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Qualitative behaviour of L1 and L2 standard deviation in insulations measurements according to standard UNE EN ISO 140-4

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Summary
Knowledge of the uncertainty of measurement of testing results is important when results have to be compared with limits and specifications. In the measurement of sound insulation following standards UNE EN ISO 140-4 the uncertainty of the final magnitude is mainly associated to the average sound pressure levels L1 and L2 measured. A parameter that allows us to quantify the spatial variation of the sound pressure level is the standard deviation of the pressure levels measured at different points of the room. In this work, for a wide number of measurements following standards UNE EN ISO 140-4 we analyzed qualitatively the behaviour of the standard deviation for L1 and L2. The study of sound fields in enclosed spaces is very difficult. There are a wide variety of rooms with different sound fields depending on factors as volume, geometry and materials. In general, we observe that the L1 and L2 standard deviations contain peaks and dips independent on characteristics of the rooms at single frequencies that could correspond to critical frequencies of walls, floors and windows or even to temporal alterations of the sound field. Also, in most measurements according to UNE EN ISO 140-4 a large similitude between L1 and L2 standard deviation is found. We believe that such result points to a coupled system between source and receiving rooms, mainly at low frequencies the shape of the L1 and L2 standard deviations is comparable to the velocity level standard deviation on a wall.

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1. Introduction

The Building Acoustics Noise Codes of the different European countries establish values and limits for the different sound insulation magnitudes. In this sense, an essential aspect of an “in situ” measurement is to give the measured magnitude and its associated uncertainty. The uncertainty evaluation process will encompass a number of influence quantities that affect the result obtained for the measurand.

The measurement procedures following standards ISO 140 require the measure of time-averaged sound pressure levels, L1 and L2, at a number of different points in a room and their spatial average. The maximum uncertainty contribution is mainly coming from this average. In this sense, it is useful and necessary to look at the spatial variation of L1 and L2 time-averaged sound pressure levels, both in theory and in practice.

Outside of the laboratory, in real situations there are a wide variety of rooms with different sounds fields. Furthermore it is difficult to establish general rules on the behaviour of these averages mainly in the low frequency range. For example, the transmission of sound between two contiguous rooms depends on the separation elements, on the connections between surrounding elements and on how propagation proceeds inside the emitting and receptor rooms. In the same line, the change in level due to the presence of the façade depends on the sound propagation from the source, diffraction effects….

Different studies have been already published in the literature, mostly related to standard 140-4 [1-3]. These works are mainly focused on the influence of the different parameters and geometrical situations on sound insulation. The most common situation is where the rooms of each side of the party wall are of the same dimensions. Strong coupling takes place when the acoustic modes have the same distribution, as in equal rooms. Between equal rooms, the sound insulation decreases faster with increasing frequency than in unequal rooms. The asymmetric room configurations thus tend to improve the sound insulation of party walls.

In the line of these studies, we believe it is interesting to analyze the room sound fields based on the standard deviation: adequate parameter of easy calculus to describe the spatial variation of the sound pressure level in a space. During the last two years, in our laboratory, Laboratorio de Acústica y Vibraciones (UPM), we have performed measurements following procedures described in international standards 140-4 and 140-5 [4]. From the analysis of these data some interesting conclusion have been extracted related to the uncertainty associate to the existence of no exactly diffuse sound fields in the source and receiving rooms. In this work, we present a qualitative description on the "in situ" measurements performed in different rooms geometries. Concerning standard 140-4 we show some results in which the L1 and L2 standard deviation fit very well to a standard deviation combined taking into account the geometrical configuration of the room and the wall vibrational field.

2. "In situ" measurements

2.1. Measurement procedure

The "in situ" measurements of airborne sound insulation between rooms have been performed following the procedure described in international standard 140-4 [5]. L1 and L2 sound pressure levels have been calculated as the energetic average of the levels measured in ten microphone positions, five different positions for each position of the loudspeaker. The loudspeaker has been sited near the corners of the source room.

These microphone positions have been uniformly distributed on the room, spaced and fixed taking in consideration the limit distances between microphone positions and to the walls, to the loudspeaker… specified in the standard. Then, the average value of the sound pressure level calculated for the rooms combines corner microphone positions with positions in the central region of each room. In principle, this method provides a good estimate of the room average sound pressure level. The sound pressure levels at the different positions have been measured using a frequency range between 100 and 5000 Hz. We show data related to room volumes from 15 to 70 m^3. These are representative of small and medium size rooms in typical dwellings. On the other hand, we have performed some measurements in rooms of volume above 400 m^3. In most situations, the volume of the receiver and source rooms are equal.

2.1. Calculus of the standard deviation

The room average sound pressure level is defined as the energy average level that is calculated using all possible microphone positions, L_{1j} or L_{2j}, in the room following the equation:

$$\overline{L}_{1,2} = 10\log\left(\frac{1}{n}\right)\sum_{j=1}^{n} 10^{\frac{L_{1j,2j}}{10}} \qquad (1)$$

From the average sound pressure level, the standard deviation of the pressure levels measured at the different points of the source and receiving rooms has been estimated according to the expression:

$$\sigma(L_{1,2}) = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(L_{1j,2j} - \overline{L_{1,2}})^2} \qquad (2)$$

For the following discussion, we consider this parameter as an appropriated descriptor of the characteristics of the room sound field.

3. Results and Discussion

We have performed twenty "in situ" measurements following the procedure described in ISO 140-4 in which the receiving and source room volumes are ranging between 15 and 70 m^3. Both rooms present equal volume in eight cases. For the rest of measurements the volume of the source room is higher than the receiving room. Also, we have carried out ten "in situ" measurements in which the volume of the source and receiving rooms are equal and above 400 m^3.

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Concerning the first volume range (from 15 to 70 m^3), basically two different behaviours have been observed: 1) the standard deviation as a function of the frequency calculated for the receiving room is smaller than the standard deviation calculated for the source room, or 2) both curves are almost coincident. In the case of volumes above 400 m^3, the two behaviours described are also observed but the calculated values of the standard deviation in the source and receiving rooms are smaller than the calculated for volumes smaller than 70 m^3. In Figures 1 and 2 we have shown some representative examples for each of the volume ranges. Figure 1 shows two examples corresponding to volumes up to 70 m^3. Figure 2 shows the two examples corresponding to volumes above 400 m^3.

The tendency observed in plots of Figures 1 and 2 is the one expected. The high standard deviation values correspond to the low frequencies, consequence of that the sound field in typical rooms in dwellings is not diffuse. In general, simulations demonstrate that the sound pressure level distribution is non-uniform at low frequencies where there are only a few modes in a frequency band: the sound pressure levels in the corners of a room are higher than in the centre of the room [6-7]. Then, at low frequencies the average sound pressure level of all points in a room will therefore be higher than the average level measured in the centre of this room. At intermediate frequencies (from 400 to 4000 Hz) the L1 and L2 standard deviation is ranging between 1 and 2 dB almost independently of the volume and configuration.

In principle from a theoretical point of view we had to consider different ways of excitation of the source and receiving room modes. While in the source room we are exciting with a single point source, all the room surfaces radiate sound into the receiving room. Michelsen [8] and Olesen [9] have investigated the standard deviation of sound pressure levels in the source and receiving rooms for sound insulation measurements in both, the laboratory and the field. Radiating surfaces in the receiving room can be represented as an equivalent number of uncorrelated point sources, hence the larger the surface, the larger the number of point sources. The implication for the standard deviation in a receiving room is that it should be lower than in the source room. Our measured data confirm that lower values in the receiving room occur in practice only in some cases.

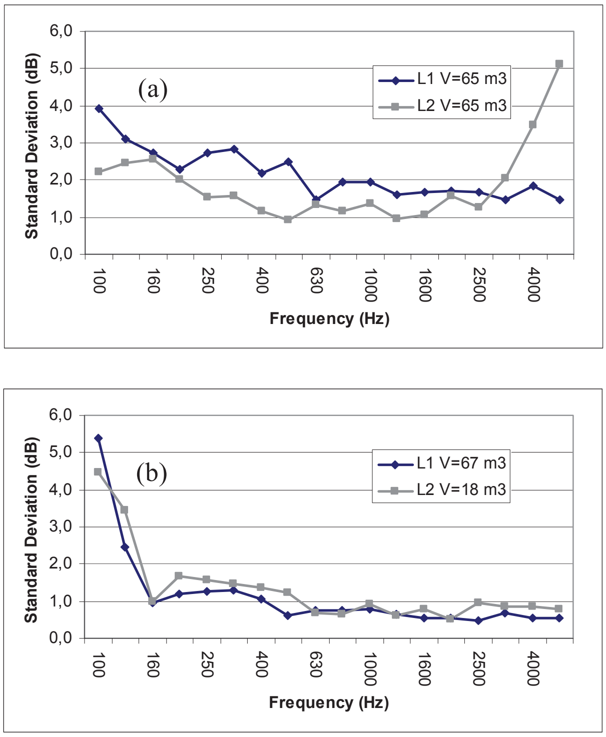

Figure 1. Standard deviation as a function of the frequency for two examples in which the volumes of the source and receiving rooms are smaller than 70 m^3. In each example the room volumes are specified.

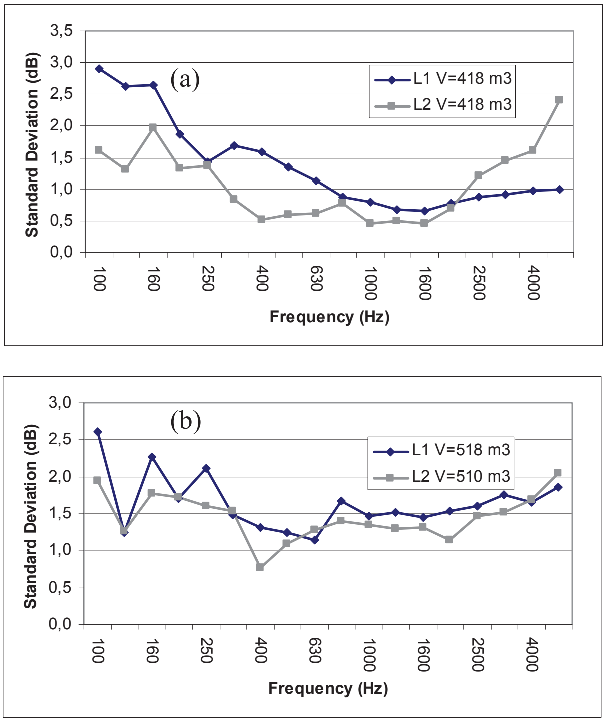

Figure 2. Standard deviation as a function of the frequency for two examples in which the volumes of the source and receiving rooms are higher than 400 m^3. In each example the room volumes are specified.

Coming to the analysis of the similarity observed between the standard deviation curves calculated for the source and receiving rooms, as the example represented in Figure 1 (b): we believe that this behaviour could be attributed to strong coupling between both rooms via the separating wall. When two or more rooms are joined together in such a way that energy can be transmitted between them, the rooms can constitute a coupled system. In this sense, a measurement of this coupling, so of the transmitted energy, could be the sound pressure level difference, L1-L2, between rooms. In Figure 3 we have plotted such difference for the two examples shown in Figure 1. The smaller L1-L2 difference corresponds to the Figure 1(b). The higher the energy transmitted between rooms, the higher the coupling and so similar behaviour of the L1 and L2 standard deviation as function of the frequency is calculated.

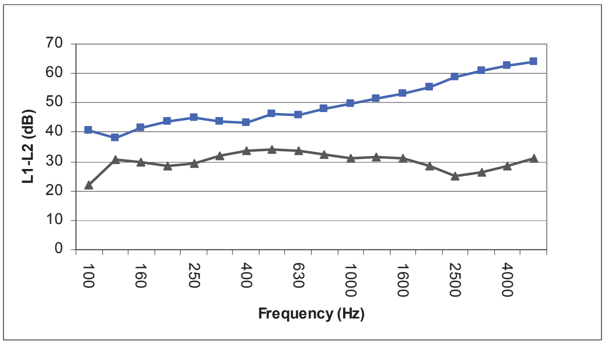

Figure 3. Difference of sound pressure levels L1-L2 for the two examples of Figure 1: blue line (Fig. 1(a)) and black line (Fig. 1 (b)).

In Figure 4, three examples of the standard deviation as a function of the frequency curves are compared to the theoretical models already published in the literature. The examples correspond to cases in which both rooms present similar dependence on frequency. For a multimodal space with broad-band excitation the following expression has been proposed [10]:

$$\sigma = \frac{5{,}57}{\sqrt{1+0{,}238BT}} \qquad (3)$$

where B is the filter bandwidth and T the reverberation time. In this line, mainly at low frequencies where the modal overlap is lower, Lubman proposed the equation (5) to estimate the standard deviation [11]:

$$\sigma = \frac{4{,}34}{-0{,}22+\sqrt{1+0{,}319N}} \qquad (4)$$

where N is the number of modes in the frequency band.

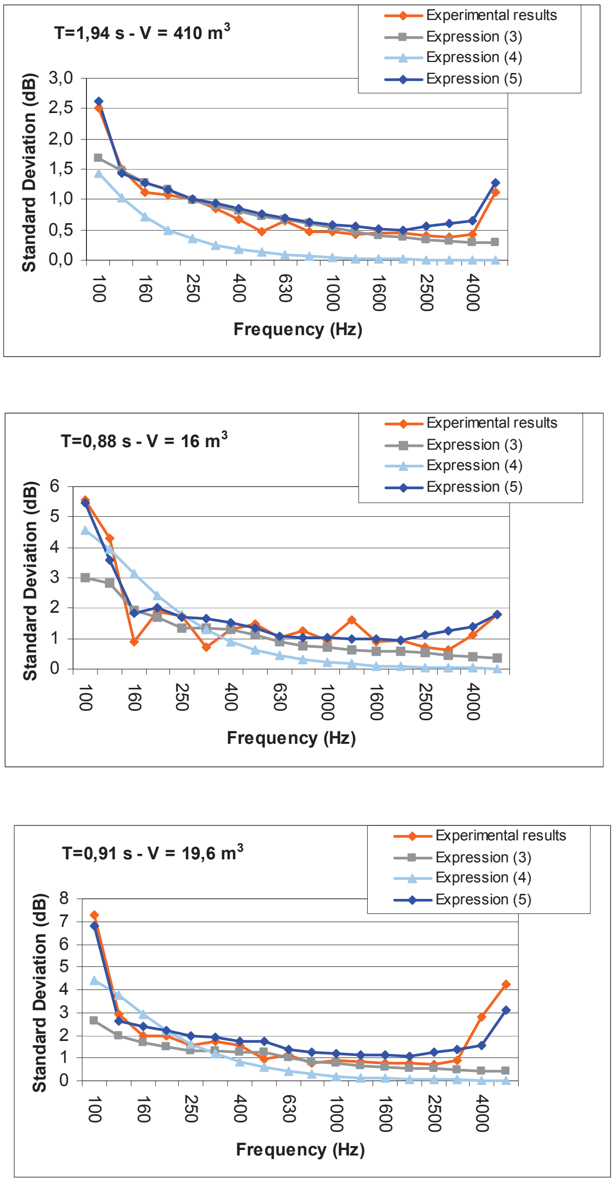

Figure 4. Comparison between the standard deviation measured and models described by equations (3), (4) and (5). The volume and reverberation time values are indicated in each case.

In general, there is a reasonable agreement between the standard deviations calculated and the prediction of equation (3) at frequencies above 300 Hz. However, no one of the theoretical models works very well at low frequencies. In this

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line, the aim of the present work is to try to achieve a better fitting to the standard deviation curves at low frequencies.

For the fitting of the standard deviation data calculated from the "in situ" measurements it is fundamental to consider the modal composition of the sound field in the source and in the receiving room. Fundamental characteristic in which expressions (3) and (4) are based. However, the non-uniform sound field in receiving and source room could also be attributed to the mass-spring-mass resonance frequency, to the radiation from local modes of walls or floors, to the modes due to the source room-separating wall-receiving room system… [12] In this line, to calculate accurately all these contributions, so all the mode frequencies and mode shapes the material properties of the wall and floors and its boundary conditions have to be known. Nevertheless, this is rarely the case.

In fact, in works already published in the literature [1-3] the sound transmission between two rooms is modelled by taking into account the sound fields of the source rooms and of the receiving rooms, the structural behaviour of the party wall and the coupling. The results obtained with the two rooms model shows that the sound insulation provided by a vertical single wall is highly dependent on the creation of stationary pressure field inside the rooms and on vibration of the separating wall, leading to the existence of pronounced dips of insulation.

On the other hand, in general the dominant sound transmission path is through the separating wall [13]. So, although it is complicated to evaluate all the contributions described we consider that the wall vibrational field contribution has to be taken into account. It has been seen that there is significant spatial variation of vibration velocity over the wall surface [14]. In Figure 5 we have plotted for several examples the values of the standard deviation as a function of the frequency. The standard deviation dependence on frequency is similar to the generalized curve of the standard deviation for the velocity level difference [14]. The values of the standard deviation at low and high frequencies, but not the shape, are the main difference between the three examples shown. We believe these differences are a consequence of a different contribution of the wall vibrational field to the standard deviation of the sound pressure level.

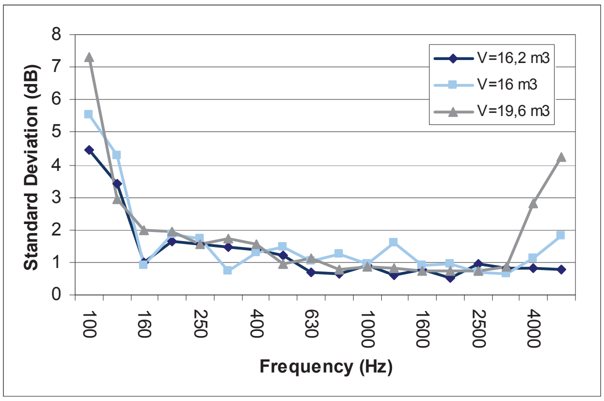

Figure 5. Standard deviation as a function of the frequency for three examples in which we believe the different effect of the wall vibration is observed.

In the uncertainty calculations, it is know that the contribution [15] of the input quantities can affect the measurand in a different way. To describe how sensitive the result is to a particular quantity, the sensitivity coefficient c_i associated with each input variable is defined. Once the standard uncertainties and the sensitivity coefficients have been calculated, the standard uncertainty components are combined to produce an overall value of uncertainty, known as the combined standard uncertainty. The combined standard uncertainty is calculated as follows:

$$u_C(y) = \sqrt{\sum_{i=1}^{N} c_i^2 u^2(X_i)} \quad (5)$$

where y is the measurand and X_i the input variables.

So, following our discussion, a combined standard uncertainty has been considered to fit the data plotted in Figure 4. The uncertainties combined to calculate the L2 standard deviation have been the associated to the modal room behaviour expressed by equation (3) and the wall vibrational field standard deviation [14]. The curves fit reasonably well to the proposed model. In the fit, the sensibility coefficients have been considered as free parameters. The sensibility coefficients values are ranging between 0,3 and 0,8 for the wall vibrational field and between 0,5 and 1 for expression (3). These values point to a different contribution of each uncertainty source depending on the particular construction characteristic of the source-receiving room system.

4. Conclusions

We have performed “in situ” measurements following the procedure described in international standard 140-4 for different volume ranges. Two general behaviours have been observed: the L2 standard deviation as a function of the frequency is smaller than the L1 standard deviation, or both curves are similar. At low frequencies, where the modal behaviour is more complex, it is difficult to evaluate what contributions to the standard deviation have to be considered. We show examples in which data fit well to a standard deviation that combine the effect of the room geometry and the wall vibrational field. However, a more refinement of this method is required taking into account the construction details of the source-receiving room system. Other interesting aspect is to prove if this combined uncertainty works for “in situ” measurements following procedure described in standard 140-5.

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