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Experimental Study on Noise Reduction of Drainage Pipes using Acoustic Materials: Comparison between Simplified Laboratory and In-situ Measurements

So-young Kim[1], GUKGON SONG[1]

[1]*Korea Conformity Laboratories, 73, Yangcheong 3-gil, Ochang-eup, Cheongwon-gu, 28115 Cheongju-Si, Republic of Korea*

Abstract

In many regions with dry-bathroom cultures, such as Europe and North America, drainage pipes are typically installed within pre-wall or above-slab systems. In contrast, Korean residential buildings predominantly adopt below-slab drainage systems, reflecting the combination of wet-bathroom layouts and Ondol floor heating. Because the pipes are exposed within the ceiling cavity of the dwelling below, drainage noise is readily transmitted to adjacent occupants and has become a common source of residential complaints. Current in-situ measurements, such as those based on ISO 16032 and KS F 2871, are often influenced by room variables. Meanwhile, full-scale laboratory methods like EN 14366-1 require complex setups that are less practical for rapid material development. To address this, we propose a simplified laboratory screening method using sound intensity techniques according to ISO 9614-1 to evaluate the acoustic reduction performance of pipe claddings and low-noise pipes in terms of sound pressure levels. A radial offset of 100 mm was found to provide the most stable measurements by minimizing phase-related errors while maintaining adequate sensitivity to differences among the test specimens. When comparing relative insertion losses, the simplified method showed noise reduction trends consistent with in-situ data, even when stationary pink noise was used instead of actual water flow. The proposed screening method also demonstrated that the greatest overall noise reduction of 66.3 dB(A) was achieved when a viscoelastic damping layer was combined with a porous sound-absorbing material. The proposed screening method also demonstrated that the greatest overall noise reduction of 66.3 dB(A) was achieved when a viscoelastic damping layer was combined with a porous sound-absorbing material. Additionally, thin E-Glass with thicknesses of 5 to 10 mm performed well as a standalone material, matching the broadband attenuation of thicker conventional foams and offering a space-efficient option for confined ceiling plenums.

Keywords: *bathroom drainage noise, low-noise drainage pipe, laboratory simplified screening method, sound intensity method*

1. Introduction

Floor-to-floor noise transmission remains a major challenge in South Korea, where multi-dwelling residential buildings are the predominant housing type. A 2022 survey indicated that while impact noise is the primary concern in living rooms, drainage noise is the most frequent disturbance in master bedrooms, accounting for 77 percent of bathroom-related complaints. As illustrated in Fig. 1, the primary reason lies in differences in residential construction practices between South Korea and other regions. Dry bathrooms, common in Europe and the Americas, allow drainage pipes to be concealed within vertical shafts or pre-wall systems. In contrast, South Korea relies on wet bathrooms with floor drains and Ondol radiant floor heating. To accommodate drainage slopes, large pipes, and Ondol layers without excessively raising the floor level or complicating leak maintenance, the below-slab drainage layout is widely used.

Corresponding author: iggy@kcl.re.kr

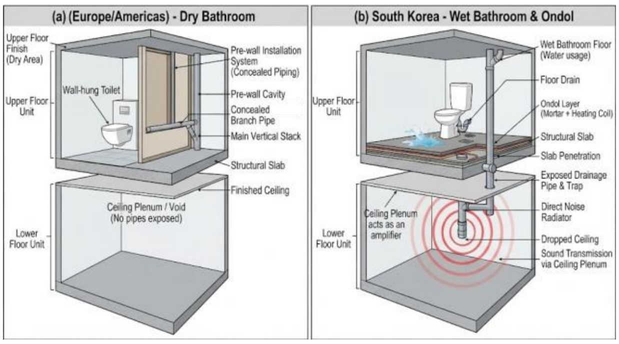

Figure 1. Conceptual comparison of above-slab drainage systems in dry bathrooms and below-slab drainage systems in wet-bathroom and ondol flooring structures.

This configuration requires pipes to penetrate the structural slab and be suspended within the ceiling plenum of the lower unit, turning them into direct noise radiators. Domestic regulations require low-noise pipes that provide at least a 5 dB acoustic insertion loss compared to standard PVC pipes. The evaluation of this plumbing noise currently relies on in-situ field measurement standards like KS F 2871, which align with the principles of ISO 16032. These methods capture real-world performance using actual water flow but evaluate the entire architectural system. It is therefore difficult to isolate the pure acoustic insertion loss of specific pipe materials or claddings from variables such as receiver room reverberation, ceiling insulation, and background noise. European standards like EN 14366-1 provide robust laboratory methods but require full-scale multi-story test facilities, which are often inefficient for rapid R&D prototyping of new acoustic materials. Recognizing the need for a simpler approach, this study proposes a laboratory screening methodology based on sound intensity according to ISO 9614-1 to evaluate pipe claddings and low-noise pipes in terms of sound pressure levels. We validate its relative reduction trends against in-situ field data and demonstrate its practical utility by testing several acoustic materials.

2. In-situ Measurement Method

A baseline was established through in-situ measurements conducted in a real-scale test building at the Korea Conformity Laboratories(KCL) Jincheon Testing Center, following the KS F 2871 standard. The setup included an upper-floor bathroom drainage pipe suspended in the ceiling plenum of the lower-floor receiver room, representative of typical Korean below-slab layouts. The tests examined four configurations to assess both the pipe material and external structural claddings. The first configuration consisted of a standard PVC pipe. The second configuration used a low-noise pipe cladded with a combination of a resin-based sound-insulating rubber TP sheet and a 3 mm polypropylene microfiber Web-Schuler sound-absorbing material. The third configuration employed a low-noise pipe cladded with a 2 mm modified butyl rubber damping sheet featuring a top aluminum sheet. The fourth configuration utilized a low-noise pipe combining both of these claddings. Noise was generated using a 6-liter flush from a water closet on the upper floor. Sound pressure levels were recorded at five receiver points, including the geometric center of the lower-floor bathroom. Microphones were placed at a vertical distance of 1 meter or more below the drainage pipe, corresponding to 1.2 meters above the floor. To capture the transient nature of drainage noise, we evaluated the A-weighted sound pressure levels with Fast time-weighting, specifically the maximum sound level $L_{A,Fmax}$ and the equivalent sound level L_{AFeq}. The field measurements indicated that standard PVC pipes perform poorly in the 500 to 2000 Hz frequency range, the dominant spectrum for drainage noise. As summarized in Table 1, combining damping and absorbing claddings on the low-noise pipe reduced the equivalent sound level by 10.5 dB(A) and the maximum sound level by 8.6 dB(A) compared to the standard pipe.

Table 1. Results of In-situ Measurement.

	Pipe Type (External Cladding Details)	L_{AFeq}	$\triangle L_{AFeq}$ (Reduction relative to Baseline)	L_{AFmax}	$\triangle L_{AFmax}$ (Reduction relative to Baseline)
Config.1 (Baseline)	Standard PVC pipe	54.2 dB(A)	-	65.5 dB(A)	-
Config.2	Low-noise pipe + Rubber TP sheet + 3 mm PP Web-Schuler	48.5 dB(A)	5.7 dB(A)	61.3 dB(A)	4.2 dB(A)
Config.3	Low-noise pipe + 2 mm Butyl rubber damping sheet (with AL sheet)	47.8 dB(A)	6.4 dB(A)	60.6 dB(A)	4.9 dB(A)
Config.4	Low-noise pipe + [2 mm Butyl rubber damping sheet (with AL sheet)] + (Rubber TP sheet + 3 mm PP Web-Schuler)	43.7 dB(A)	10.5 dB(A)	56.9 dB(A)	8.6 dB(A)

3. Simplified Laboratory Measurement Setup

A simplified laboratory setup was developed to provide a reproducible alternative to full-scale testing. Since in-situ ceiling plenums are generally too confined for three-dimensional intensity scanning, this setup isolates a 600 mm straight horizontal pipe section in a standard laboratory room. Sound intensity equipment according to ISO 9614-1 was used to filter out background noise and room reverberations. To enable direct comparison with the field data, the evaluation index was derived as the A-weighted sound pressure level in dB(A) instead of the sound power level L_W. Field boundary conditions were simulated by point-supporting the pipe at its ends and using an internal pink noise speaker. A stationary source like pink noise was selected for comparative screening because the non-stationary nature of actual water flow makes it challenging to isolate pure transmission loss differences between materials.

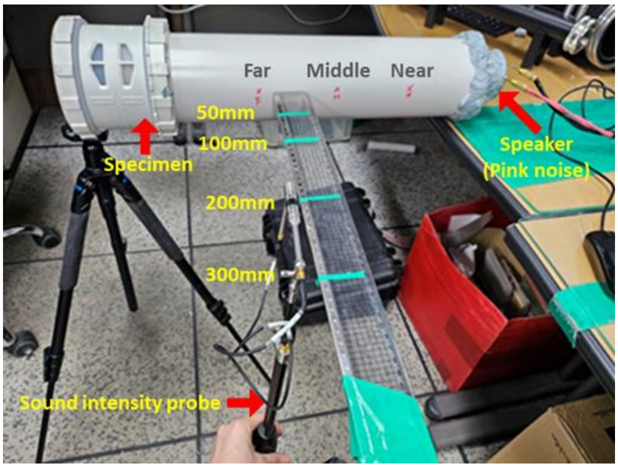

Figure 2. Experimental setup for sound intensity measurement.

As illustrated in Fig. 2, we evaluated three longitudinal sections and four radial offset distances ranging from 50 to 300 mm to find an appropriate measurement location. The center point at a 100 mm radial offset was selected. This position yielded the lowest pressure-residual intensity index of 2.0 to 2.1 dB, indicating minimal phase errors, while providing sufficient energy capture to distinguish insertion loss differences between the materials.

4. Comparison and Methodological Verification

The simplified method was verified by comparing the relative noise reduction of the four configurations with the in-situ data. Although a theoretical concern might arise from comparing the non-stationary water flow encountered in the field with the stationary pink noise utilized in the laboratory, evaluating relative insertion loss preserves the validity of the comparison. The physical mechanisms of the acoustic treatments, such as viscoelastic damping for low-frequency vibrations and porous absorption for high-frequency airborne sound, operate consistently regardless of the excitation source. The relative reduction trends of the A-weighted sound pressure levels were similar in both environments. Although the absolute reduction magnitudes varied slightly due to the differences in measurement techniques, as the laboratory setup measured near-field directional intensity vectors whereas the field measurements captured far-field spatial average pressures, the one-third octave band spectra analysis showed clear alignment in the reduction trends, notably in the 50 to 80 Hz and 200 to 1600 Hz bands (see Fig. 3). These results support the use of the simplified method as a practical screening tool.

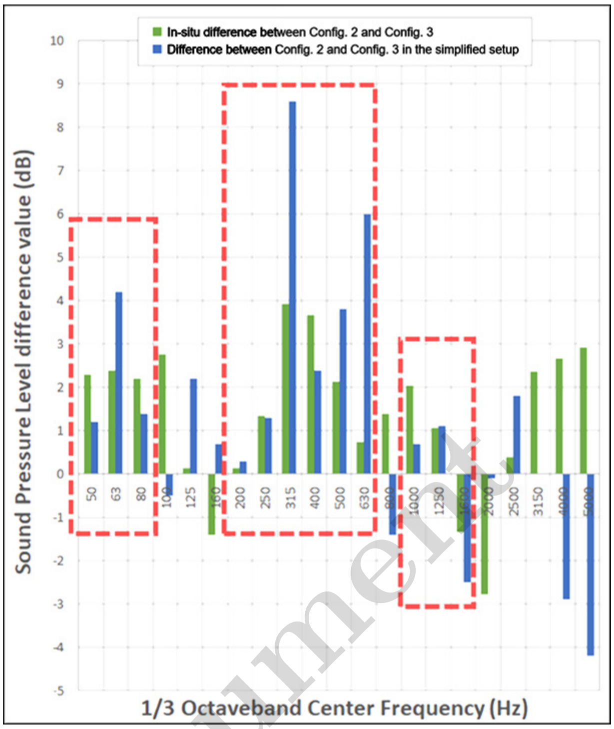

Figure 3. Comparison of noise reduction trends between in-situ measurements and the simplified laboratory setup across one-third octave frequency bands.

5. Application and Optimization of Structural Claddings

To apply the screening method, seven additional structural claddings were evaluated on the low-noise pipes. The test materials included 25 mm melamine foam, 25 mm polyurethane foam, 4 mm and 25 mm polyethylene terephthalate, 25 mm glass wool, and composite E-Glass consisting of fiberglass with an aluminum sheet at thicknesses of 5 mm and 10 mm. The measurements showed that combining the resin-based damping layer with the porous absorber resulted in the highest overall noise reduction of 66.3 dB(A). When evaluating standalone materials, thin E-Glass claddings with thicknesses of 5 mm and 10 mm performed well across a broad frequency range, ranking in the top three for 11 specific one-third octave bands alongside the combined cladding. Because the overall A-weighted value is dominated by the 500 to 2000 Hz range, which is the primary target for drainage noise control, the fact that 10 mm E-Glass achieving 67.4 dB(A) reached reduction efficiencies comparable to 25 mm polyethylene terephthalate foam achieving 67.3 dB(A) suggests that its high-density structure effectively dissipates this frequency band. These results indicate that such materials can offer space-efficient acoustic solutions suitable for confined below-slab ceiling plenums.

Table 2. Results of overall A-weighted noise reduction for the seven additional structural claddings.

Test configuration	L_{AFeq}[dB(A))
Config.2	68.3
Config.3	67.1
Config.4	66.3
Melamine foam 25 mm 9.3 kg/ ㎥	68.1
PU foam 25 mm 32 kg/ ㎥	67.7
PET 4 mm 238 kg/ ㎥	69.1
PET 25 mm 32 kg/ ㎥	67.3
GW 25 mm 24 kg/ ㎥	67.7
E-glass 5 mm 161 kg/ ㎥	67.7
E-glass 10 mm 130 kg/ ㎥	67.4

6. Conclusions

1. This study holds significant value in developing a simplified laboratory methodology based on ISO 9614-1 to evaluate the reduction of sound pressure levels in drainage pipes.
2. The below-slab piping layout, common in South Korea due to Ondol and wet-bathroom constraints, necessitates a practical R&D tool to evaluate pipe claddings independent of room variables.
Measurements taken at a 100 mm offset provided stable phase reliability and resolution. By assessing relative insertion loss, the method reproduced in-situ reduction trends despite the use of a pink noise source.
3. The screening method confirmed that combining structural damping with porous absorbers yields the highest overall attenuation. Furthermore, thin E-Glass as a standalone material effectively targeted the 500 to 2000 Hz band, offering broadband attenuation comparable to thicker conventional materials.

While useful as a screening tool, this methodology has certain limitations. The point-supported boundary condition was intended to isolate airborne sound radiation for material evaluation, thereby excluding structure-borne sound transmission through the concrete slab. Additionally, minor discrepancies in specific frequency bands between the in-situ and laboratory reduction trends can be attributed to differences in the sound fields, because the laboratory setup measures near-field intensity vectors from stationary pink noise, removing the effects of receiver room reverberation and transient fluid dynamics found in actual water flushes. Lastly, although pink noise is adequate for evaluating straight pipes, it does not fully capture the turbulent fluid impacts at 90-degree elbows. To address this limitation, future research will incorporate Simcenter-based Fluid-Structure Interaction and acoustic simulations to model turbulent noise generation and refine acoustic treatments specifically for elbow sections.

7. Acknowledgments

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