Accuracy of prediction methods for the improvement of impact sound pressure levels using floor coverings

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ABSTRACT

The improvement of impact sound pressure levels from floor coverings, ΔL, can be measured using the method detailed in Annex H of ISO 10140-1:2016. Manufacturers of floor coverings readily provide ΔL measurement data to aid the design of floor constructions to achieve acoustic performance criteria. In the case of heavyweight floor constructions, which typically include a concrete slab, it is also possible to predict the improvement of impact sound pressure levels by considering the floor covering as a mass-spring system. This paper provides a brief outline of some available prediction methods. The accuracy of these methods is evaluated by comparison with published measurement data.

Keywords: Floor coverings, tapping machine, underlay I-INCE Classification of Subjects Number(s): 51.5

1. INTRODUCTION

A reasonable objective for the accuracy of methods for predicting the improvement in impact sounds pressure levels (ISPLs) using floor coverings is to replicate the accuracy of laboratory measurements. This kind of objective provides a bound on prediction accuracy, in the best case, of being equivalent to the accuracy of laboratory measurements. In this sense, indicators of laboratory measurement accuracy such as reproducibility are relevant for assessing the accuracy of predictions.

Guidance on measurement accuracy is reviewed briefly here and, once established, it is used as a indicator of variation between the measurement and prediction of improvement of ISPLs using floor coverings.

Two separate prediction models are employed depending on whether the floor covering is flexible such as cork or rubber flooring or whether it comprises plate and elastic elements such as a tiled floor with resilient underlay. For each model, variations between measurement and prediction data are evaluated for a range of different floor coverings.

2. PREDICTION TOLERANCES

In Australia, the relevant standard for measuring the improvement in ISPLs is AS ISO 140-8:2006 (1). Equation (5) from this standard provides the following expression for the improvement of ISPL using floor coverings, ΔL:

$$\Delta L = L_{n0} - L_n \tag{1}$$

Here L_{n0} and L_n are, respectively, the normalized ISPLs of a heavyweight standard floor without and with a floor covering. More generally, procedures for measuring the improvement in ISPLs using floor coverings are documented in the ISO 10140 series of standards, with equation H.1 of ISO 10140-1:2016 (2) being equivalent to equation 1 above.

Regarding the precision of measurements, Clause 7 of AS ISO 140-8:2006 provides the following remarks:

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It is required that the measurement procedure gives satisfactory repeatability. This shall be determined in accordance with the method shown in ISO 140-2 and shall be verified from time to time, particularly when a change is made in the procedure or instrumentation.

A comparable set of remarks are provided in Clause 8 of ISO 10140-3:2010 (3).

The quoted standard, ISO 140-2:1991 (4) provides one-third octave band uncertainty data for ΔL measurements in terms of both repeatability and reproducibility. These two conditions are described in Table 1 below.

Table 1 – Uncertainty conditions

Condition	ISO 12999-1:2014 definition
Repeatability	Condition of measurement that includes the same measurement procedure, same operators, same measuring system, same location…
Reproducibility	Condition of measurement that includes different locations, operators, measuring systems…

The source of the uncertainty data is reportedly:

[…] a set of 21 tests conducted in 1983 involving four laboratories in Scandinavia using a loosely installed flexible PVC flooring cover […] having a weighted impact sound improvement index ΔL_w of about 14dB"

140-2:1991 was formally superseded in 2014 by the standard ISO 12999:2014 (5). This more recent standard provides typical one-third octave band standard uncertainty data for the reproducibility condition (referred to as *Situation A* in that standard). The source of the standard uncertainty data is noted as follows.

They are derived from inter-laboratory measurements according to ISO 5725-1 and ISO 5725-2 and represent average values derived from measurements on different types of test specimens […]

Figure 1 below provides a comparison of these different sets of uncertainty data. In the figure the values of reproducibility standard deviation from ISO 12999-1:2014 are expressed as an expanded uncertainty with a coverage factor of 1.96. From the figure it is apparent that the reproducibility standard deviation data from ISO 12999-1:2014 is broadly comparable to the sets of uncertainty data from the earlier standard, although variations in particular one-third octave bands can be pronounced. The 'Reproducibility' data shown in Table 1 are used through the remainder of this paper as a general indicator of the accuracy of methods for prediction ΔL.

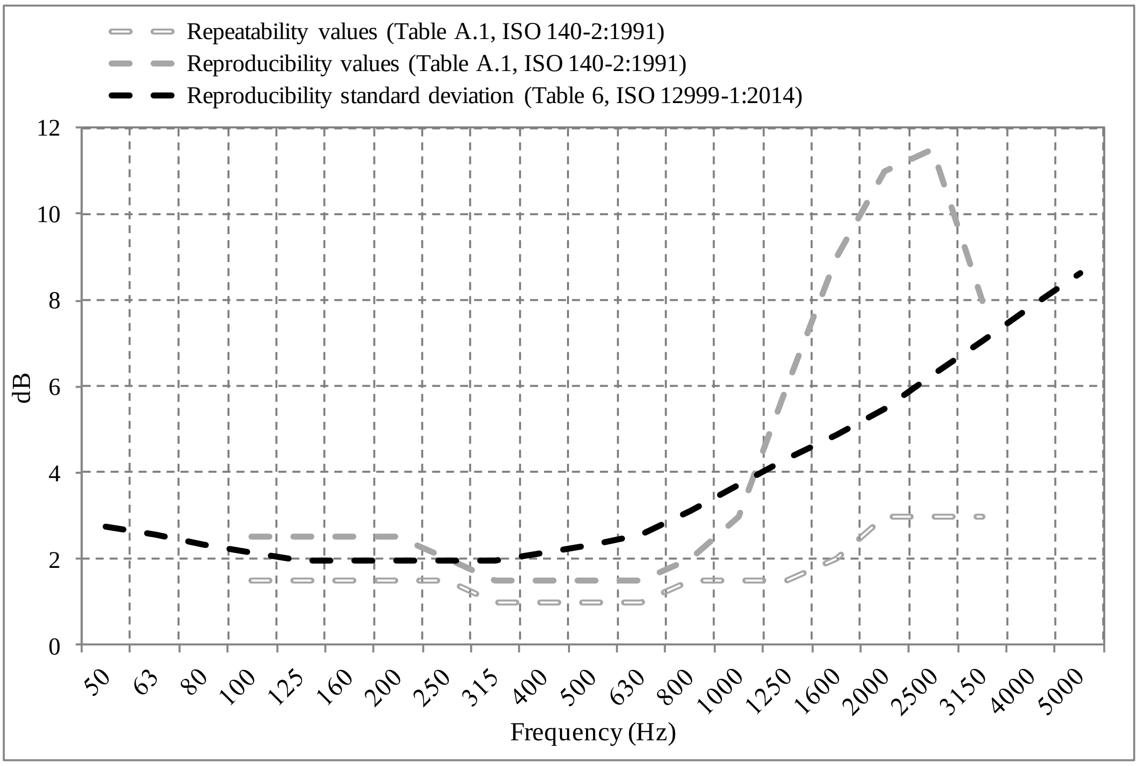

Figure 1 - Examples of precision tolerances for ΔL measurements

3. FLEXIBLE FLOOR COVERINGS

3.1 Prediction method

Ver (6) provides the following expression for estimating the improvement of ISPLs using flexible floor coverings:

$$\Delta L = 20 \log \frac{|F_n|}{|F_n'|} \tag{2}$$

F_n and F_n' are the Fourier coefficients without and with a floor covering respectively. Assuming a very stiff and massive floor, the value of F_n is commonly estimated as:

$$|F_n| \approx \frac{2m}{T}\sqrt{2gh_{fall}} \tag{3}$$

Here m (kg) is the mass of the ISO tapping machine hammer, T (s) is the time between hammer impacts, g (m/s^2) is acceleration due to gravity and h_{fall} (m) is the fall height of the hammer. Ver provides the following equation for F_n' assuming a flexible floor covering without damping installed on a very stiff floor:

$$|F_n'| = \frac{2}{T}\int_0^{1/2f_0} \upsilon_0 2\pi f_0 m \sin(2\pi f_0 t)\cos\left(\frac{2\pi nt}{T}\right)dt \tag{4}$$

υ_0 (m/s) is the hammer velocity at the time of impact, and f_0 is the resonance frequency given by:

$$f_0 = \frac{1}{2\pi}\left[\frac{s}{m}\right]^{1/2} = \frac{1}{2\pi}\left[\left(\frac{A_h}{m}\right)\left(\frac{E}{h}\right)\right]^{1/2} \tag{5}$$

Here s is the dynamic stiffness, A_h is the area of the hammer impacting the floor covering, E is the dynamic Young's modulus and h (m) is the floor covering thickness. The resonance frequency represents the onset of improvement in ISPLs using the floor covering. Below the resonance frequency, ΔL is generally expected to be 0.

When damping is considered as part of the model, the following equation for F_n' applies where η is the loss factor:

$$|F_n'| = \frac{2}{T}\int_0^{1/2f_0} \upsilon_0 e^{-\alpha t}\left[\left(\frac{\alpha^2-\beta^2}{\beta}\right)\sin\beta t - 2\alpha\cos\beta t\right]\cos\left(\frac{2\pi nt}{T}\right)dt \qquad (6)$$

Where:

$$\alpha = \frac{\eta\sqrt{s/m}}{2m} \qquad (7)$$

and

$$\beta = \frac{\sqrt{4ms - \left(\eta\sqrt{s/m}\right)^2}}{2m} \qquad (8)$$

.

3.2 Comparison of predictions and measurements

The prediction model for flexible floor coverings from equations 6, 7 and 8 has been used to predict ΔL values for a range of floor coverings for which laboratory measurement data is published and available. Figure 2 and Figure 3 below present three examples of the comparison between measurements and predictions for floor coverings comprising one or two layers of flexible material.

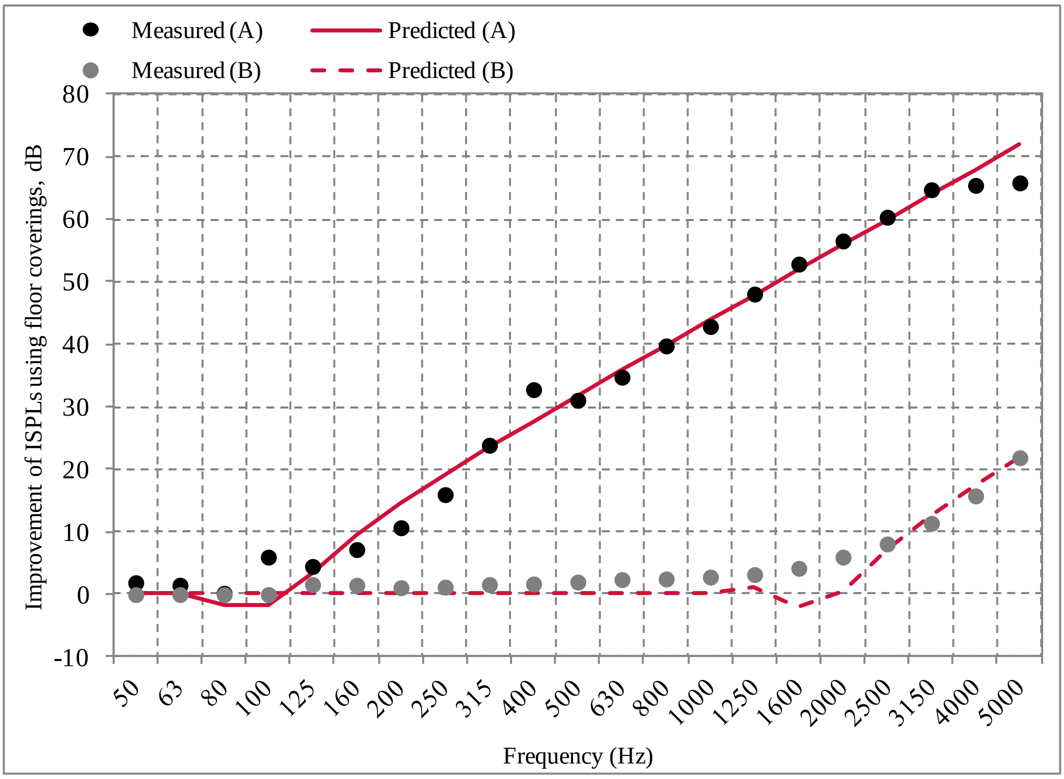

Figure 2 - Comparison of measured and predicted ΔL values for: (A) 2 mm rubber matting, and; (B) 6 mm rubber matting.

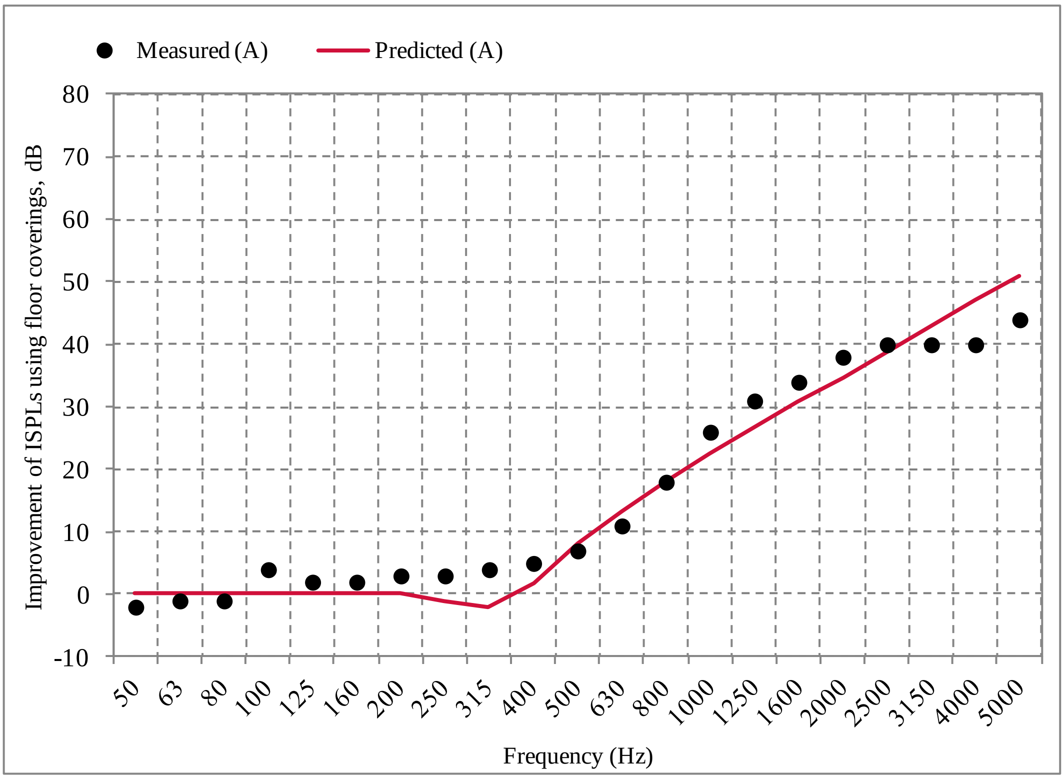

Figure 3 - Comparison of measured and predicted ΔL values for: 3.2 mm vinyl planks on 5 mm rubber underlay

The agreement between measurements and predictions shown in the figures above is generally reasonable.

However, such a limited set of comparisons does not provide a robust overview of general accuracy. To quantify the accuracy over a wide range of flexible floor coverings, 25 comparisons have been made between theory and measurements.

Predictions were made for each floor covering using stated material properties where possible. Where material properties were not explicitly provided, estimated values have been used. In particular, the dynamic Young's modulus, E, was not commonly provided yet it has a significant effect on a flexible floor covering's ability to reduce ISPLs. For example, E is a factor in equation 5 for the resonance frequency. Values of E were estimated with reference to any relevant data on similar materials and also to provide a prediction result that offered reasonable agreement with the measurement data. In this sense, the measurement data has been used to directly determine an 'effective' dynamic Young's modulus.

Figure 4 below presents a summary of the comparisons. The figure shows the mean difference between predicted and measured ΔL values both for 1/3 octave band centre frequencies and also the overall ΔL_w values. The error bars shown for the mean differences represent one standard deviation.

The figure also includes the reproducibility values from ISO 140-2:1991 and ISO 12999-1:2014, as they were presented in Figure 1 above. It is important to recognise that these values, which effectively represent a 95% confidence interval, are not strictly comparable with the error bars of the mean differences (which show one standard deviation). Rather, the reproducibility values are included to provide context to the range of mean differences between predictions and measurements. In this figure, any consideration of the ISO values as confidence intervals should be avoided.

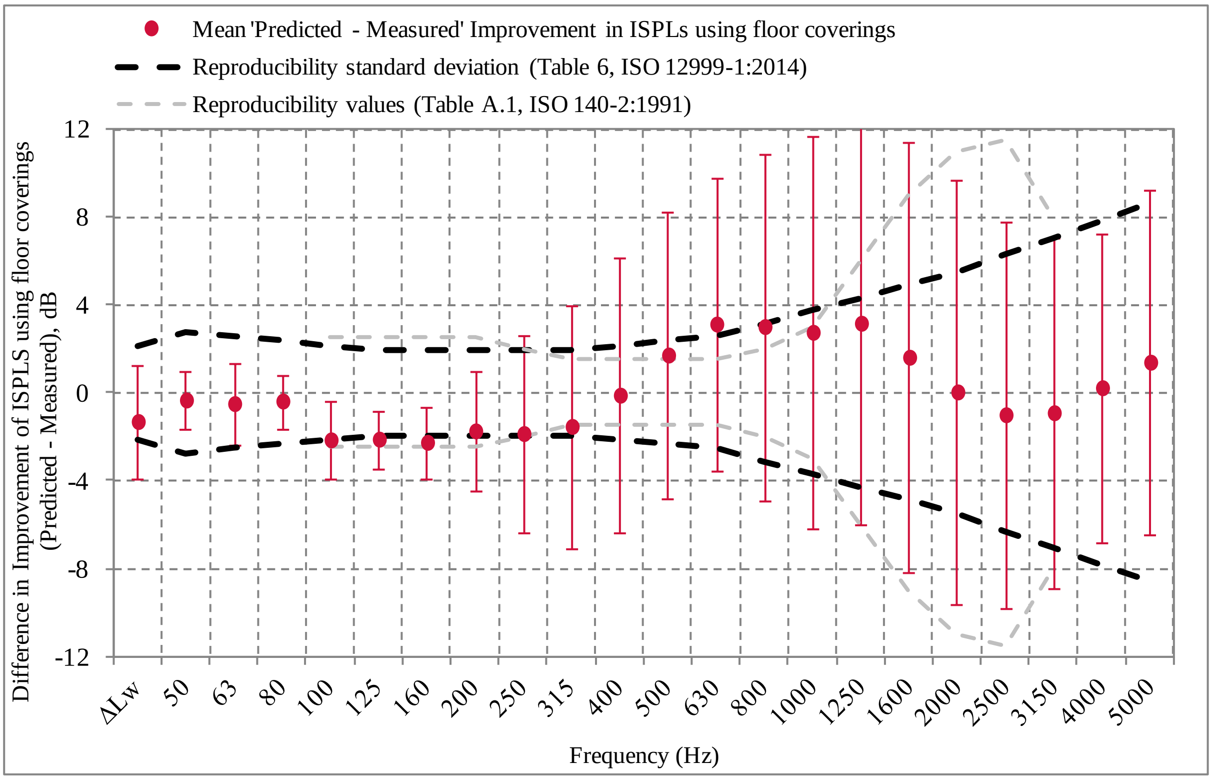

Figure 4 - Mean difference between predicted and measured ΔL values for 25 flexible floor coverings

It can be seen in the figure that the mean difference values and standard deviations at lower frequencies are relatively small. This broadly corresponds to the region below the resonance frequency, where ΔL values are expected to be 0. Above approximately 400 Hz, the mean difference is a positive value and the standard deviation values increase noticeably.

The mean difference in ΔL_w values is -1.3 dB, with a standard deviation of 2.6 dB.

4. COMPLEX FLOOR COVERINGS

4.1 Prediction method

Cha et al (7) provides the following expression for estimating the improvement of ISPLs using floor coverings which include a rigid plate and an elastic underlay:

$$\frac{|F_n|}{|F_n'|} = \frac{1 + i\eta(\omega/\omega_0) - (\omega/\omega_0)^2}{1 + i\eta(\omega/\omega_0)} + \frac{i\omega M}{Z_p} \tag{9}$$

ω is the angular frequency, ω_0 is the angular resonance frequency, M (kg) is the mass of the rigid plate and Z_p is the point impedance of that plate.

Examples of complex floor coverings include timber, tile and screed finished floor surfaces with a resilient or flexible underlay material beneath such as cork or rubber.

4.2 Comparison of predictions and measurements

The prediction model for complex floor coverings from equation 9 has been used to predict ΔL values for a range of floor coverings where laboratory measurement data is also available. Figure 5 below presents two examples of the comparison between measurements and predictions.

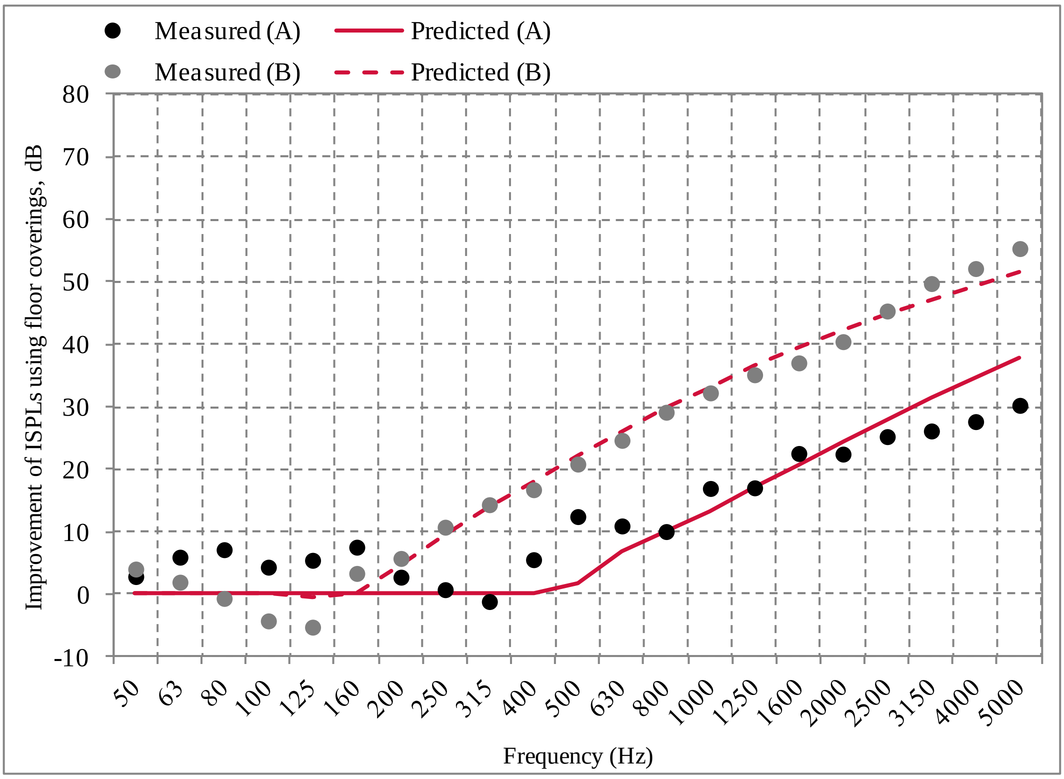

Figure 5 - Comparison of measured and predicted ΔL values for: (A) 27 mm ceramic tiles and ≈ 50 mm screed on a 5 mm rubber underlay, and; (B) 55 mm screed on 4 mm rubber and cork underlay.

The figure shows that agreement between measurements and predictions is reasonable. It can also be seen from the figure that:

- The measured ΔL values for system (A) are greater than 0 at frequencies below the estimated resonance frequency at ≈ 500 Hz. This may be due to measurement error, or perhaps due to the additional mass being added to the floor structure by the screed and ceramic tiles.
- The measured ΔL values for system (B) are negative in the one-third octave frequency range from 80 Hz to 125 Hz. The likely coincides with the resonant frequency which is estimated to be ≈ 130 Hz.

In total, 59 different complex floor coverings have been modeled for comparison with measurements. Results of this comparison are presented in Figure 6 below using the same approach as that shown in Figure 4 above for flexible floor coverings. The Figure 4 comments about interpreting reproducibility values also apply here.

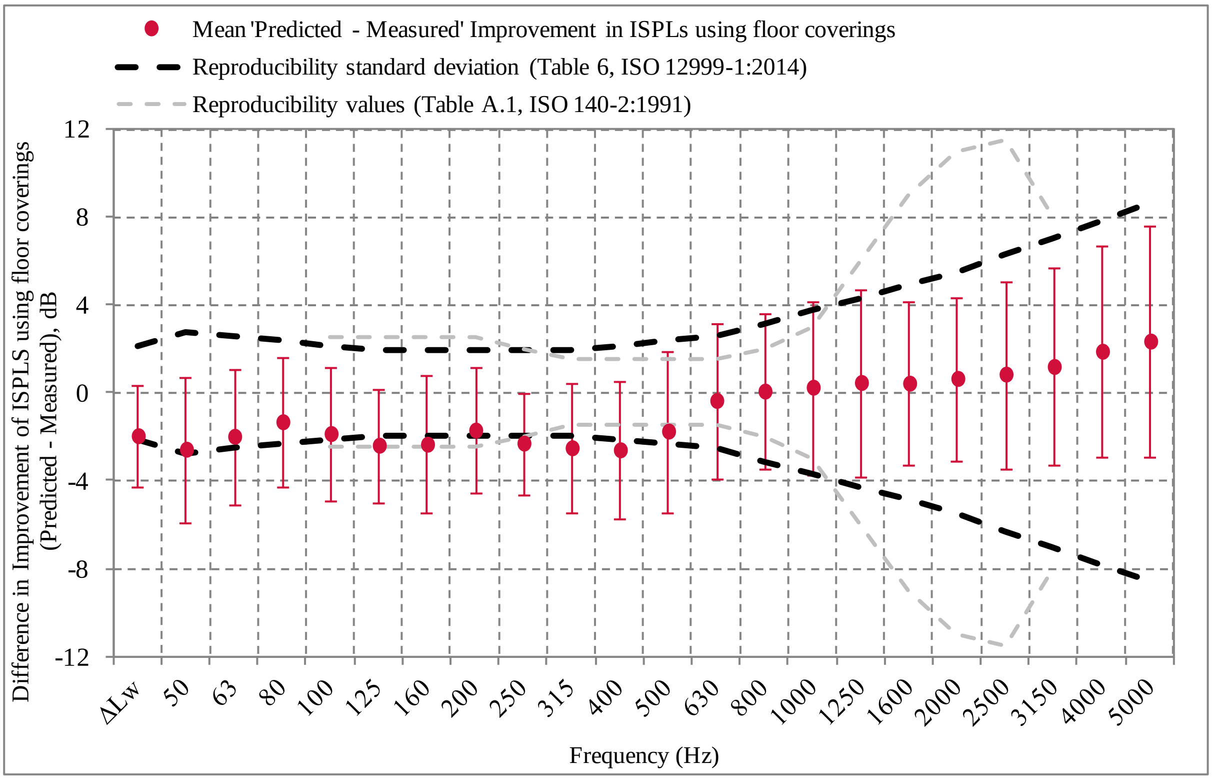

Figure 6 - Mean difference between predicted and measured ΔL values for 59 complex floor coverings

It can be seen in the figure that the mean difference values and standard deviations at lower frequencies are relatively small and are negative meaning that the predicted ΔL values are on average lower than measured in the frequency range that, typically, is below the resonance frequency.

The mean difference in ΔL_w values is -2.0 dB, with a standard deviation of 2.3 dB.

5. CONCLUSION

Two different models for predicting the improvement of ISPLs using floor coverings have been reviewed. Comparisons have been made with measured data to evaluate the accuracy of the predictions. For each model, the agreement between measurements and predictions is reasonable, with a absolute mean difference of not more than 2.0 dB and a standard deviation of not more than 2.6dB in each case. This extent of the observed variations seems comparable to the prediction tolerances for laboratory measurements of ΔL, suggesting that the prediction models could be helpful in designing heavyweight floor constructions for apartments and other noise sensitive spaces.

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