

ASSESSMENT OF REPEATABILITY OF FIELD MEASUREMENTS OF IMPACT SOUND INSULATION IN DIFFERENT FLOOR SCENARIOS

Romero Fernández, Amelia¹, Trujillo Gallego, José Alberto², San Millán Castillo, Roberto³

¹ Instituto de Ciencias de la Construcción Eduardo Torroja. IETcc – CSIC
{e-mail: aromero@ietcc.csic.es}

² Labenac – Grupo de Investigación en Instrumentación y Acústica Aplicada (I2A2).
{e-mail: jtrujillo@i2a2.upm.es}

³ Universidad Rey Juan Carlos-Departamento de Teoría de la Señal y Comunicaciones - EIF
{e-mail: roberto.sanmillan@urjc.es}

Resumen

Las mediciones in situ del aislamiento a ruido de impactos están normalizadas en ISO 16283-2:2020. La determinación y aplicación de la incertidumbre debe cumplir con la norma ISO 12999-1:2020. Para proporcionar un desempeño adecuado de estas mediciones, se debe considerar la repetibilidad. Por lo tanto, después de realizar varios ensayos, la desviación estándar máxima de repetibilidad en las bandas de tercio de octava de interés debe permanecer por debajo de los límites establecidos en la ISO 12999-1:2020. Este estudio proporciona una evaluación de la repetibilidad de los ensayos de aislamiento acústico a ruido de impactos en distintos escenarios de suelo típicos en España. Los resultados no son conformes en todo el rango de frecuencia. Estas desviaciones generan preocupación sobre la idoneidad de los límites de repetibilidad y el procedimiento de ensayo que se debe considerar al realizar mediciones de acuerdo con las normas ISO.

Palabras clave: aislamiento a ruido de impactos, ensayos in situ, incertidumbre, repetibilidad.

Abstract

Field measurements of impact sound insulation are standardised in ISO 16283-2: 2020. The assessment of the uncertainty must comply with ISO 12999-1:2020. To provide an adequate performance of these tests, repeatability must be considered. Hence, after performing several measurements, the maximum standard deviation of repeatability must remain under the limits reported in ISO 1299-1:2020, regarding the one-third octave bands of interest. This study assesses the repeatability of the impact sound insulation tests in different typical floor scenarios in Spain. The results are non-compliant with the frequency bands limits in all the studied cases. These deviations raise concerns about the appropriateness of the repeatability limits and the testing procedure that should be considered when performing tests according to ISO standards.

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

PACS nº. 43.55.-n

1 Introduction

The standard ISO 16283-2:2020 is the method for the field measurement of impact sound insulation from 2015. The standard procedures rely on sound pressure levels and using an impact source [1]. In building acoustics, the uncertainty assessment is central to offering comprehensible and practical data. ISO 16283-2 requires uncertainty determination according to the standard ISO-12999-1:2020. The principal concepts in ISO 12999-1:2020 are reproducibility and repeatability. Hence, the uncertainty of methods and measurements can be reported based on interlaboratory data, namely reproducibility figures [2]. However, ISO 12999-1:2020 recommends verifying laboratory testing procedures, and repeatability becomes the target to this end. Hence, ISO-12999-1:2020 provides the maximum value for the typical deviation of repeatability (σ_r) versus the frequency range of interest, in one-third octave bands. In repeatability conditions, measuring procedures, operators, equipment, rooms and tested specimens must be the same within a short delay.

Repeatability requirements are the same for airborne sound insulation, façade sound insulation, and impact sound insulation. Hence, the maximum σ_r decreases from low to high frequencies becoming constant from the 400 Hz band. ISO-12999-1:2020 lacks a reference for this data. This differs significantly from the previous standard EN 20140-2 with different repeatability limits (r) (i.e., interlaboratory repeatability) for various tests in laboratory conditions [3]. Those values are different in this withdrawn standard. Generally, the limits appear tighter than the current ones and show the same behaviour in frequency for impact sound insulation measurements in laboratory conditions (ISO 140-6). However, another frequency behaviour was presented for the measurements of reduction of transmitted impact noise by floor coverings on heavyweight standard floors in laboratory conditions (ISO 140-8), although σ_r and r are not equivalent terms. Table A.1 presents an increasing tolerance from the 800 Hz band to the high-frequency end and a medium tolerance in low frequencies. Moreover, the frequency range is a reduced version of ISO 12999-1:2020, from 100 Hz to 3150 Hz. EN 20140-2 data comes from 34 tests of a 12 cm deep concrete slab with a floating floor in a German laboratory, for ISO 140-6, and from 21 tests of PVC covering (i.e., a weighted reduction of impact sound pressure (ΔL_w) of 14 dB) on the reference floor in 4 Scandinavian laboratories, for ISO 140-8.

Some studies by Loverde et al. [4,5] focused on the number of tapping machine positions that are averaged in field and laboratory testing but did not consider the lowest frequency range (<100 Hz). Neither works confirm systematic differences among tapping machine positions in global ratings. Larson et al. [6] studied the effect of tapping machine position relative to the joists in a wood floor, which increased the impact sound pressure level from 4 dB to 7 dB when closed to the subfloor between the joists in the frequency range 25-160 Hz. Thus, the authors considered that the standards should clarify source positions to avoid those discrepancies.

Dong et al. worked on vinyl plank flooring on gypsum concrete with solid wood joists, fibreglass batt insulation, and resilient channels [7]. Hence, σ_r estimation, for four consecutive times with the tapping machine in the same position, remains within the limits of ISO 12999-1:2020 but the frequency curve is increased at high frequencies. However, the results of σ_r for nine positions of the tapping machine exceed the limits of ISO 12999-1:2020 at some bands. A similar study by the authors with a concrete floor revealed equivalent results with high variations between individual positions leading to small deviations when averaged. The extensive survey in [5] suggests that the tapping machine position scarcely affects the insulation rating. However, high variation between source positions correlated with certain flooring types, even in laboratory testing. The current limits of σ_r might be exceeded due to the coupling between finish and structure. This effect is underlined when the test involves fewer source positions and in-field tests. These authors consider the need for further studies to reduce uncertainty

about the specification of source locations and the increase in positions and limits within a range of 3 dB and 5 dB for laboratory testing.

Building technology in Spain is particular and remarkably different from those of Northern Europe or the USA. Thus, considering the potential variations in sound insulation tests depending on floors, it is relevant to assess repeatability. This work aims at 1) evaluating the σ_r of 3 typical Spanish floors; 2) comparing σ_r to the limits of ISO 12999-1:2020; and 3) discussing the consequences of the results for practitioners.

The remainder of this work is organized as follows. Section 2 describes the testing procedures, the equipment and the scenarios employed in this study. Then, Section 3 offers the testing outcomes in the selected scenarios and a detailed discussion of the results. Finally, Section 4 concludes. Given the results, some lines of work are also proposed to continue with this research.

2 Material and Methods

2.1 Measurement procedure and equipment description

Impact sound insulation measurements were performed following ISO 16283-2:2020 [1] in 3 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 equation 1, in the frequency range from 50 Hz to 5000 Hz in one-third octave bands. The default procedure ($V > 25 \text{ m}^3$) and fixed microphone positions were used. A tapping machine was used as an impact source.

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

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, $T_0 = 0,5 \text{ s}$).

Four different positions of the tapping machine were used, randomly distributed on the floor under test. Likewise, 4 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 seconds. 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 2:

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

where m is the number of tapping machine positions; $L'_{nT,j}$ is the standardised impact sound pressure level for tapping machine position j .

Generally, by applying the ISO 717-2:2020 standard [9], the weighted standardised impact sound pressure level, $L'_{nT,w}$ is obtained, but this parameter has not been studied in this work.

The airborne sound contribution from the tapping machine was also evaluated to determine whether it should be considered negligible or it may influence the results in some way.

The measuring system used for impact noise tests was:

- Class 1 sound level meter, one-third octave band analyser, Brüel & Kjaer model 2260;
- ½” Microphone model 4189 and preamplifier ZC-0026, Brüel & Kjaer;
- Class 1 sound calibrator, Brüel & Kjaer model 4231;
- Tapping machine, Brüel & Kjaer model 3207;
- Omnidirectional sound source, Lookline model E2502; and Brüel & Kjaer model 4296

Data post-processing was performed with Brüel & Kjaer's Qualifier Type 7830 PC software and Microsoft Excel. The system was verified at the beginning and the end of each measurement set.

2.2 Scenarios description

The test scenarios correspond to 3 typical separating floor configurations in Spain. The first two correspond to existing buildings, that is, before the entry into force of the present building regulations, DB HR [10], with the current acoustic requirements, which represent close to 90% of the buildings in Spain [11]. The third scenario corresponds to a newly built residential building under this regulation, which requires the installation of a floating floor to meet the impact sound insulation requirements. The measurement rooms are vertically adjacent in all cases, with the source room located in the upper room and the receiving room in the room below. Table 1 shows the details of each scenario and the separating floors tested.

Table 1 – Description of test scenarios and construction solutions of the separating floors.

Scenario	Type of building	Source room	Receiving room	Separating floor	
1	Administrative (furnished)	Office P06, 1 st floor	Office S204, Ground floor	* Typical concrete beam and block floor. * Probably some layers of mortar and sand. (≈300 mm)	* No suspended ceiling. * No floating floor * Floor finish: ceramic tiles.
2	Multifamily dwellings (furnished)	Bedroom, 5 th floor	Dining room, 4 th floor	* Typical concrete beam and block floor. * Probably some layers of mortar and sand. (≈300 mm)	* No suspended ceiling. * No floating floor * Floor finish: wooden parquet floor.
3	Multifamily dwellings (unfurnished)	Living Room /Kitchen, 1 st floor	Living Room /Kitchen, Ground floor	* Prestressed slabs with a compression layer and light blocks (≈250+50 mm)	* Suspended ceiling: 15 mm plasterboard and 100 mm air gap. * Floating floor: 50 mm cement screed with a 30 mm layer of elasticised expanded polystyrene. * Floor finish: wood effect PVC floor.

3 Results and discussion

The following sections show the results of the measurements for the 3 scenarios. For each measurement set, compliance with the repeatability requirements of ISO 12999-1:2020 was evaluated.

For each of the scenarios, the results graphs are organised as follows:

- Figures 1, 4 and 7 represent the spectra of the 5 repeated measurements of L'_{nT} .
- Figures 2, 5 and 8 compare σ_r of the 5 repeated measurements with the limits given in Table 1 of ISO 12999:2020. Values from the measurements should be smaller than those in ISO 12999-1:2020.
- Figures 3, 6 and 9 show the spectrum of the level of signal and background noise combined (L_{sb}) measured in the receiving room, for each source position (F1 to F4) and its 2 corresponding measurement points (P1 and P2).

The airborne sound contribution from the tapping machine was evaluated in all scenarios. Its influence was not notable in them. This contribution is usually much more controlled when the rooms are vertically adjoining, as in this case.

3.1 Scenario 1

Figures 1 and 3 present a high variability within the test repetitions. There is non-compliance with the repeatability requirements indicated in the reference standard starting at 1600 Hz and more notably above 3150 Hz, as shown in Figure 2. Also, a 315 Hz peak appears in the standard deviation curve above the limit. Figure 3 shows that received levels depend more on the source than the microphone position.

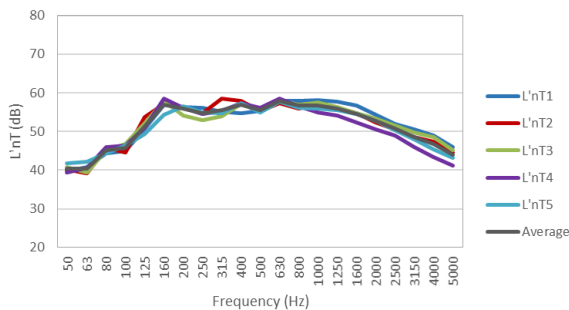


Figure 1 – Spectra of the 5 repeated measurements of L'_{nT} . Scenario 1.

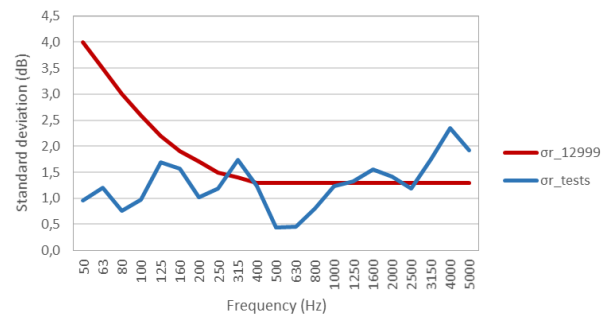


Figure 2 – Standard deviation: ISO 12999 vs measurements. Scenario 1.

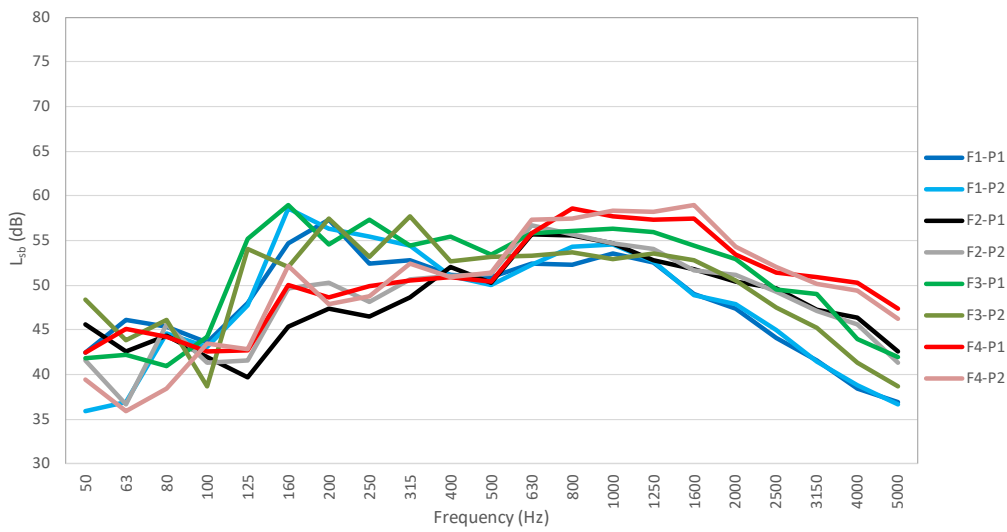


Figure 3 – Level of signal and background noise combined (L_{sb}) in the receiving room. Combinations of source position and measurement points for one of the repetitions. Scenario 1.

Data in Figure 3 may be grouped roughly in pairs, mostly broadband. Each pair of microphone positions with a similar response in the receiving room corresponds to the same source position. Thus, the tapping machine positions seem to influence the results of this test and provide variability in repeatability.

This separating floor had a floor finish made of ceramic tiles, without any damping layer. A ceramic tile floor without an impact insulation layer might cause an increase in the variability of the levels of transmitted noise, depending on where the hammer hits (e.g., on a gap, or on an area where the tile may be better or worse attached).

3.2 Scenario 2

In this case, a more homogeneous floor was selected which allows, in principle, a more uniform response of the transmitted impact noise. The separating floor is finished with a wooden parquet floor.

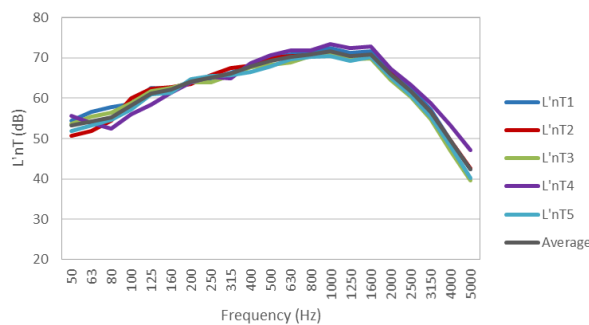


Figure 4 – Spectra of the 5 repeated measurements of L'_{nT} . Scenario 2.

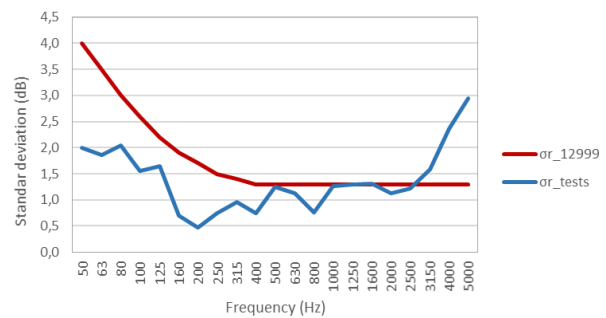


Figure 5 – Standard deviation: ISO 12999 vs measurements. Scenario 2.

Figure 5 shows that non-compliance with the repeatability limits set in the standard continues. However, there is an improvement in the results as the non-compliance begins from 3150 Hz, compared to the

previous scenario, where it started from 1600 Hz. However, values of σ_r are slightly higher than in scenario 1 at 4000 Hz and 5000 kHz.

In this case, Figure 6 shows a convergence of data in the highest frequencies, and it seems that the dependence on the source position vanishes. In the low-frequency range, the microphone positions can be roughly paired but less clear than in scenario 1. The wooden parquet floor finish might help provide a homogeneous surface for hammer hits.

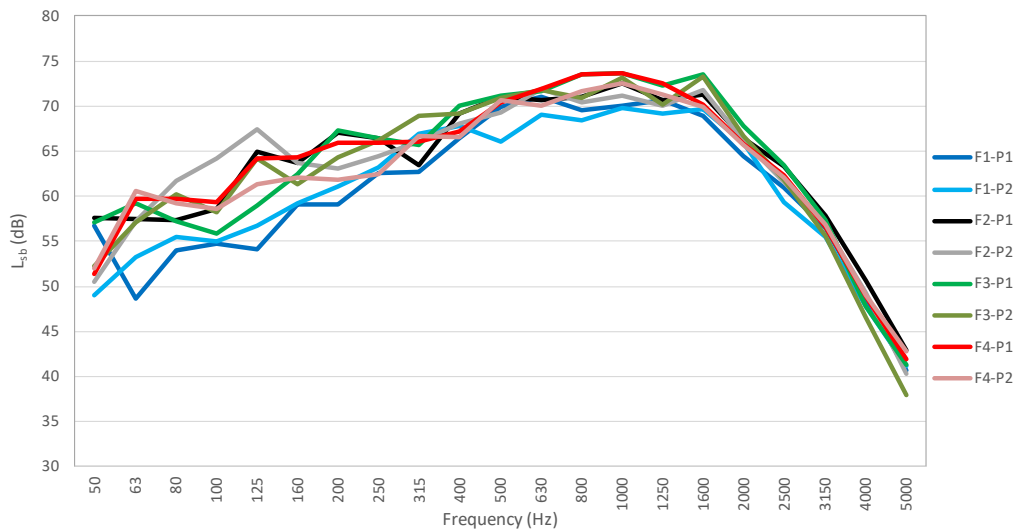


Figure 6 – Level of signal and background noise combined (L_{sb}) in the receiving room. Combinations of source position and measurement points for one of the repetitions. Scenario 2.

3.3 Scenario 3

The separating floor in this scenario represents the usual construction solution for new buildings that comply with the DB HR regulation. Thus, a floating floor is required to meet the impact sound insulation requirements between two adjoining dwellings.

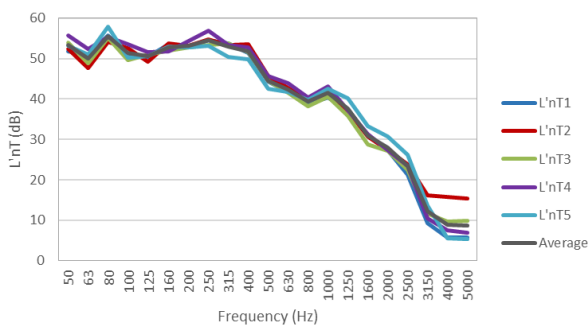


Figure 7 – Spectra of the 5 repeated measurements of L'_{nT} . Scenario .3

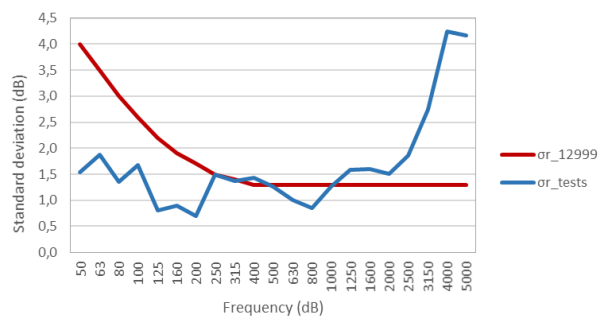


Figure 8 – Standard deviation: ISO 12999 vs measurements. Scenario 3.

In this case, the compliance with σ_r is worse than in the previous cases (See Figure 8). The value of σ_r exceeds the limit curve from 1000 Hz reaching values close to 3 dB at 3150 Hz and above 4 dB at 4000

and 5000 Hz. It is worth mentioning two facts that can explain these repeatability results at the highest frequencies.

On the one hand, given L'_{nT} in Figure 7, the insulation is extremely high from 3150 Hz with noise levels in the receiving room below 10 dB and a limitation due background noise. This construction solution (see Table 1) provides a weighted reduction of impact sound pressure (ΔL_w) up to 33 dB meaning an excellent performance. On the other hand, this scenario was subject to unstable background noise. This led to differences up to 10 dB in the impact noise levels at reception, among repetitions. The authors consider that the repeatability results would improve when better controlling this fact.

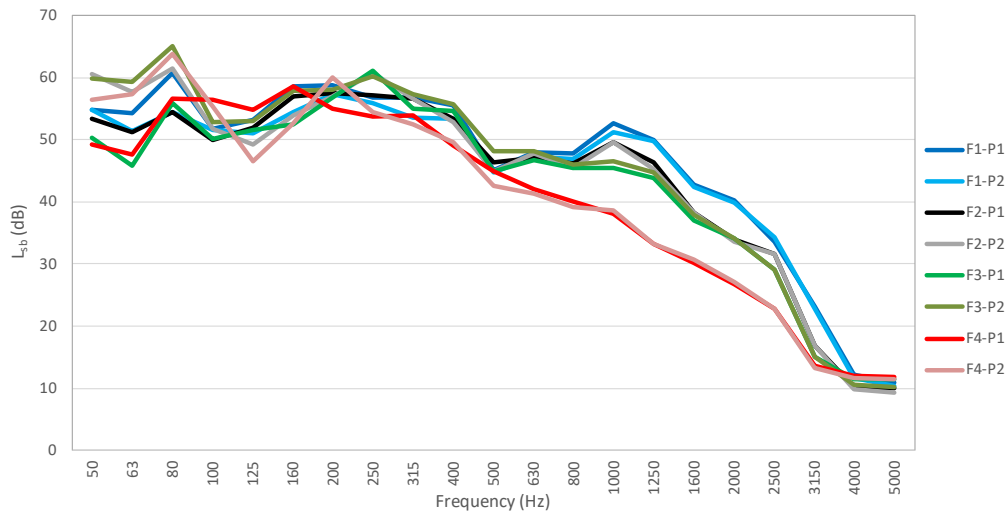


Figure 9 – Level of signal and background noise combined (L_{sb}) in the receiving room. Combinations of source position and measurement points for one of the repetitions. Scenario 3.

Figure 9 shows again the dependence of the impact sound levels on the position of the source in high frequencies as in Figure 3 in scenario 1. However, this is not the case in the low-frequency range.

A comparison of σ_r for the 3 scenarios is represented in Figure 10. None comply with the broadband limits, mostly in the high-frequency range. All the studied scenarios show a similar increasing trend of σ_r with frequency from a turning point. However, scenario 3 shows the highest variability. In mid and low frequencies data is compliant, but few bands in scenarios 1 and 3, with slight exceedances.

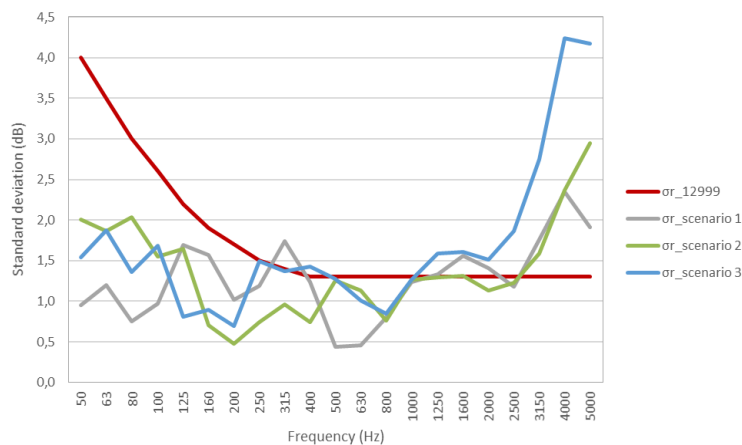


Figure 10 – Comparison of the repeatability in the 3 scenarios.

4 Conclusions

This work studies the repeatability of impact sound insulation tests in 3 typical scenarios in Spain, considering a wide sampling scope with 4 source positions and 4 microphone positions. None comply with the suggested limits in ISO 12999-1:2020, mostly in the high-frequency range. It seems the floor type and its insulation performance notably influence σ_r . Moreover, receiving levels depend on tapping machine positions in different ways. Thus, we find the current σ_r limits for field testing controversial since scenarios may differ extensively. A common comparison framework for airborne sound insulation, façade sound insulation and impact sound insulation seems too general for such different tests. This can make it difficult for practitioners to comply with current repeatability requirements, despite performing adequately. The extended limits in the low-frequency range appear sufficient comparing to the previous reference standard and literature. Consequently, the high-frequency range may benefit from specific and wider limits, as suggested in EN 20140-2 and studies of other authors.

Moreover, high-insulation partitions may include background noise levels as an additional uncertainty factor when assessing σ_r . Hence, σ_r might become overwhelming in field testing, mostly in high frequencies.

Future research lines will work on the effect of increasing the source and microphone positions in σ_r . Also, the study needs more samples to obtain general conclusions.

Referencias

- [1] International Organization for Standardization. (2020). ISO 16283-2: acoustics: field measurement of sound insulation in buildings and of building elements: part 2: impact sound insulation.
- [2] International Organization for Standardization. (2020). ISO 12999-1: Acoustics– Determination and application of measurement uncertainties in building acoustics– Part 1: Sound insulation.
- [3] Comité Européen de Normalisation. (1993). EN 20140-2: Acoustics - Measurement of sound insulation in buildings and of building elements - Part 2: Determination, verification and application of precision data (ISO 140-2:1991).
- [4] LoVerde, J. J., & Dong, D. W. (2007). Evaluation of field impact sound pressure levels as a function of tapping machine location. *The Journal of the Acoustical Society of America*, 121(5_Supplement), 3113-3113.
- [5] LoVerde, J., & Dong, D. W. (2017). Variations in impact sound level as a function of tapping machine position. *The Journal of the Acoustical Society of America*, 141(5_Supplement), 3929-3929.
- [6] Larsson, K., Simmons, C., Amirarahmadi, N., & Zhang, X. (2012). Influence of tapping machine position on timber joist floors on the low frequency impact sound. In 41st International Congress and Exposition on Noise Control Engineering 2012, INTER-NOISE 2012; New York, NY; United States; 19-22 Aug., 2012 (Vol. 8, pp. 6620-6630).
- [7] Dong, W., Lo Verde, J., & Girdhar, S. (2020). Measurement of low frequency impact insulation. *The Journal of the Acoustical Society of America*, 148(4_Supplement), 2513-2513.
- [8] International Organization for Standardization. (2008). ISO 3382-2 - Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms.

- [9] International Organization for Standardization. (2020). ISO 717-2: Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation.
- [10] Ministerio de Transportes, Movilidad y Agenda Urbana, *Documento Básico DB HR Protección frente al Ruido. Código Técnico de la Edificación. (DB HR Protection against noise. Spanish Building Code)*. 2019. [Online]. Available:
http://www.codigotecnico.org/cte/export/sites/default/web/galerias/archivos/DB_HR_sept_2009.pdf
- [11] Boletín estadístico “on line” del Ministerio de Fomento, “Estimación del parque de viviendas”. Available: <https://apps.fomento.gob.es/BoletinOnline2/?nivel=2&orden=33000000>