Est-il vraiment impossible d'améliorer la reproductibilité des essais acoustiques et la mesure en basse fréquence avec la série de norme ISO 10140 ?

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In this paper, we will investigate several ways to improve ISO 10140 series regarding reproducibility and low frequency. All those investigations have been undertaken keeping in mind that we have to deal with existing facilities that cannot realistically be rebuilt. With such a constraint, the question we asked ourselves is: how can we improve measurements? This work has been done after the last ISO 10140-4 Annex A draft revision (requirement for low frequency measurement). We have investigated the number of diffusers, of loudspeaker position, but also the impact of using synchronized but uncorrelated sources instead of one source position after one other. Using synchronized but uncorrelated sources, a major technical question is how to equalize the contribution of each sources so that one does not prevail. We have tested an equalization in third octave band to a pink noise after one turn of rotating boom, but also one in narrowband. Effects on the airborne sound insulation itself, but also on repeatability and reproducibility will be presented for three different facilities. A numerical investigation will also be presented in order to compare tendencies with FEM/BEM approaches.

1 Introduction

Airborne sound insulation measurements in laboratory follow, most of the time, ISO 10140 series. Those standards describe a method using two reverberant rooms and were mostly developed more than forty years ago. This is the reason why hundreds of such acoustic laboratory, designed according to those standards exist in the world. Today the acoustic community agrees on the fact that reproducibility of the measurement method actually described in ISO 10140 series is not as good as expected regarding low frequencies, i.e. below the Schroeder frequency of these different facilities.

The aim of this paper is to investigate several ways to improve this measurement method (repeatability and reproducibility) assuming that the current overall design of the facilities cannot be changed (except at quite important expenses).

The main focus in this work concern several recommendations of ISO 10140-4 Annex A in order to improve low frequency measurement, more especially on the microphone positions, the number of loudspeaker positions, their synchronization or not and the equalization of each signal played in each loudspeaker.

The first part of this paper is dedicated to describe the different setups used for this study (excitation type, the sample tested and the three different investigated facilities). Note that all these facilities are located at CSTB LABE in France.

The second part will present a specific analysis performed in the emission room of MEGA test facility in order to evaluate the impact of the different types of excitation investigated. This analysis focuses on the emission sound field: incident on the sample and inside the measurement room volume.

The third part will be dedicated to the impact on the repeatability and the reproducibility of the different types of excitation.

A short forth part will investigate with a FEM code, the impact of the sample size on the airborne sound insulation.

2 Description of the different setup used

2.1 Short description of the three facilities

The different investigations have been performed in the three different acoustic facilities of CSTB where it is possible to handle airborne sound insulation measurement (MEGA, EPSILON and DELTA). All of them use parallelepiped box-shaped rooms where samples are set in "duct" conditions (in opposition to baffled or semi-baffled ones), except in the emission side for the top border (see Figure 2).

Table I. Basic description of CSTB facilities

	Emission room		Reception room		Tested surface (m²)
	Volume (m³)	Schroeder frequency	Volume (m³)	Schroeder frequency	
MEGA	83,2	266 Hz	64,2	282 Hz	10,8
EPSI	82,9	290 Hz	62,3	310 Hz	10,5
DELTA	80	267 Hz	70,5	277 Hz	15,1

2.2 Setup for the excitation (common to all)

One of the recommendation of ISO 10140-4 Annex A is to increase the number of source positions, up to four. So four positions of loudspeaker have been chosen according to the ISO 10140 method in each facility emission room. Each one has been played alone with a pink noise and then with an equalization of the signal to have a pink noise after averaging the acoustic pressure level during one rotating boom rotation (signal fed to the loudspeaker amplifier is equalized to have an averaged pressure level as flat as possible). This equalization has been done both in one third (1/3) octave band and in one twenty-seventh (1/27) octave band. The level of each independent sources is manage in order to have the same contribution, in each third octave band, to the sound pressure level averaged on a rotation of the microphone.

Then two sources have been played at the same time using uncorrelated signals and with the two types of equalization (1/3 and 1/27 octave band sources by sources). Finally the same process is repeated using four sources positions.

2.3 Description of the test sample ("common" to all)

The test sample is physically the same for the three facilities: a concrete slab of 200 mm in thickness. But, due to the facilities different opening sizes, the excitation area of the sample is not the same; Figure 1 gives an illustration of these different configurations. This sample has been chosen in order to have a high impedance in order to limit the coupling with the rooms modes. This choice has been done even though it is known that acoustic measurements on such heavy elements are usually less reproducible, especially concrete wall/floor (low internal loss factor, critical frequency below the Schroeder frequency…). In

DELTA test facility, the sample is horizontal however in the two other ones it is placed vertically.

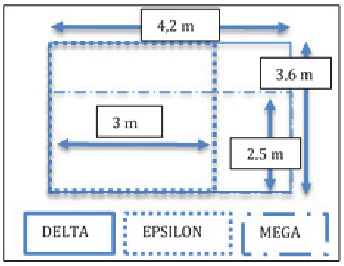


Figure 1: A single concrete plate for three facility opening.

2.4 Description of the measurement points in the emission room of MEGA test facility for sound field scanning.

The MEGA emission room sound field has been investigated in details both close to the tested concrete element surface and in the measurement volume. For this matter a line of nine ¼'' microphones (spaced 34 cm apart) has been used. On the tested concrete element surface, this line of microphones was moved eleven times at 5 cm away from the sample starting and ending at 15 cm of the vertical lateral room walls (corresponding to a total of 99 microphone positions). Regarding the "scanning" of the volume, the same line of microphones was used, but starting from 75 cm of the room walls. A grid of 7 x 11 positions of this line was selected, but some of those positions were not possible to implement due to the presence of the acoustic sources (592 over the 693 theoretical positions are used). All the microphone positions have been chosen in order to fulfill the minimum distance requirement of the ISO 10140 series to the walls, diffusers and sources.

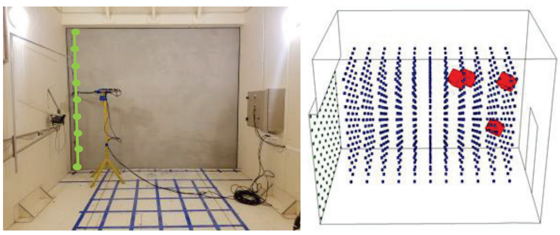


Figure 1: Photo and drawing of the measurements points in MEGA

3 Impact on the sound field of the different types of excitation

3.1 Sound field investigation on within the room volume

There were two main goals for this investigation.

The first one was to check if the traditional rotating boom averaging was enough to estimate the averaged pressure level in the room and to see if the type of excitation did change the averaged pressure level. Globally, as expected, the traditional averaging performs rather well above the Schroeder frequency and even below starting at 100 Hz. Below this frequency range, depending on the excitation type and the rotating boom position, some significant differences can be observed. One case is shown in Figure 3; the potential consequence is to have an incorrect estimation of the averaged pressure level at some 1/3 octave bands (here in the emission room but it also true in the reception room). In Figure 3, an improvement of the correlation between the sound pressure level (Lp) averaged over the volume and the rotating boom microphone positions, is observed when four sources are used instead of just two (amelioration of 0.5 dB to 1 dB in the low frequency range). A solution to overcome this limitation is to enlarge the diameter of the rotating boom and to set a higher slope in order to have a better coverage of the volume (see Figure 3 and 4.). In figure 3, the red curves show the improvement obtained with a more adapted position and size of rotating boom regarding the actual ones (blue curves). It is indeed one of the recommendations of ISO 10140-4 Annex A for low frequency measurements. This Annex gives also the recommendation to use microphone positions less close to the room walls, but regarding to Figure 3 and 12, it does not seem necessary.

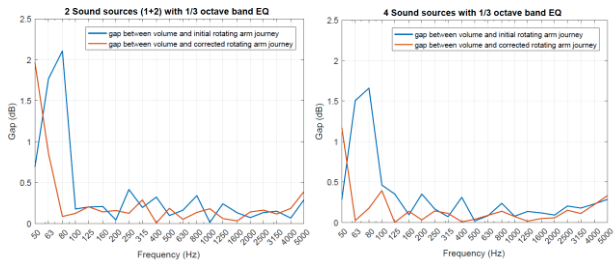


Figure 3: Difference between Lp averaged on the volume and Lp averaged on the rotating boom (For two type of excitation and two position of rotating boom.

The second goal of this scanning was to check the uniformity of the sound field within the room volume, assuming that the more uniform distribution, the better for good measurement. The standard deviation of the sound pressure level has been used as an indicator the acoustic field distribution. It can be seen in Figure 5 that the increase of the sources number decreases the standard deviation, however not drastically. The equalization of the sources in 1/27 octave bands instead of 1/3 octave ones does not either improve the situation noticeably.

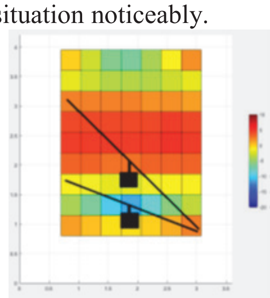


Figure 4: Illustration of the position of the rotating boom regarding the sound field in the volume at 80Hz (lower one is the existing one uper one is a more switable one)

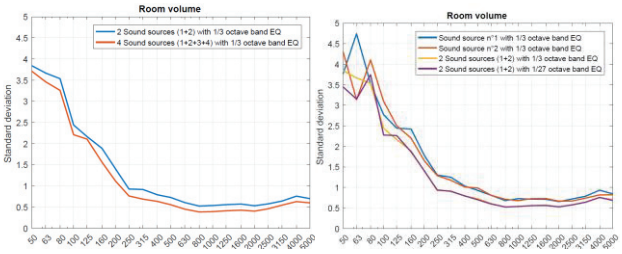


Figure 5: Standard déviation between Lp in the volume, for different type of excitation (both) and for different equalization (right - yellow and purple curves)

3.2 Sound field investigation on the tested surface

The standard deviation of the sound pressure level over the tested sample surface is slightly improved when new sources are added. This is illustrated by Figure 6 where it can be seen that, at low frequencies, one specific source (N°1) can have a lower standard deviation than the four sources at a specific 1/3 octave band. This is due to its specific position regarding the room modes in particular 1/3 octave band (here 50 and 63Hz). The equalization in 1/27 octave band does not really improve the situation.

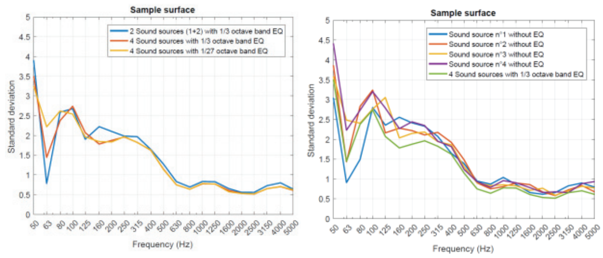


Figure 6: Standard deviation of the Lp at 5 cm of the test sample

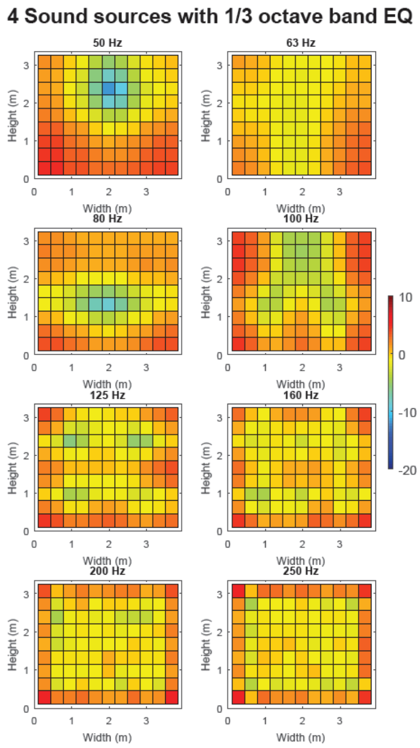


Figure 7 : Exemple of the parietal sound field scanning on the sample

In Figure 7 and Figure 12, different maps representing the sound pressure level distribution normalized to the average over the full surface (in Figure 7 & first colon of Figure 12) and over the full volume (Figure 12 except the first colon). Those pictures represent several maps of the sound field on a plane parallel to the tested concrete sample. It is shown that below the critical frequency (here 297 Hz) the homogeneity of the sound field is not perfect and the first modes of the room, up to 125Hz can clearly been seen. It is exactly what is seen in Figure 8. a very good correlation with the modes in the volume is obtained.

3.3 Conclusion on the sound field investigation

As it has been shown in this section, the impact of the different types of excitation investigated here is not revolutionary. There is an improvement of the quality of the correlation between the sound pressure levels averaged in the source room volume and on the rotating boom, when the number of source positions is increased. This also improves the homogeneity of the sound field. But anyway, the room modes at low frequencies are still very marked, even with equalization of the sources in 1/27 octave band. The use of several synchronized uncorrelated sources is an energetic averaging of single sources, so the results are not so surprising.

Further investigation could be done in order to, at least, reduce the influence of those modes. The use of correlated sources instead of uncorrelated ones and the choice of some specific source positions could be efficient. The first limit of this approach is to be out of the scope of the standard (it could take years to change it). Furthermore, it is also a huge initial work to find the good setup (loudspeaker position…) and it is certainly not sure that this setup will not be very sensitive to small change in the dimension of the room (due to the thickness and mounting position of the tested samples), or in the loudspeaker position, or diffusers one.

The main conclusions of this analysis should be similar for all "small" "reverberant" room.

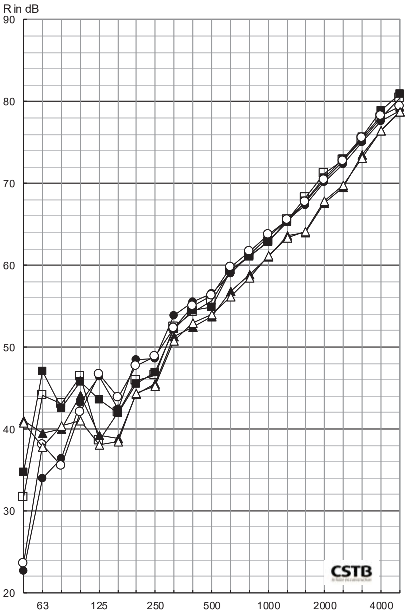
4 Impact on the Repeatability and Reproducibility of the different excitation types

In each of the three facilities, all the standard measurements were performed six times in order to calculate the reproducibility. Three types of excitation have been tested: two sources used sequentially one after the other (corresponding to the actual minimum requirement of the ISO standard), four sources uncorrelated, synchronized and equalized in 1/3 octave band to a pink noise, and the same with an equalization in 1/27 octave band.

4.1 Airborne sound performances

Several airborne sound insulation results are shown in Figure 8. The acoustic performance, especially at low frequencies is highly scattered between the different facilities and the different excitation types does not really reduce these differences. In order to analyze Figure 8, it is important to keep in mind several things. The first one is that DELTA tests are different for at least two major reasons: the concrete element tested is placed horizontally and its size is 50% larger than the other two. The second one is the sample itself, indeed the performance of a single concrete wall is not easy to reproduce (mounting conditions are very important and not easy to keep exactly similar from one mounting to another) and no test openings were similar.

	Test facility	Type of sources	R_w	$(C;C_{tr})$100-3150	$(C;C_{tr})$50-3150
■	MEGA	2 asynchronous sources with no egalisation	59	(-1;-5)	(-1;-7)
●	EPSILON		61	(-2;-6)	(-4;-15)
▲	DELTA		57	(-1;-5)	(-1;-6)
□	MEGA	4 synchronous sources with 1/3 octave bands egalisation	59	(-2;-6)	(-2;-8)
○	EPSILON		61	(-2;-6)	(-4;-14)
△	DELTA		57	(-2;-6)	(-2;-7)



	■	●	▲	□	○	△
f	R	R	R	R	R	R
50	34.7	22.7	41.0	31.7	23.6	40.8
63	47.0	34.0	39.5	44.1	38.1	37.8
80	42.5	36.4	40.0	43.1	35.5	40.4
100	45.8	43.2	44.1	46.4	42.0	41.0
125	43.6	46.4	39.2	38.6	46.7	38.1
160	41.9	42.4	38.9	42.1	43.9	38.4
200	45.5	48.5	44.2	45.9	47.7	44.4
250	46.9	48.6	45.5	46.6	48.9	45.3
315	52.2	53.8	51.3	52.4	52.3	50.8
400	54.5	55.5	52.5	54.2	55.0	53.0
500	54.9	56.6	53.7	55.7	56.3	54.0
630	59.4	59.0	56.8	59.4	59.8	56.2
800	61.0	61.3	58.9	61.2	61.7	58.5
1k	63.0	63.5	61.1	62.8	63.7	61.2
1,25k	65.3	65.6	63.6	65.5	65.5	63.4
1,6k	67.9	67.3	64.0	68.2	67.7	64.1
2k	70.7	70.1	67.6	71.2	70.4	67.8
2,5k	73.0	72.3	69.5	72.8	72.7	69.8
3,15k	75.7	75.0	73.5	75.3	75.5	73.1
4k	78.9	77.6	76.5	78.0	78.3	76.4
5k	80.9	78.9	78.7	80.4	79.4	78.7
Hz	dB	dB	dB	dB	dB	dB

Figure 8 : Airborne sound insulation in the thres facilities with two type of excitation

4.2 Impact on Repeatability

As expected the repeatability is very good, far better than the one from ISO 12999-1, an improvement in EPSILON test facility is observed when the number of sources is increased, but in DELTA, more or less the opposite can be noticed. In any case, it is not the main source of uncertainty as already known.

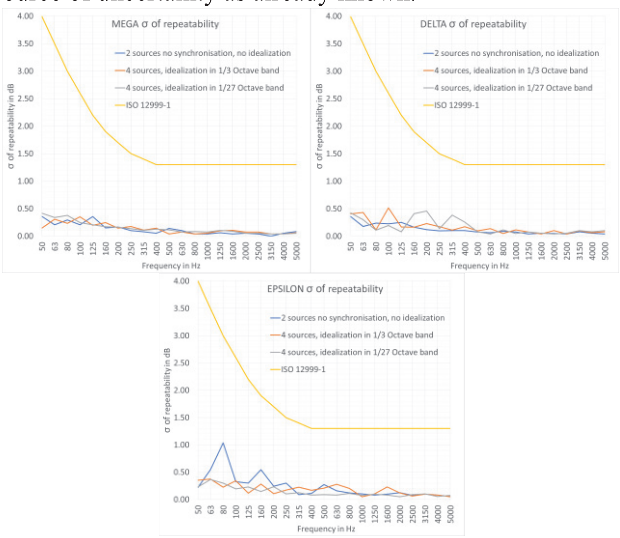


Figure 9 : Impact of the type of excitation on σ of repeatability in the three test facility Vs ISO 12999-1 one

4.3 Impact on Reproducibility

The overall reproducibility is not easy to establish with only three facilities in terms of statistic.

Anyway Figure 10 shows a bad level of reproducibility, especially around the Schroeder frequency of the different rooms (around 250Hz). The use of uncorrelated synchronized and equalized sources improves the reproducibility at 50 and 63 Hz but deteriorates it between 100 and 200 Hz. The question now is to try to identify real reproducibility trouble (on metrological point of view) due to the method itself and the part due to the differences between samples (size of excitation).

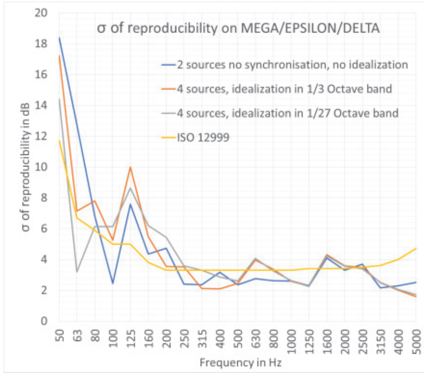


Figure 10 : σ of reproducibility on three facilities, for three excitation compare to ISO 12999-1 curve.

5 Numerical investigations

In order to have a first idea of the influence of the sample size on the airborne sound insulation with no consideration to the emission and reception sound field, a FEM calculation [2] has been performed. These simulations use a theoretical diffuse field (from 0 to 78° for angular angle) and clamped boundary conditions. Three sample size configurations were investigated according to Figure 1.

The Figure 11 represent the numerical reproducibility obtain (the absolute R value were not the main goal and we do not have time to manage them in order to have a perfect correlation with the measurement). It is even worth than what we found in measurement, but it is in line on the fact that the reproducibility start to be reasonably "good" after 250 Hz.

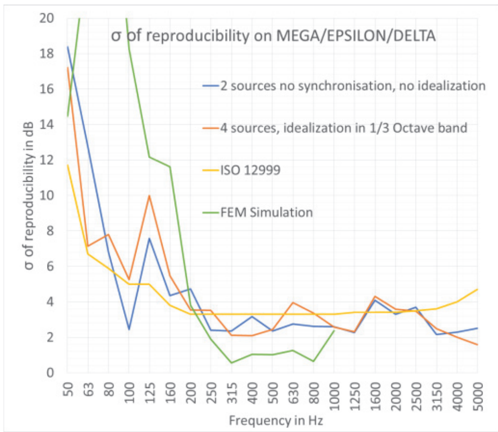


Figure 11 : σ of reproducibility on three facilities, comparison of measured and simulated one.

Further investigation could be done to handle exactly the same measurement in the three test facilities, but for a

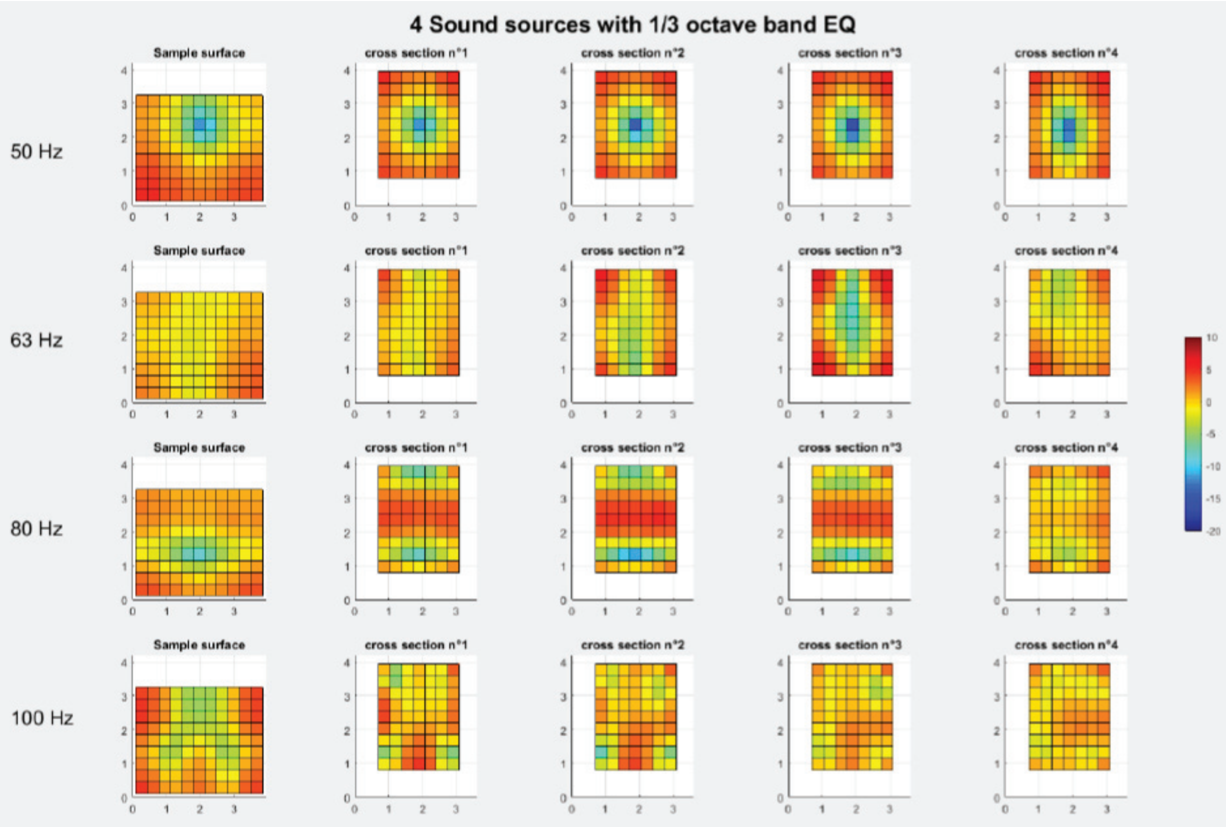


Figure 12 : Exemple of the sound field scanning in between 50Hz and 100Hz - 4 sources equalized in 1/3 octave band

small element (Ex: panel of 1.23 x 1.48 m²). Such type of measurement (semi-baffled with exactly the same sample in each facility) could give a better overview of the impact on reproducibility of the different types of excitation.

5 Conclusion

Many factors have been investigated during this study, in order to evaluate their effect on the repeatability and reproducibility. If, as expected repeatability is never a problem, it is not the same for reproducibility. The concrete wall of 200 mm in thickness tested in the three test facilities shows a very large spread of performances. Numerical investigation illustrates the influence of the test sample size. Further investigation on a test sample with the same size in the different facilities, will have to state if size is really the main factor regarding bad reproducibility.

If this was the case, a recommendation to the ISO technical comity, could be to fix a smaller sample dimension than the actual one “around” 10 m² (Ex: 8m²) but with strict length and width (Ex: 3.4 x 2.4 (h) m) to be compatible with the main actual acoustic facilities.

In those investigations, others improvement factors have been investigated and most of them are already in ISO 10140-4 Annex A. The increase of loudspeaker positions and the augmentation of the rotating boom diameter slightly improve the measurement quality and limit the risk of errors. On the opposite, the recommendation to increase the distance between microphone position and the walls of the room does not seems necessary. Finally, the use of synchronized uncorrelated sources with a specific equalized process has two main interests (before verifying its impact on small element measurement): to reduce measurement time by a factor larger than two, and at the same time to increase (slightly) the measurement quality.

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