DOI: 10.61782/fa.2025.0648

FORUM ACUSTICUM EURONOISE 2025

ON THE INFLUENCE OF SAMPLING SIZE IN THE ASSESSMENT OF UNCERTAINTY AND REPEATABILITY OF FIELD MEASUREMENTS OF IMPACT SOUND INSULATION IN VARIOUS FLOOR SCENARIOS

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ABSTRACT

One of the most widely used standards for field measurements of impact sound insulation is ISO 16283-2: 2020. The assessment of the standard deviation of repeatability must comply with ISO 12999-1, as repeatability is a crucial factor in ensuring reliable test performance. However, in some cases, the frequency band results do not comply with the maximum standard deviation limits for repeatability. These deviations raise concerns about the adequacy of the current repeatability limits and the testing procedures outlined in the ISO standard. This study compares the maximum standard deviation of repeatability between impact sound insulation tests conducted with four and six sound source positions, as well as the limits specified in ISO 12999-1, regarding the one-third octave bands of interest in various typical floor scenarios in Spain. Furthermore, these tests study the effect of increasing the number of tapping machine positions on global uncertainty.

Keywords: *impact sound insulation, field testing, uncertainty, repeatability).*

1. INTRODUCTION

ISO 16283-2 is a widely used standard for field measurement of impact sound insulation [1]. This standard aims at assessing impact sound insulation by measuring sound pressure level in a receiving room employing an impact source [1]. Generally, building acoustics standards require uncertainty by ISO 12999-1 [2].

The measurement uncertainty limits can be determined through reproducibility rates [2]. Moreover, ISO 12999-1 recommends repeatability for verifying the quality of laboratory's testing procedures, on their own. In repeatability conditions, results must remain under the maximum values of the typical deviation of repeatability (σ_r) versus frequency in one third-octaves resolution, from 50 Hz to 5 kHz; higher tolerances in the low-frequency range up to 400 Hz, and in higher frequencies, it remains constant. This limit is the same for airborne sound insulation, façade sound insulation, and impact sound insulation. This differs from previous standards such as EN 20140-2 [3], and even *Case C* of ISO 12999-1: 2020, for inter-laboratory repeatability assessment. An extensive survey in [4, 5] reports significant deviations in impact sound insulation testing for different tapping machine positions, correlated with some types of floor, structure and finish. However, no systematic differences were found in global ratings. The study in [6] on gypsum concrete floors and concrete floors shows that repeatability tests exceed σr limits in ISO 12999-1 at some bands. The structure of wood floors may lead to increases on impact sound pressure level in low frequencies, reaching out from 4 dB to 7 dB, depending on tapping machine location, according to [5]. A previous work by the authors [7], presented some examples for a range of typical Spanish floors and four source positions, in which σ_r exceeded the recommended repeatability limits.

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This study provides additional data to this issue by performing tests with a reasonable increase on source positions and related insights about uncertainty.
Current literature suggests that impact source location and building technology may influence testing and requires further research to decrease measurement uncertainty. This work aims at 1) assessing σ_r of four typical Spanish floor scenarios in horizontal and vertical set-up, including four and six impact source locations within the same test; 2) comparing σ_r to the limits of ISO 12999-1 and the impact on measurement uncertainty.
The remainder of this paper is organized as follows. Section 2 describes the measurement procedure and scenarios. After that, Section 3 includes the results and discussion of the testing. Section 4 provides conclusions.

2. MATERIALS AND METHODS

2.1 Measurement procedure and equipment description

Impact sound insulation measurements were performed following ISO 16283-2 [1] in 4 different scenarios (see Section 2.2). In each of them, the measurements were repeated 5 times, under conditions of repeatability, that is, with the same measurement procedure, the same measuring system and the same operators, over a short time; but modifying the source and microphone positions for each repeated measurement and selecting them again more or less randomly.
The magnitude measured was the 'standardised impact sound pressure level' (L'_{nT}), defined in Eqn. (1), in the frequency range from 50 Hz to 5000 Hz in the one-third octave bands. The default procedure ($V > 25$ m^3) and fixed microphone positions were used. A tapping machine was used as an impact source.

$$L'_{nT} = L_i - 10 \cdot \lg \frac{T}{T_0} \quad \text{[dB]} \qquad (1)$$

where L_i is the energy-average impact sound pressure level in the receiving room corrected by background noise; T is the reverberation time in the receiving room [8]; T_0 is the reference reverberation time, in s (for dwellings, $T_0 = 0{,}5$ s).
Six and four different positions of the tapping machine were used, randomly distributed on the floor under test. Likewise, four or six different microphone positions were used, measuring impact noise levels in two of these positions for each source position. The averaging time for the level measurements was 15 s. The location of the tapping machine and microphone positions met the specifications of the reference standard regarding the distances between them, the source positions and room boundaries.

For each tapping machine position, the standardised impact sound pressure level is calculated, and an averaged final value is obtained, according to equation Eqn. (2):

$$L'_{nT} = 10 \cdot \lg \frac{1}{m} \sum_{j=1}^{m} 10^{L'_{nT,j}/10} \quad \text{[dB]} \qquad (2)$$

where m is the number of tapping machine positions; $L'_{nT,j}$ is the standardised impact sound pressure level for tapping machine position j.
For each scenario and each test, two L'_{nT} index results were obtained. The first was derived from the combination of all six tapping machine positions with their associated microphone positions, while the second was obtained by combining only four tapping machine positions with their corresponding microphone positions.
The airborne sound contribution from the tapping machine was also evaluated to determine whether it should be considered negligible or if it might influence the results in some way.
The suitable Class 1 equipment, according to reference standards, for measurements and the tools used for data post-processing are defined in [7].

2.2 Scenarios description

The four measurement scenarios correspond to existing dwellings with a typical separating floor configuration in Spain. This configuration consists of a concrete beam and block floor, likely with some layers of mortar and sand (total thickness ≈ 300 mm). The only difference between them lies in the floor finish: non-floating wood flooring (ID1) and non-floating ceramic tile flooring (ID2, ID3, ID4).
Regarding the relative positioning of the test rooms, ID1 and ID2 are horizontally adjacent, while ID3 and ID4 are vertically adjacent.

3. RESULTS AND DISCUSSION

The following sections present the measurement results for the four scenarios. For each measurement set, compliance with the repeatability requirements of ISO 12999-1 was evaluated.
First, the L'_{nT} spectra for the four measurement scenarios are presented, considering both six and four tapping machine positions during testing (Fig. 1).
Next, the received noise levels in the receiving room are analyzed for each source position in the emitting room and its two corresponding measurement points in the receiving room (Fig. 2).
Finally, the standard deviation of repeatability (σ_r) and the expanded uncertainty (U) are analyzed for the different

scenarios, assessing the differences caused by using six or four tapping machine positions (Fig. 3 and 4).
The airborne sound contribution from the tapping machine and its influence was found to be negligible in most cases. This contribution is usually much more controlled when the rooms are vertically adjacent. In this case, some transmission was found from 630 Hz onwards in scenario ID1, where the rooms are horizontally adjacent.

3.1 Spectra of the 5 repeated measurements of L'$_{nT}$

Fig. 1 shows the L'_{nT} spectra corresponding to the average of the five repetitions in each set-up, comparing results obtained using four and six tapping machine positions.

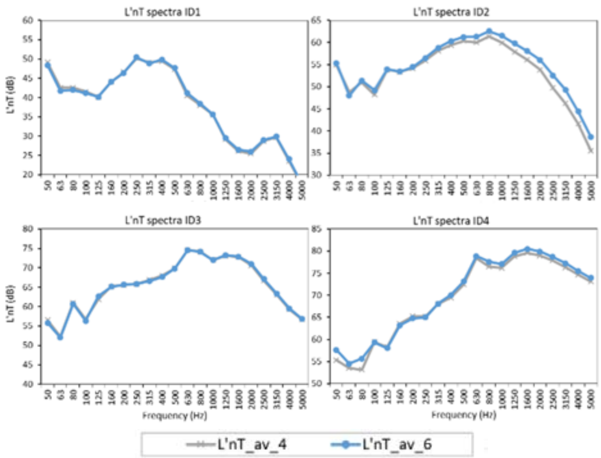


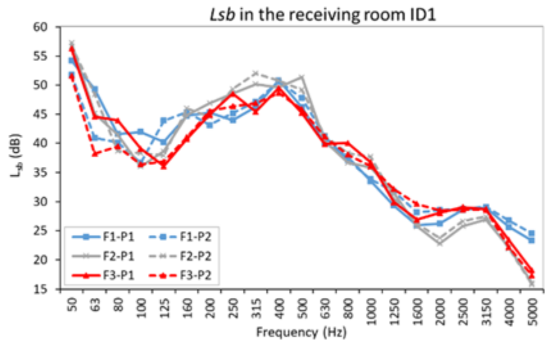
Figure 1. Spectra of the 5 repeated measurements of L'_{nT}.

The L'_{nT} spectra for each scenario remain practically overlapping when using four and six tapping machine positions. This suggests that increasing the sampling size by adding more tapping machine positions has minimal influence on the final result. However, compared to performing the test five times under repeatability conditions, some variations may still be observed, as discussed in section 3.3.

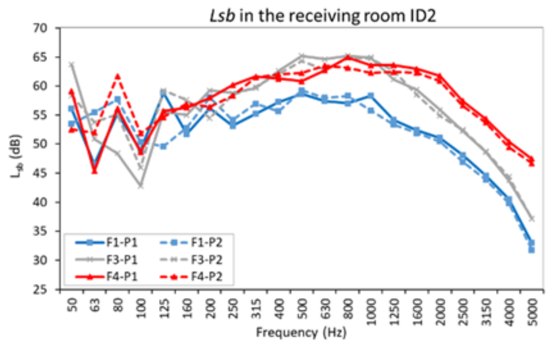
3.2 Analysis of signal and background noise levels (L_{sb}) in the receiving room

The following graphs represent the spectra of the combined signal and background noise level (L_{sb}) measured in the receiving room for the four test scenarios The data correspond to one of the repetitions and represent the combinations of source positions (F_i) and their corresponding microphone positions (P1 and P2).

Although four and six tapping machine positions were used for the tests, the graphs only show measurement combinations for three source positions to simplify the representation.



(a)



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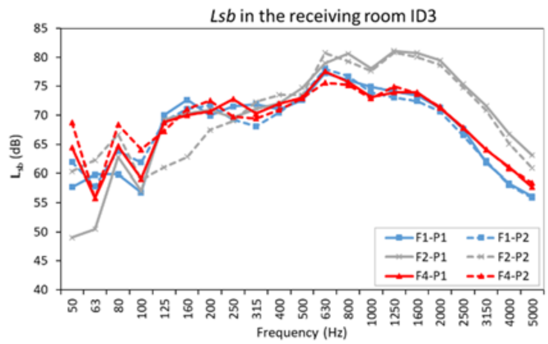
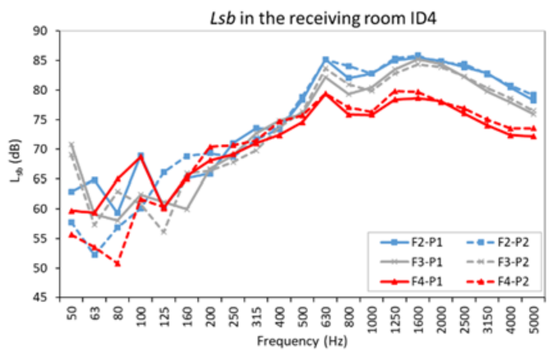


(c)



(d)

Figure 2. Combined signal and background noise level (L_{sb}) in the receiving room. Combinations of source position and measurement points for one of the repetitions. (a) ID1, (b) ID2, (c) ID3, (d) ID4.

The data in Fig. 2 can be roughly grouped into pairs, mostly from mid frequencies onwards. Each pair of microphone positions with a similar response in the receiving room corresponds to the same source position. This suggests that the tapping machine positions influence the results of this test and introduce variability in repeatability. The same findings were reported in [7].

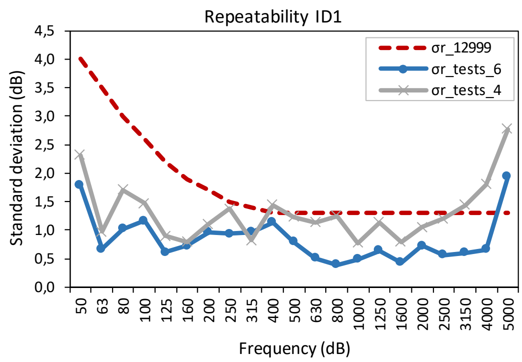
In scenario ID1 (Fig. 2a), the microphone positions can also be roughly paired, but the grouping is less clear compared to the other scenarios. In this case, the floor was more homogeneous, which theoretically allows for a more uniform response of the transmitted impact noise. The separating floor is finished with a non-floating wooden flooring, which might contribute to providing a homogeneous surface for hammer impacts. As a result, the variability between measurement points is lower than in other cases, though small deviations can still be observed at higher frequencies.

The dependence of impact sound levels on the source position is very clear in scenarios ID2, ID3, and ID4 (Fig. 2b, 2c, and 2d), where the curves for P1 and P2 are almost completely overlapped from 1 kHz onwards. This indicates a strong consistency between the measurement points when the same source position is used. However, these scenarios exhibit greater variability, particularly at lower frequencies. In these cases, the separating floor is finished with a non-floating ceramic tile flooring, which might increase the variability of the transmitted noise levels. The differences observed between measurement points could be influenced by the location of the hammer strikes and possible variations in the attachment quality of the tiles. Similar results have been reported in previous studies for both wood and ceramic flooring [5-7].

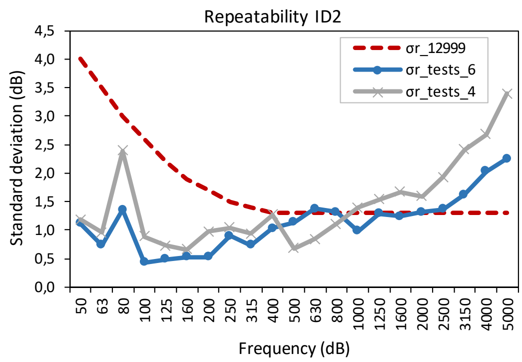
These results reinforce the idea that the positioning of the tapping machine can affect measurement repeatability.

3.3 Analysis of repeatability results (Standard deviation)

Fig. 3 presents the standard deviation of repeatability (σ_r) for each test scenario, comparing the results obtained using four and six tapping machine positions with the limits given in Table 1 of ISO 12999-1 [2]. When values from measurements are higher than those indicated in the reference standard, they are non-compliant with repeatability requirements.



(a)



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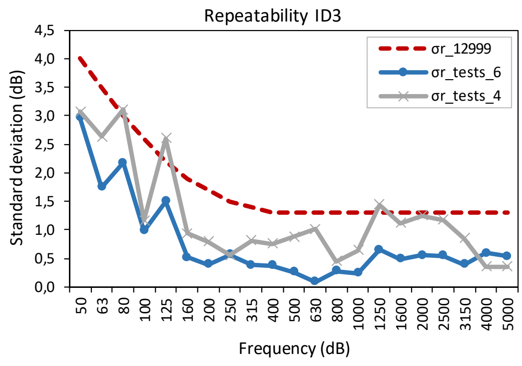

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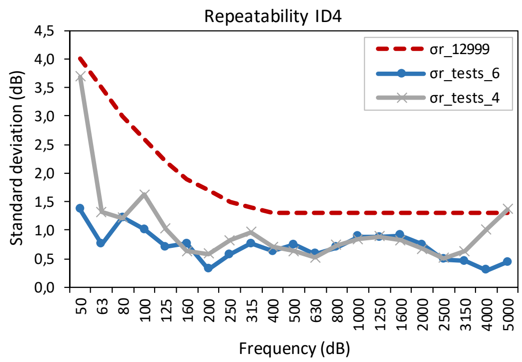


(d)

Figure 3. Standard deviation: ISO 12999-1 vs measurements. (a) ID1, (b) ID2, (c) ID3, (d) ID4.

Overall, a significant improvement in repeatability values is observed when increasing from four to six tapping machine positions. Although this improvement is noticeable across all scenarios, each scenario presents particular nuances depending on the frequency range considered.

Scenarios ID1 (Fig. 3a) and ID2 (Fig. 3b) generally comply with the repeatability requirements up to the highest frequencies. However, at high frequencies, improvements in repeatability can still be observed when increasing from four to six positions. The non-compliance shifts from 2.5 kHz to 4 kHz in ID1 and from 800 Hz to 2 kHz in ID2, indicating a beneficial effect of using more tapping machine positions. In ID2, a peak in the value of σ_r exceeding the limit curve repeatability appears at 80 Hz, which, although still within the standard limits, improves significantly when increasing positions.

Scenario ID3 (Fig. 3c) exhibits the worst repeatability issues at low frequencies (80 Hz, 125 Hz) when using four positions, exceeding the ISO limit. There is also a minor non-compliance with σ_r at 1.25 kHz. Increasing positions significantly reduces these deviations, bringing them below the ISO threshold. At mid and high frequencies (from 500 Hz onwards), repeatability remains stable when using six source positions, with no exceedances of the ISO 12999-1 limit.

Scenario ID4 (Fig. 3d) shows relatively stable repeatability values across the entire frequency range. At 50 Hz, repeatability is quite high with four source positions, nearly exceeding the limit, but this value improves significantly with six positions. A notable improvement is also observed at 5 kHz.

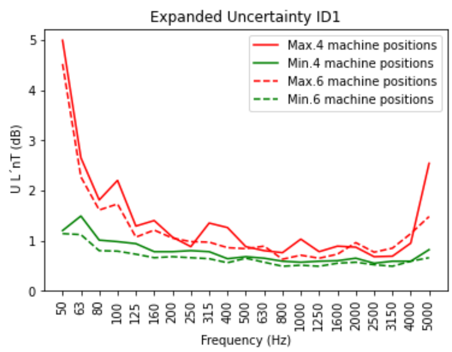
As a summary, it has been observed that compliance with ISO 12999-1 and repeatability values generally improves when increasing from four to six source positions, although issues in ID1 and ID2 remain problematic, exceeding the ISO 12999-1 limit in both cases even with six positions.

The most notable improvement occurs at 50 Hz in scenario ID4, where the repeatability value is significantly reduced when using six positions. Peak repeatability values at 80 Hz and 125 Hz in ID3 and at 80 Hz in ID2 are also significantly reduced.

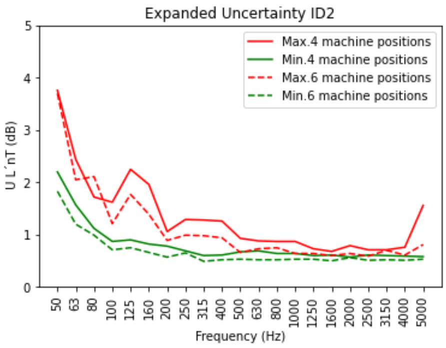
These results confirm that increasing the number of tapping machine positions improves repeatability in most situations. However, remaining high-frequency deviations require further research to determine whether other factors may be influencing the variability.

3.4 Uncertainty

Generally, in building acoustics, expanded uncertainty provides insights of the testing quality and robustness. Fig. 4 presents the expanded uncertainty range vs. frequency for all the scenarios, using four and six source positions, of five test under conditions of repeatability.



(a)



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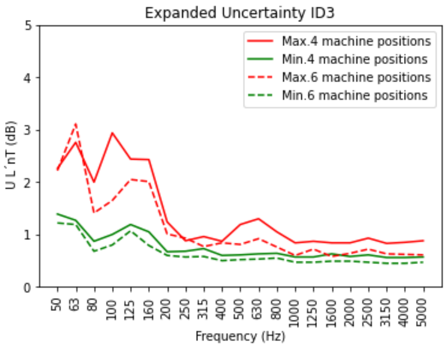

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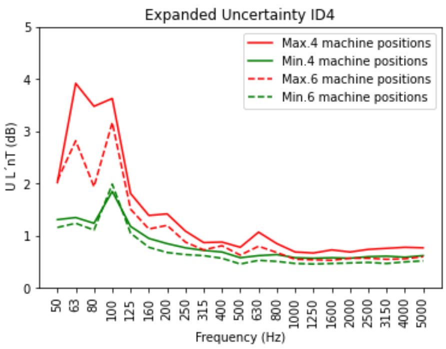

(d)

Figure 4. Expanded uncertainty range for four and six source positions: (a) ID1, (b) ID2, (c) ID3, (d) ID4.

The uncertainty analysis highlights the impact of increasing the number of tapping machine positions. The comparison of expanded uncertainty allows us to evaluate the effect of this increase results in a reduction of both minimum and maximum uncertainty values.

This effect is particularly noticeable in low frequencies, where uncertainty tends to be higher, mainly in the vertical scenarios ID3, Fig. 4(c), and ID4, Fig. 4 (d). In higher frequency the deviations are less prominent.

In the horizontal scenarios ID1, Fig. 4(a), and ID2, Fig. 4 (b), the difference is less relevant than in vertical set-ups. Although the uncertainty improvement is evident, it is not generally substantial.

4. CONCLUSIONS

The results confirm that increasing the number of tapping machine positions from four to six does not introduce significant changes in the averaged L'_{nT} spectra. Therefore, reducing the number of source positions could be considered without significantly affecting the final values of the results in L'_{nT}. However, there is a significant affectation in repeatability values.

A clear dependence of the received noise levels on the tapping machine position was observed. This finding reinforces the idea that increasing the number of microphone positions alone would not contribute to better repeatability. Instead, the key factor in measurement variability appears to be the location of the tapping machine. Given this, future research should explore whether reducing the number of microphone positions to one per source position while maintaining six source positions could still ensure reliable results while optimizing test procedures. Additionally, expanding the dataset with more samples would allow for broader conclusions.

Despite the lack of significant spectral differences, increasing the number of source positions led to a notable reduction in standard deviation in all scenarios, improving repeatability. This confirms that a higher sampling density contributes to more stable and consistent measurements. However, some high-frequency deviations remained, particularly in scenarios ID1 and ID2, indicating that further research is needed to understand whether other factors could be influencing the observed variability.

The results confirm that increasing the number of source positions enhances measurement reliability by reducing the uncertainty range. This is particularly beneficial in cases where uncertainty is initially higher, such as in low-frequency regions. However, at high frequencies, while some improvements are observed, they are less pronounced. When comparing the uncertainty results associated with the tests using four source positions to those obtained using six, it can be observed that, at mid and high frequencies, there is no significant difference between the uncertainties in both cases. However, this trend is not reflected in the repeatability

curves, where the use of six source positions instead of four does show a clear improvement in the levels of repeatability achieved.
The increase of tapping machine positions does not significantly change the final L'_{nT} values, but it plays a relevant role in reducing measurement uncertainty and improving repeatability. This suggests that an optimized balance between source positions and uncertainty reduction should be considered.

5. REFERENCES

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