Prediction method for the acoustic performance of permanent form systems

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Systems considered in this paper combine a layer of porous or fibrous material and a concrete floor slab. These systems are of several types: the concrete slab can be poured directly onto the fibrous layer (permanent form systems), or the fibrous material can be attached or sprayed on the underside of the concrete floor slab. Such systems allow the fulfilment of French thermal regulations. However, their acoustic performance is quite limited. Indeed, the acoustic performance of the concrete layer is usually reduced by the presence of the porous or fibrous layer. The modelling of such multi-layered structures submitted to acoustic excitation is discussed in this work. The behaviour of such a system is investigated by using a wave approach based prediction tool. The porous layer is modelled following Biot's theory. The effect of the metallic anchors that connect the fibrous layer and the concrete floor slab is also investigated. The acoustic performance of such systems is studied both experimentally and analytically. The model is thus used to obtain insight into the behaviour of such systems in order to develop solutions that result in improved acoustic performance.

1 Introduction

Systems considered in this paper combine a layer of porous or fibrous material and a concrete floor slab. Such systems are used for floor slab located between unheated space (a garage on ground floor for example) and a heated space situated above (a dwelling on the first floor for example). In the case of permanent form systems usually implemented in new buildings, the concrete slab is directly poured onto the fibrous layer. For existing building, similar systems exit: the fibrous material layer (mostly rock-wool) in the form of rigid boards can be stud driven in the underside of the concrete slab, or in the form of flocking it can also be sprayed on the underside of the concrete slab. Metallic anchors between the fibrous layer and the concrete slab can also be implemented for fire safety reason. This type of systems allows the fulfilment of French thermal regulation. However, their acoustic performance with respect to airborne noise is quite limited. Indeed, the acoustic performance of the concrete layer is usually reduced by the presence of the porous or fibrous layer. However, it should be noted that this fibrous layer allows decreasing the reverberation time in the unheated space in where they are installed (parkings for example) since their absorption coefficient is usually quite important. The modelling of such multi-layered structures submitted to acoustic excitation is discussed in this work. The behaviour of such a system is investigated by using a wave approach based prediction tool. The porous layer is modelled following Biot's theory. The effect of the metallic anchors that connect the fibrous layer and the concrete floor slab is also investigated. The acoustic performance of such systems is studied both experimentally and analytically. The model is thus used to obtain insight into the behaviour of such systems in order to develop solutions that result in improved acoustic performance.

2 Model description

A model for infinite multilayered structures is used, based on a transfer matrix approach [1]. The different infinite isotropic layers of constant thickness can be either solid, fluid or porous (following Biot's theory [2]) elements. A computer program (CASC software), based on this approach, has been developed at CSTB and used to predict sound transmission, sound absorption, impact noise and rainfall noise of building elements. This paper is only concerned with sound transmission; the system is excited by a diffuse acoustic field composed of multiple acoustic plane waves incoming in different directions.

A technique based on a spatial windowing of plane waves presented in [3] is used in order to take into account the finite size of a planar structure in sound radiation and sound transmission calculation. This technique leads to prediction results much closer to experimental measurements than the classical wave approach applied to infinite structure. It is a very simple method in the case of sound transmission since the associated radiation efficiency depends only on the spatial window considered (i.e. the size of the structure) and can therefore be pre-calculated.

3 Acoustic performance

In this section, the acoustic performance obtained from the prediction model and measurements is presented for different systems. The effect of the number of metallic anchors is investigated. A schematic of the system investigated is proposed in Fig.1. The fibrous layer is mostly heavy rock-wool (density above 100 kg/m^3). The different systems considered have a size of 4.2x3.6 m^2; this size is taken into account in the prediction model.

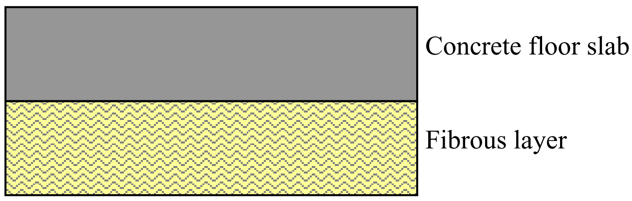

Fig.1 Schematic of investigated systems.

3.1 Permanent form system

The first system considered is composed a concrete floor slab 160 mm in thickness poured on a rock-wool layer 100 mm in thickness. The rock-wool layer has a density around 110 kg/m^3. In this case, there is full contact between the rock-wool layer and the concrete slab.

Fig.2 presents the predicted and the measured sound transmission index of this system as well as the acoustic performance ΔR with respect to the bare floor slab. It can be seen that over the frequency range investigated (except for the 100 Hz octave band), the predicted sound transmission indexes are quite close to the measured ones. Especially, the different frequency ranges where the sound transmission index exhibits a minimum (i.e. around 200-

315 Hz and 800 Hz) obtained by the prediction model are in good agreement with those observed in the measurements.

Since the rock-wool layer is in full contact with the concrete floor slab, the wave propagation in the fibrous layer is mostly in the form of a compressional wave propagating in the porous material frame; this wave is often referred to the frame-borne compressional wave. The decrease clearly observed in acoustic performance ΔR around the third octave bands 250-315 Hz and 800 Hz is associated to this frame-borne compressional wave resonance in the fibrous layer ; the first resonance occurring when the fibrous layer thickness is equal to half the frame-borne compressional wavelength and the second resonance when this thickness corresponds to this compressional wavelength.

The corresponding global acoustic indexes are shown in Table 1. Therefore, it can be deduced that the presence of the rock-wool layer decreases the performance of the 160 mm thick floor slab with respect to airborne noise by about 5 dB (6 dB predicted by the model). This is mainly due to the important decrease in the sound transmission performance between the third octave bands 200 and 315 Hz.

(a)

(b)

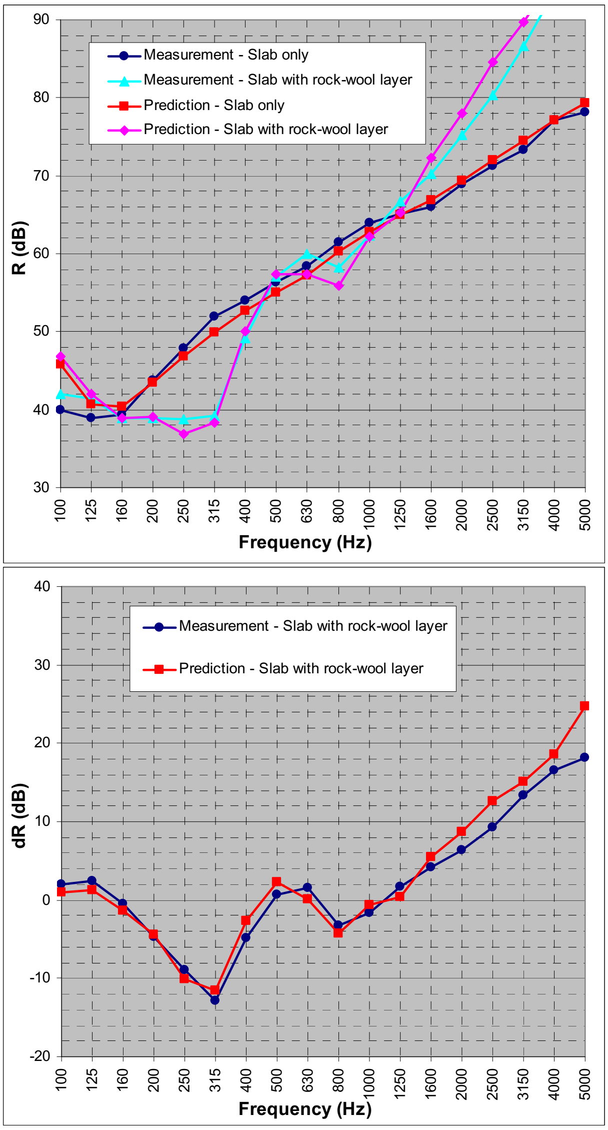

Fig.2 Permanent floor system; (a) sound transmission index R and (b) acoustic performance ΔR.

Thus, in order to reduce the decrease in the sound transmission index associated to the frame-borne compressional wave resonance in the fibrous layer, the full contact between the fibrous layer and the concrete floor slab should be avoided. By avoiding or rather limiting this full contact, the excitation of the frame-borne compressional wave will be reduced, resulting in an improvement of the sound transmission index in the frequency range where this compressional propagation wave is of importance.

System			
Rw dB	C dB	Rw+C dB	Δ(Rw+C) dB
Measurement – Slab only			
59	-2	57	–
Prediction – Slab only			
58	-1	57	–
Measurement – Slab with rock-wool layer			
54	-2	52	-5
Prediction – Slab with rock-wool layer			
54	-3	51	-6

Table 1 Global acoustic index for permanent form system.

3.2 Metallic anchors and thickness effect

The second system considered is composed of a concrete floor slab 220 mm in thickness and a rock-wool layer 100 mm in thickness. The rock-wool layer has a density around 150 kg/m^3. In this case, the rock-wool boards (around 1.1 m^2 in size) are mounted on the underside of the floor slab with metallic anchors (i.e. by stud shooting) and the number of these anchors per board is varied. Since the concrete slab is not poured on the rock-wool layer, it is believed that the boundary condition between these two components is not a full contact. However, the number of metallic anchors is expected to modify this boundary condition: an increasing number of anchors will be associated to an increase in contact between the slab and the fibrous layer. The prediction model considered two different cases: either the rock-wool layer is in full contact with the floor slab or there is no contact at all. These two different boundary conditions do not quite correspond to the one found on the experimental system; but they represent the extreme borders of the possible actual condition.

Fig.3 presents the effect of the metallic anchors number on the measured sound transmission index of this system as well as the acoustic performance ΔR with respect to the bare floor slab. First, it can be observed that a decrease in metallic anchors number is associated to an improvement of the measured acoustic performance. The measured performance around the frequency range of the resonance associated to frame-borne compressional wave is modified by the metallic anchors: the least number of anchors per board the better. The measured performance is bordered by the predictions considering the two different boundary conditions. The predicted performance considering no contact between the floor slab and the rock-wool layer does not present as expected the resonance effect associated to frame-borne compressional wave; this effect is however very well marked on the acoustic performance when there is full contact between these two components (around third octave band 200 Hz in this case).

The corresponding acoustic performance global index is shown in Table 2. The implementation of the rock-wool board with 5 anchors par board allows a 1 dB increase of the performance of the 220 mm thick floor slab with respect to airborne noise. The results demonstrate the importance of the contact between the concrete slab and the rock-wool layer: these two components should be as much decoupled as possible.

(a)

(b)

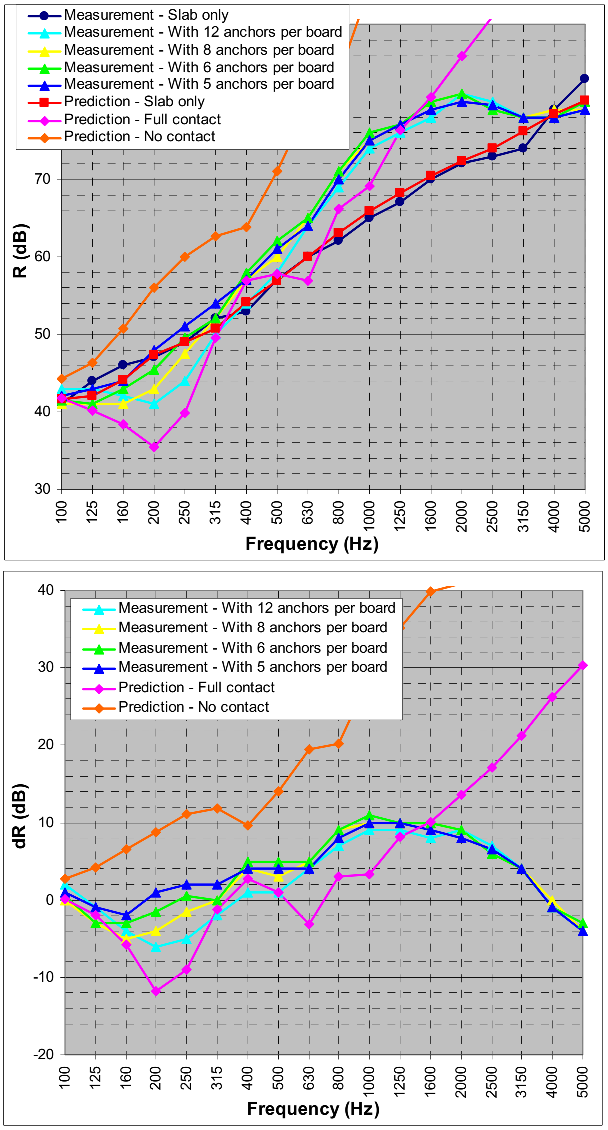

Fig.3 Metallic anchor effect; (a) sound transmission index R and (b) acoustic performance ΔR.

System	Δ(Rw+C) dB
Measurement – 12 anchors per board	-2
Measurement – 8 anchors per board	-1
Measurement – 6 anchors per board	0
Measurement – 5 anchors per board	2
Prediction – Full contact	-6
Prediction – No contact	8

Table 2 Metallic anchor effect on global acoustic index.

The effect of the rock-wool layer thickness is investigated next. A number of 5 anchors per board was used in the experimental evaluation. The measured acoustic performance ΔR with respect to the bare floor slab is shown in Fig.4 for three different rock-wool layer thicknesses: 100, 60 and 40 mm. The predicted performance considering the two different boundary conditions discussed above (full contact and no contact) is also presented in Fig.4. When the rock-wool layer is 40 mm thick, the measured performance corresponds to the predicted one when considering full contact between the concrete slab and the fibrous layer. The effect of the frame-borne compressional wave resonance in the fibrous layer is clearly observed around the third octave bands 500 Hz and 1600 Hz. When the fibrous layer thickness is increased, the model predicts a decrease of the frame-borne compressional wave resonance frequency. On both the measurement and the prediction, the resonance frequency is moved from 500 to 315 Hz when the thickness is increased from 40 to 60 mm. For the 100 mm thick fibrous layer, the behaviour associated to this resonance is not clearly observed on the measurement results. The acoustic performance obtained from the measurements decreases as the fibrous layer thickness decreases, as seen in Table 3.

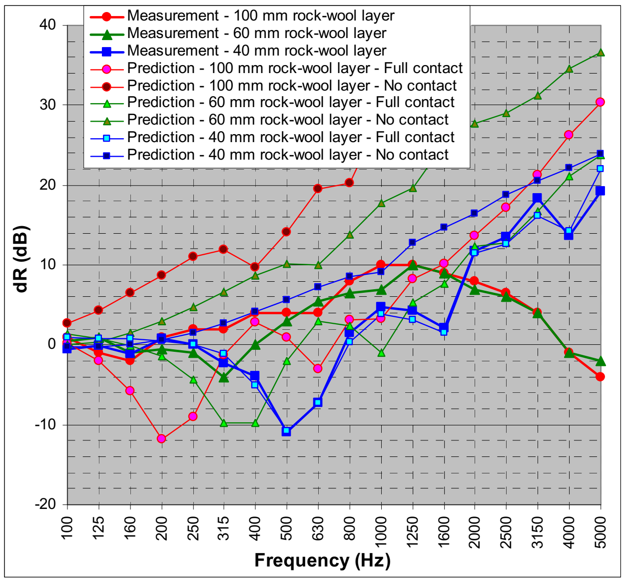

Fig.4 Rock-wool layer thickness effect on the acoustic performance ΔR.

System	Δ(Rw+C) dB
Measurement – 100 mm rock-wool layer	2
Measurement – 60 mm rock-wool layer	0
Measurement – 40 mm rock-wool layer	-4
Prediction – 100 mm rock-wool layer	-6 / 8
Prediction – 60 mm rock-wool layer	-5 / 3
Prediction – 40 mm rock-wool layer	-4 / 2

Table 3 Rock-wool layer thickness effect on global acoustic index.

3.3 Sprayed flocking system

The second type of systems considered is concerned with sprayed flocking system: the rock-wool flocking is sprayed on the underside of a concrete floor slab. This type of system is mostly used to add thermal insulation on an existing building between unheated space (parking) and heated space (dwelling).

The studied system is then composed of a concrete floor slab 220 mm in thickness with a sprayed rock-wool flocking 100 mm in thickness. The rock-wool flocking has a density around 170 kg/m^3. In this case also, there is full contact between the rock-wool flocking and the concrete slab.

Fig.5 presents the predicted and the measured sound transmission index of this system as well as the acoustic performance ΔR with respect to the bare floor slab. It can be seen that over the frequency range investigated, the predicted sound transmission indexes are again quite close to the measured ones. Again, the different frequency ranges where the sound transmission index exhibits a minimum (i.e. around 400 Hz and 1250 Hz) are well observed in both the prediction and the measurements. The frequencies at which the acoustic performance ΔR presents a minimum are higher than those observed for the permanent form system in Section 3.1. This is due to the fact that the rock-wool flocking is stiffer than the permanent form rock-wool layer (both having the same 100 mm thickness).

The reason for this behaviour around the third octave bands 400 Hz and 1250 Hz is the same as the one discussed in Section 3.1. At these frequencies, a resonance of frame-borne compressional wave in the rock-wool flocking layer occurs. Since the rock-wool flocking layer is in full contact with the concrete floor slab, this frame-borne compressional wave in the fibrous layer is well excited and dominant in the vibrational response.

The corresponding global acoustic indexes are shown in Table 4. It can be deduced that the presence of the rock-wool flocking decreases the performance of the 220 mm thick floor slab with respect to airborne noise by about 4 dB (5 dB predicted by the model).

Thus, for the sprayed flocking system, a way to avoid or limit the full contact with the floor slab in order to reduce the decrease in the sound transmission index associated to the frame-borne compressional wave resonance has to be introduced. It could be achieved by introducing an intermediate layer between the sprayed flocking layer and the floor slab. A system including a metallic lattice is investigated next.

A metallic lattice is riveted (7-8 rivets per m^2) on the underside of a concrete floor slab 160 mm in thickness; the rock-wool flocking 60 mm in thickness is then sprayed on it. The rock-wool flocking has a density around 200 kg/m^3. Fig.6 presents the predicted and the measured sound transmission index of this system as well as the acoustic performance ΔR with respect to the bare floor slab. The prediction model considered two different cases: either the sprayed flocking layer is in full contact with the floor slab or there is no contact at all. As mentioned before, these two different boundary conditions do not quite correspond to the one found on the experimental system; but they represent the extreme borders of the possible actual condition. First, it can be observed that the implementation of the metallic lattice provides an improvement of the measured acoustic performance. The resonance associated to frame-borne compressional wave does not appear on the measured performance: the metallic lattice is therefore able to decouple the floor slab and the sprayed flocking layer. Indeed, it can be observed that the measured performance is bordered by the predictions considering the different boundary conditions. The predicted performance considering no contact between the floor slab and the sprayed flocking layer does not present as expected the resonance effect associated to frame-borne compressional wave; this effect is however very well marked on the acoustic performance when there is full contact between the two components (around third octave band 630 Hz in this case).

The corresponding global acoustic indexes are shown in Table 5. Therefore, the presence of the metallic lattice between the floor slab and the rock-wool flocking allows an improvement of the acoustic performance. This improved flocking system increases the performance of the 160 mm thick floor slab with respect to airborne noise by about 2 dB.

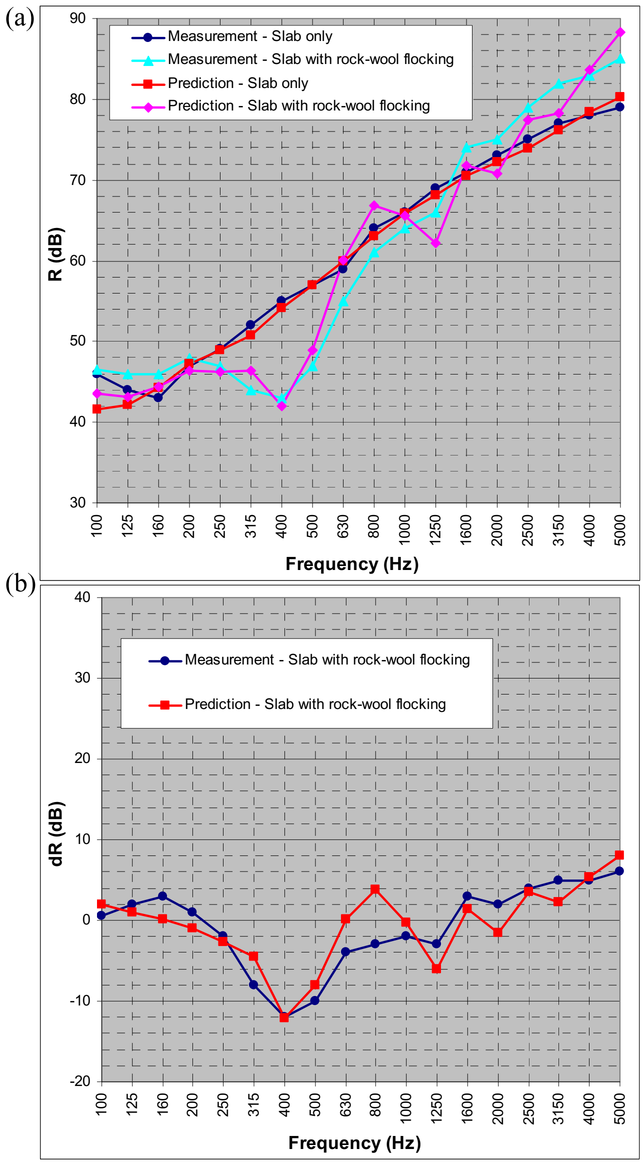

Fig.5 Sprayed flocking system; (a) sound transmission index R and (b) acoustic performance ΔR.

System			
Rw dB	C dB	Rw+C dB	Δ(Rw+C) dB
Measurement – Slab only			
61	-2	59	–
Prediction – Slab only			
60	-1	59	–
Measurement – Slab with sprayed flocking			
55	-1	54	-5
Prediction – Slab with sprayed flocking			
56	-2	54	-5

Table 4 Global acoustic index for sprayed flocking system.

(a)

(b)

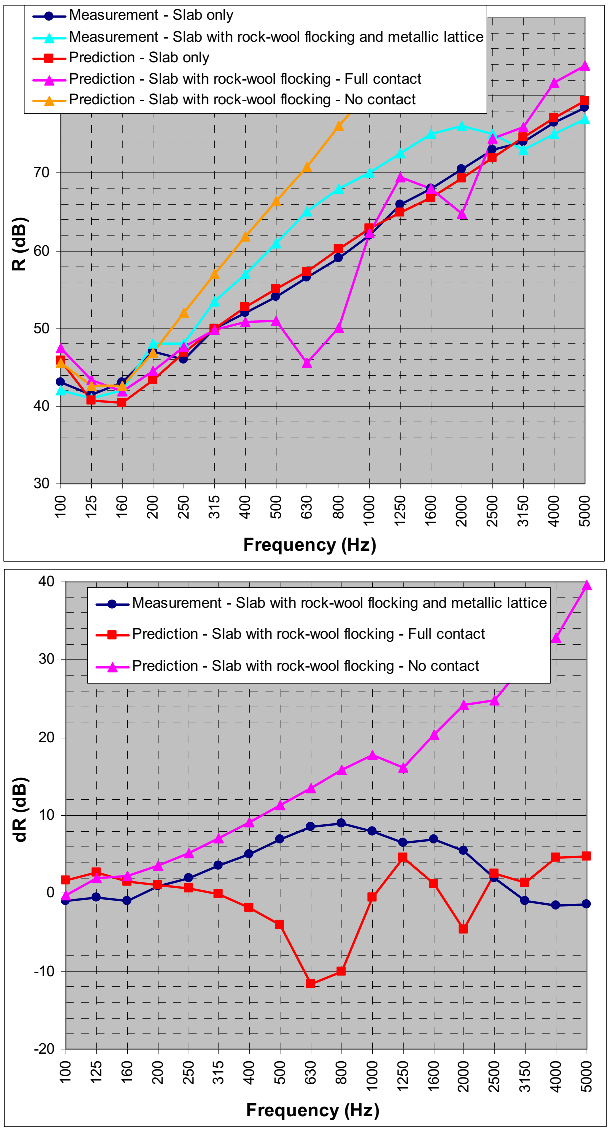

Fig.6 Sprayed flocking system with improved mounting; (a) sound transmission index R and (b) acoustic performance ΔR.

4 Conclusion

Systems combining a layer of fibrous layer and a concrete floor slab have been considered in this paper. Such systems are used for floor slab located between unheated space (a garage on ground floor for example) and a heated space situated above (a dwelling on the first floor for example).

The frame-borne compressional wave propagating in the fibrous layer was found to be responsible for the decrease in acoustic performance with respect to airborne noise when the fibrous layer is in full contact with the concrete floor slab. When the fibrous layer is decoupled from the concrete floor slab, the acoustic performance is, as expected, increased. For the sprayed flocking system, a metallic lattice can be introduced as a decoupling element between the concrete slab and the fibrous layer. For the permanent form system, the decoupling is more difficult since the concrete is directly poured on the fibrous layer; however, some kind of corrugated film could be implemented to introduce partial decoupling. The effect of metallic anchors used to fix the fibrous boards onto the underside of a concrete slab was also investigated. The least number of metallic anchors per fibrous board the better for the acoustic performance. The studied case also demonstrated that a thicker fibrous material layer provides a better acoustic performance.

System			
Rw dB	C dB	Rw+C dB	Δ(Rw+C) dB
Measurement – Slab only			
58	-1	57	–
Prediction – Slab only			
58	-1	57	–
Measurement – Slab with sprayed flocking on lattice			
61	-2	59	2
Prediction – Slab with sprayed flocking – Full contact			
55	-2	53	-4
Prediction – Slab with sprayed flocking – No contact			
64	-3	61	4

Table 5 Global acoustic index for sprayed flocking system with improved mounting.

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