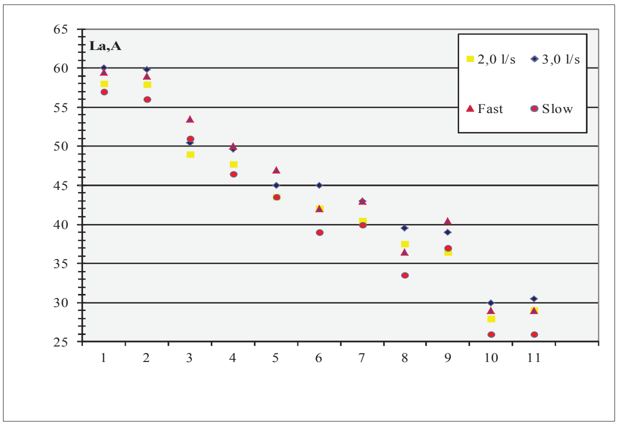

Figure 5. Measured sound pressure level at a constant flow rate of 2,0 l/s and 3,0 l/s compared to the maximum level due to a toilet flushing using time weighting Slow and Fast. This comparison is made in 11 different measurement set-ups.

4. Flow-rate

In figure 6 the comparison is given between the SPL of the bare pipe at the nominal flow rate (Q_0= 3,0 l/s) and the other measured constant flow rates. The measured SPL at 3,0 l/s is set to zero and the increase or decrease of the SPL at the other flow rates is calculated. When the starting point is a known (measured) SPL at Q_0 the SPL at an other flow rate (between 1,0 l/s and 4,0 l/s) can be estimated using equation 2.

$$C_Q = L_{b,an} + 10\ lg\ \frac{Q}{Q_0} \qquad (2)$$

in which:

$L_{b,an}$ = the SPL of the bare pipe at Q_0 [dB(A)]
Q = the constant flow rate [l/s]
Q_0 = the nominal flow rate (= 3,0 l/s)

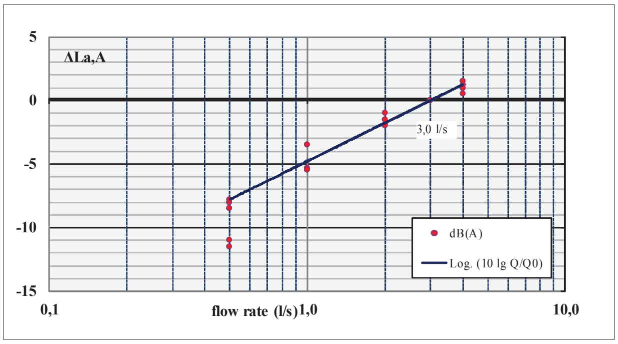

Figure 6. Measured sound pressure level at a constant flow rate of 3,0 l/s compared to the measured SPL at the other flow rates and compared to 10 lg/Q/Q_0.

5. Pipe insulation

An acoustic insulation or pipe lagging is applied as an outer cover with the aim of reducing the noise radiated from the pipe. Such a pipe lagging consists typically of a sound absorbing material (porous layer) on the piping and an impermeable outer cover (cladding). The acoustical performance of a pipe lagging is defined using the insertion loss, which is calculated according to equation 3.

$$D_W = L_{b,an} - L_{c,an} \qquad (3)$$

in which:

D_W = the insertion loss [dB]
L_{an} = the airborne sound pressure level normalized to an equivalent absorption area of 10 m^2 of the bare pipe (L_b) and the insulated pipe (L_c) [dB]

The investigated pipe lagging system consists of a glasswool porous layer, thickness 10 mm, and an outer mass layer of 4 kg/m^2. The measurement results are given in figure 7. Firstly the bare pipe (for the 3 investigated piping materials) is insulated over the full length of 4,5 m with the cladding system. Secondly, the cladding is removed in steps of 0,5 m towards the first 45° bend. At each step the insertion loss is measured.
The influence of the cladding system depends on the material of the bare pipe.

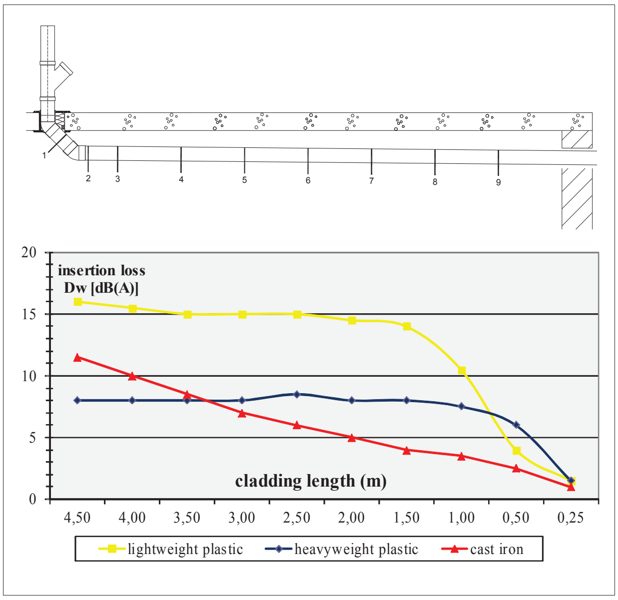

Figure 7. Measured insertion loss of the cladding system at a steady flow rate of 3,0 l/s mounted on the 3 different piping system materials.

The maximum insertion loss of about 15 dB(A) is measured when the cladding system is applied to the bare lightweight plastic pipe. When the same cladding system is applied to the heavyweight plastic pipe an insertion loss of about 8 dB(A) is measured. For both lightweight and heavyweight pipes it appears that it is most important to insulate the bends including a straight pipe length of about 1,5 m after the bends. After 1,5 m behind the second bend no important further improvement of the insertion loss is found.
However, the length of the cladding system is important when the bare pipe is made of cast iron. This is caused by the small reduction of the vibration level in the iron pipe with increasing distance to the bend. When only the bends of the bare iron pipe are insulated the insertion loss is 4 dB(A), increasing to 12 dB(A) when the complete length of the pipe is provided with the cladding system, see figure 7.

6. Acoustic enclosure

In figure 8 a drawing is given of the investigated acoustical enclosure consisting of a double layer of gypsum board mounted at a metal frame of C- and U-profiles. In the cavity between gypsum boards and the bare pipes a glasswool layer is applied. Each rigid contact between the metal frame and the piping system is carefully avoided. The measurement results are given in figure 8.

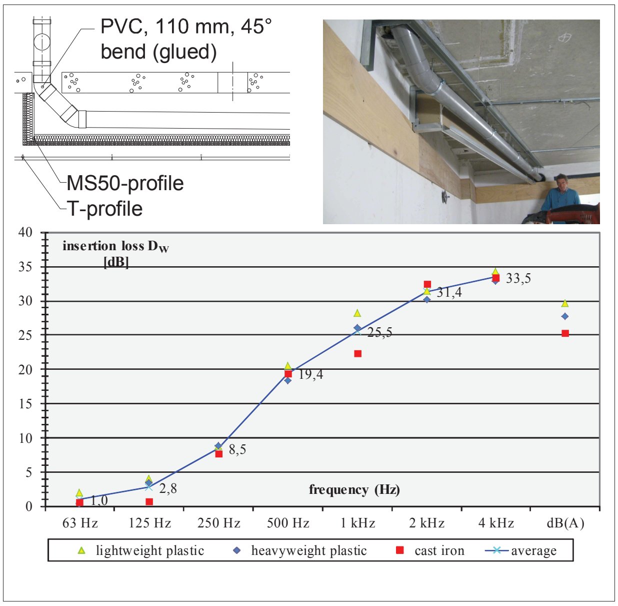

Figure 8. Measured insertion loss of an enclosure measured at a steady flow rate of 3,0 l/s mounted around the 3 different piping system materials.

There is only a small dependency found in the insertion loss of the enclosure from the piping system materials. On average the measured insertion loss is 25 to 30 dB(A).

7. Suspended ceilings

Next step is to gain insight in the sound reduction by the suspended ceiling. The reduction of the radiated noise from the piping system due to the suspended ceiling is also defined using the insertion loss (D_W), calculated according to equation 3. In this case the "source" level relates to the radiated airborne SPL, normalized to an equivalent absorption area of 10 m^2, from the bare pipe (L_b) without suspended ceiling. The "receive" level is the measured sound pressure level (also normalized to A_0) measured in the receiving room, including the influence of the suspended ceiling (L_c). For each of the tested suspended ceilings, the insertion loss is measured with the 3 different piping system materials as described above at the different flow rates. Additionally a loudspeaker was used in stead of the piping systems, mounted flush in the overlying concrete ceiling.
This loudspeaker reproduces broadband noise with sufficient sound level to achieve a good signal to noise ratio. In this case the "source" level relates to the radiated airborne SPL, normalized to A_0, from the loudspeaker without suspended ceiling. The "receive" level is the measured SPL (also normalized to A_0) in the receiving room, including the influence of the suspended ceiling under test.

Figure 9. Investigated ceiling panels.

7.1. Investigated suspended ceilings

As representative suspended ceiling is chosen for a lay-in system with T-profiles. The dimensions of the grid are 1200 x 600 mm. The ceiling is provided with 4 light luminaires including ventilation slots. The selection of the ceiling panels is based on the room-to-room sound insulation (defined in [4]) to be expected, divided in the following 3 acoustical quality levels, see also figure 9.

A) lightweight sound sound absorbing ceiling panels. Room-to-room sound insulation: D_{nfw} = 20 -25 dB
B) wet-felt ceiling panels. D_{nfw} = 30 -35 dB
C) double layered ceiling panels. Sound reducing hoods over the luminaires: D_{nfw} = 40 -45 dB

7.2. Insertion loss of the suspended ceilings

The measurements are carried out with the suspended ceilings mounted at a construction height of 460 mm. For some variants the influence of an other depth of the cavity is investigated. No significant change in measured insertion loss is found when the construction height is increased to 585 mm or decreased to 335 mm. The results of the measurements performed at the various ceiling panels are summarized in figure 10.

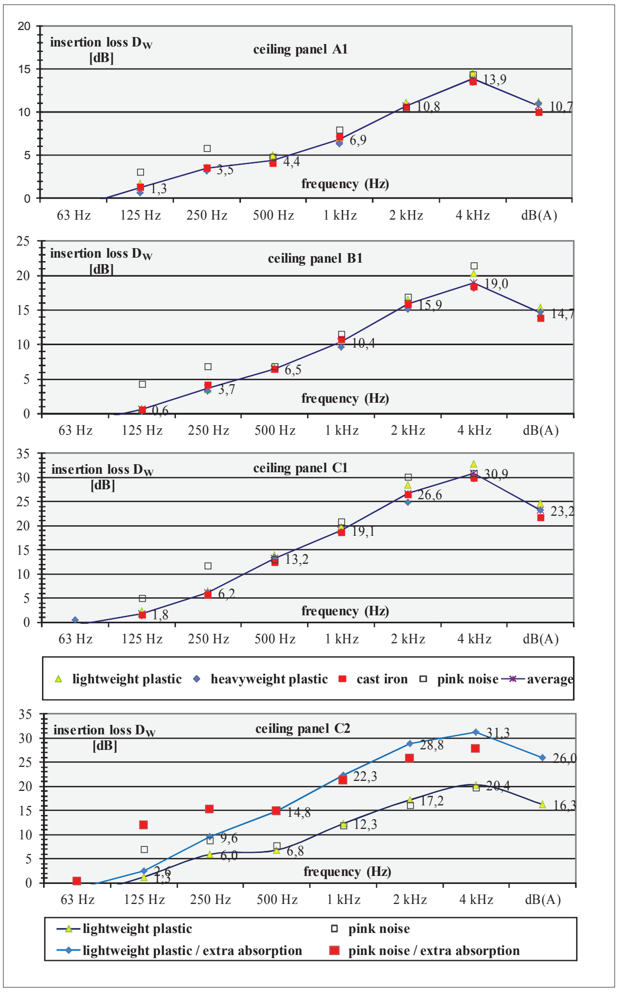

Figure 10. Measured insertion loss of suspended ceiling with panels type A1, B1, C1 and C2 measured with pink noise and a steady water flow in 3 different piping system materials. The construction height of the ceilings is 460 mm.

From the results the following conclusions can be drawn:

- the measured insertion loss of the ceilings appears to be rather independent from the piping material;
- when using a loudspeaker and broad band noise as sound source, the measured insertion loss is in the low frequencies is somewhat higher compared to the measurements with the pipes. In the middle (500 Hz) and higher frequencies the measured insertion loss with the noise source is comparable to the measured insertion loss with the pipes as source;
- The measured insertion loss of a suspended ceiling provided with lightweight mineral wool panels (type A) is 10 dB(A) and with wet-felt panels (type B) is about 15 dB(A);
- The maximum insertion loss is measured when ceiling panels type C1 are used (about 25 dB(A)). These panels are composed out of a sound absorbing layer on top side and also a sound absorbing layer at the rear (cavity) side. There is an interlayer of aluminium-foil in the centre of the panel;
- The measured insertion loss of ceiling panel C2 is only 16 dB(A) in spite of the gypsum board at the rear side of the panel.
- This is caused by the non absorbing cavity above the suspended ceiling. When adding an extra sound absorbing layer on top of the gypsum board, the insertion loss increases to a measured value of 26 dB(A).

8. Prediction method

Starting point in the prediction method is the noise of the bare piping system material at the nominal flow rate (Q_0) for the frequency bands of interest ($L_{b,an,i}$). This should be measured according to the standard laboratory method [3]. A correction for other flow rates (C_Q) can be made using equation 2. In the next step the frequency dependent insertion loss of the pipe lagging ($D_{W,1,i}$) and/or the enclosure ($D_{W,2,i}$) and/or the suspended ceiling ($D_{W,3,i}$) has to be subtracted. The result is the airborne sound level transmitted to the receiving room via the suspended ceiling ($L_{an,i}$), in formula:

$$L_{an,i} = L_{b,an,i} + C_Q - D_{W1,i} - D_{W2,i} - D_{W3,i} \qquad (4)$$

For all 398 measured laboratory variants the $L_{a,A}$ (dB(A)) values are calculated for the different constant flow rates using equation 4, based on the insertion loss of the different elements as presented in this paper. These calculation results are compared with the direct measured $L_{a,A}$ values. In 90% of the compared variants the difference between the calculated en the measured $L_{a,A}$ value is 4 dB(A) as maximum. The largest differences appear at a low flow rate of 0,5 l/s. When the calculated flow rate is chosen in a range between 1 l/s and 4 l/s, the maximum difference between the prediction and the measurement result is 3 dB(A).

References

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