Noise propagation through wooden posts

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Abstract
The problem of vibration transmission by wooden posts in two superimposed rooms is here considered. As all surfaces (walls and floor) are covered with sound insulating lining, we want to predict the transmission of vibrations and noise through the visible wood posts. Two practical situations are considered with several posts conveying vibrations. A hybrid method has been used. The modal behaviour of the source volume is used to compute the incident acoustic pressure on all surfaces and used as an input to a FEM model of both posts and floor. The radiated acoustic pressure is computed by means of an integral representation which combines the uncoupled velocity of all radiating surfaces in the receiving volume and the modal response of this volume. Transmission by posts has been assessed and compared to the transmission by the floor. It is showed that when the floor between the two rooms is acoustically treated and performant, the transmission by the posts may become significant.

Keywords: wooden buildings, posts, hybrid approach, finite elements

1. Introduction

Wooden frame buildings are often designed with a wish to maintain some wooden parts, such as posts, visible. These posts can either be situated along the walls (with 1, 2 or 3 sides visible) or in the middle of rooms with the 4 sides visible.
With regard to sound insulation between two superposed rooms, these bare posts will raise several questions: i) what is the contribution of any given post to the overall sound insulation, ii) how many posts can be left untreated without significant reduction of the sound insulation?
For safety reasons against fire, posts must have a cross-section of at least 30 cm x 30 cm and may be as thick as 60 cm x 60 cm. These two dimensions will be considered. Also, the connection between the posts and the floor can be a full connection or decoupled.
To assess the noise radiated by wooden posts we propose to extend an existing approach, published under the name GRIM [1,2,3]. It is a decoupled approach based on an extension of the Raileigh integral.

2. The model

We adapt a hybrid approach developed in 2006 in the case of complex floors. Rather than modelling the full coupled problem (source volume, structure, receiver volume) we use a sequential approach:

1) Computation of the pressure field in the volume containing the acoustic source. This field is computed using a modal approach considering a rectangular volume, therefore neglecting the effect of the posts. The incident pressure on any surface is then retained (floor, posts,..). Note that any other acoustic model can be employed, such as beam tracing.
2) Computation of the structural response of the complete structure: floor + posts, or only posts, when excited by the incident pressure field. A 3D FEM software is here employed, but any model can be employed such as analytical models.
3) Based on the known surface velocities (surfaces in the receiving volume), the sound pressure field is computed using the GRIM approach.

The GRIM approach is an integral approach which generalizes the Rayleigh integral. Full developments can be found in [1,2,3].
We consider a rectangular volume *V* with one vibrating boundary *Sv* and 5 acoustic surfaces of known absorption. We define $G_V(M,Q)$ as being the pressure at *M* due to a unit source at *Q* placed in *V'* which is the same volume as *V* but with a rigid *Sv* surface. G_V is then a particular Green function. We note *v* the normal velocity on *Sv*. The use of G_V in a classical boundary representation in *V* will give the expression of the acoustic pressure P as

$$P(M) = -j\omega\rho \int_{S_v} v(Q) G_V(M,Q) dS(Q) \qquad (1)$$

This expression is an extension of the Rayleigh integral with a more complex Green function.
G_V is here computed using a simple modal computation, based on cosine modes. Any other acoustic model can be employed. The above expression is a fully coupled integral since *P* and *V* are related (full coupling).
The weak coupling here employed assumes that once G_V and *V* are known *P* is simply obtained by carrying the integration of the $G_V.V$ product over *Sv*.
We here generalize this integral to the case of a floor with one or several posts in both volumes. S_v is therefore the sum of the contributions of ceiling and/or posts' bare sides radiating in the receiving volume.

In practice, the sound pressure *P* is computed at 30 random positions and averaged (rms). The radiated power (total or for any group of surfaces) is computed as

$$Wr = \langle P^2 \rangle .A/4\,\rho\, c \qquad (2)$$

where $\langle P^2 \rangle$ is the mean square pressure value and *A* is the total absorption area. From the knowledge of both incident and radiated powers on/from a post, one can compute the sound reduction index

$$R=10.\log(Wi/Wr) \qquad Wi = P^2.S/4\rho c \qquad (3)$$

S is the total excited surface. *S* may be just the floor, the floor and posts, just the posts or any given post since the insulated floor or posts are not included in *S*.

The approach here employed assumes weak coupling between both acoustical volumes and the structure (floor and posts). This means, on the source side, that the radiation of the structure does not modify the acoustic response of the volume; on the receiver side, the acoustic pressure in the volume is similarly assumed to have no significant effect on the velocity field on the structure. This assumption is fully valid [1,2,3] for large volumes (it would not be true, for instance, for the volume withing a double glazing).
This approach greatly reduces computation times and will allow computations to be carried up to the one-third octave band 2000 Hz. One computation takes about 1 hour.

This method is synthesized in Figure 1.

On the left: a decoupled structural computation (decoupled from the volumes) with 3D finite elements (step 2). On the right: modal acoustic computation in the volumes: to compute the rms pressure and the incident pressure on S in the source volume (step 1) and to compute the radiated noise.

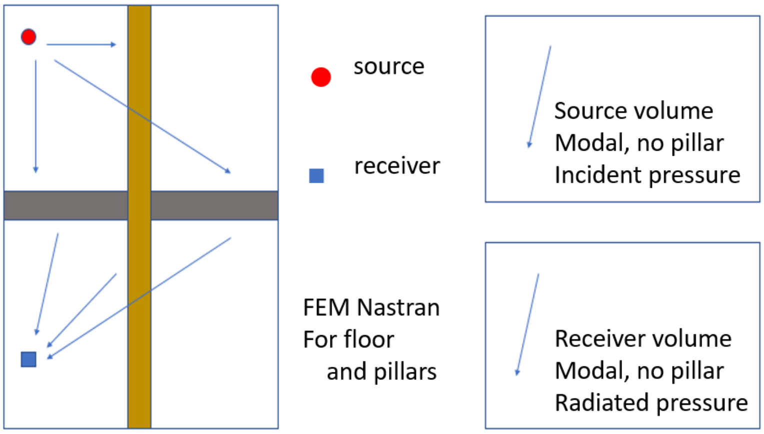

Figure 1 – General diagram of the decoupled process

3. Numerical application

3.1 Cases considered

We consider two superimposed rooms with wooden posts at different positions. The two cases differ by the size of the rooms and the numbers of posts.
Case 1 considers two volumes of dimensions 3x3x2.5m^3 with three posts along the facades (with one in a corner); this size of rooms could represent bedrooms. In case 2 (larger volumes more adapted o represent living rooms) the dimensions are 5x4x2.5 m^3 with six posts: four along the facades, one in a corner and one central post. The reverberation time in all rooms is taken as 0.5 sec.
Central, façade and corner posts have respectively 4,3 and 2 excited (source side)/ radiating (receiver side) surfaces. In each case, the posts are either 30 cm x 30 cm or 60 cm x 60 cm and the posts are either fully connected (continuity of displacement) or disconnected (a small 1 mm gap around the posts) from the floor. The case of an untreated 16 cm wooden CLT floor is also computed.

A point source is placed close to a post, 1 m above the floor. Figure 2 shows a horizontal view of both cases (rotated sketch). Each square corresponds to a post (2 sizes). The * marks correspond to boundary conditions: the posts are clamped at both extremities; the floor is simply supported along its periphery. Note that the posts are only partly inside the volumes.

For these two cases, the standardized sound level difference (D_{nT}) can be deduced from the presented sound reduction by deducing 1 dB assuming negligeable the other flanking transmission paths; a similar adjustment can be applied for the associated sound insulation ($D_{nT,w}$+C= $D_{nT,A}$) from the weighted sound reduction index R_w+C= R_A.

The French regulation regarding sound insulation between dwellings requires to achieve the performance of $D_{nT,A}$ = 53 dB. To reach this performance level, it is usually considered that the separating element should have a performance of around R_A = 59 dB.

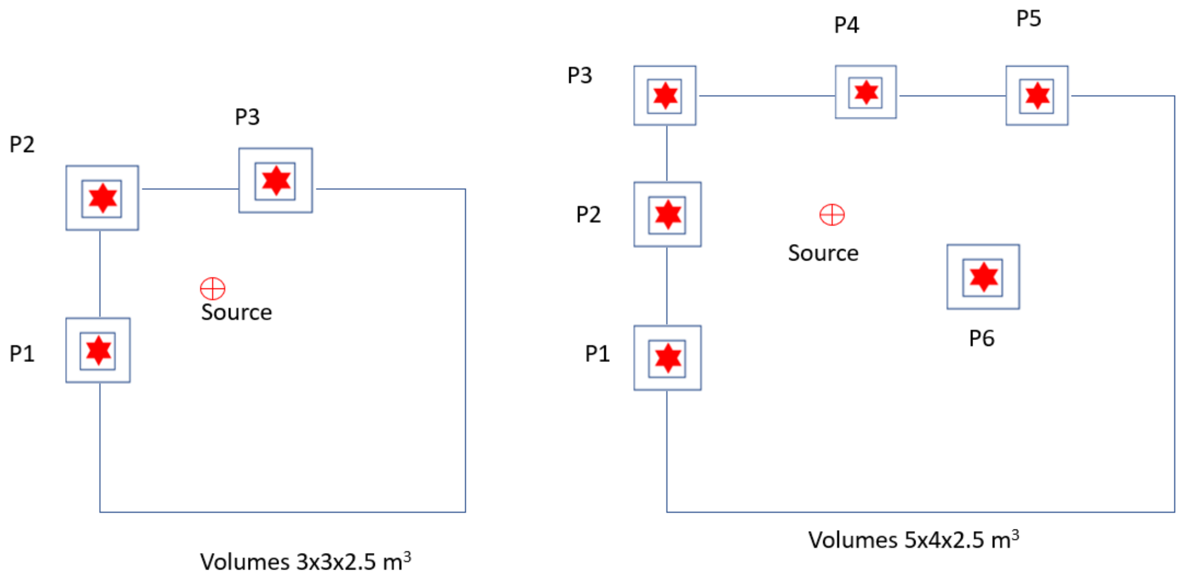

Figure 2 – Two configurations: living rooms (5x4 m^2) and bedrooms (3x3 m^2)

Figure 3 gives a 3D overview (rotated view) of the problem in the case of the large volumes and 30 cm x 30 cm posts. This snapshot results from a calculation at 500 Hz. The top volume (on the left) contains the source, and the sound pressure levels are displayed on all surfaces. The right volume is the receiver side and the velocity levels on all surfaces are displayed. The full volumes and full posts are displayed as thin lines. In this Figure to a simple 16 cm wooden CLT floor (no insulation) is considered.

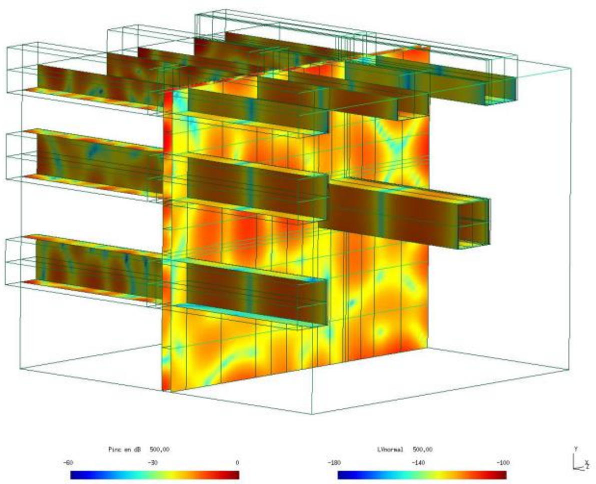

Figure 3 – Global view in the case of large volumes (living rooms) at 500 Hz. Source volume (left): incident pressure. Receiver volume (right): normal velocity.

3.2 Small volumes

Figures 4a et 4b show at 500 Hz and for the case of a simple 16-cm thick untreated wooden floor, a combined view of the incident acoustic pressure level (left side with a dynamic range of 60 dB) and on the right side the normal velocity level on all vibrating surfaces (dynamic range of 180 dB).

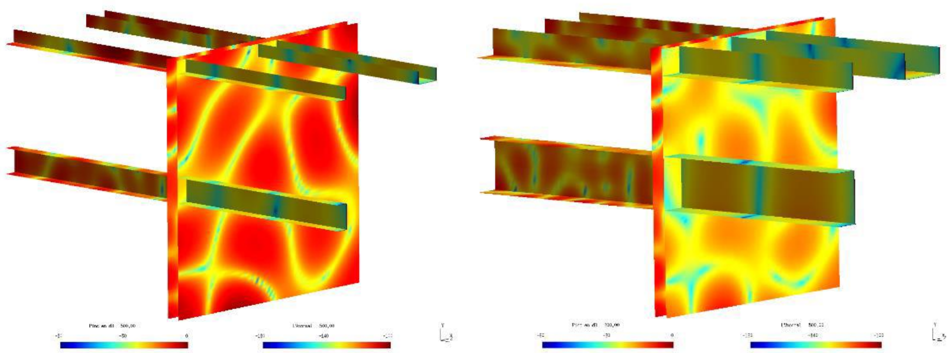

Figure 4 – Bedrooms: incident pressure (dynamic range 60 dB) and normal velocity (dynamic range 180 dB) (resp. source and receiver volumes). Left) 30 cm square posts, right) 60 cm square post. 500 Hz.

Figure 5 shows the sound reduction index (R) of these two cases together with a measured R for an efficiently treated floor as measured in CSTB's laboratory. This floor has an overall thickness of 33 cm and is composed of a CLT floor with a floating floor and a suspended fireproof ceiling.

Figure 5 shows four cases: two post cross-sections and either connected or disconnected posts. Each graph compares R for i) the 33 cm measured floor (*), the 16 cm bare floor used in the full computations (figure 4) (posts insulated) (o) and iii) (□) the case of the insulated floor with 3 posts excited and radiating (the floor is assumed not to radiate). The sound transmitted by the 30 cm posts is higher (lower R) than the transmission by a treated floor. The 60 cm posts transmit less than the insulated floor below 630 Hz and becomes comparable at higher frequencies.

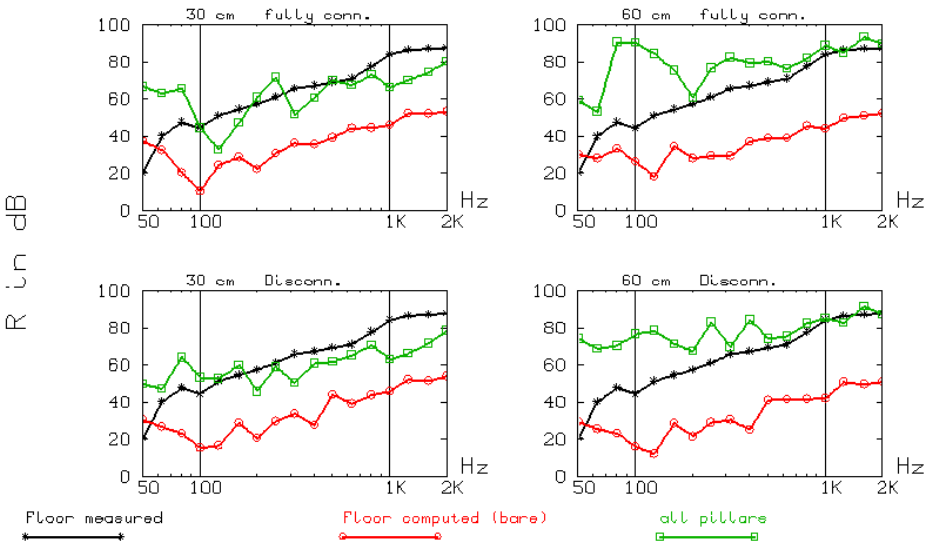

Figure 5 - Transmission Loss R in dB for the small volumes. Two post sizes, two types of floor/posts contact.

Figure 6 shows separate spectra of R for each post assuming that the other posts are insulated. Note that results for posts 1 and 3 are identical since the problem is fully symmetric (see Figure 2). For the narrower posts, the corner post (number 2) has the highest transmission loss below 400 Hz.

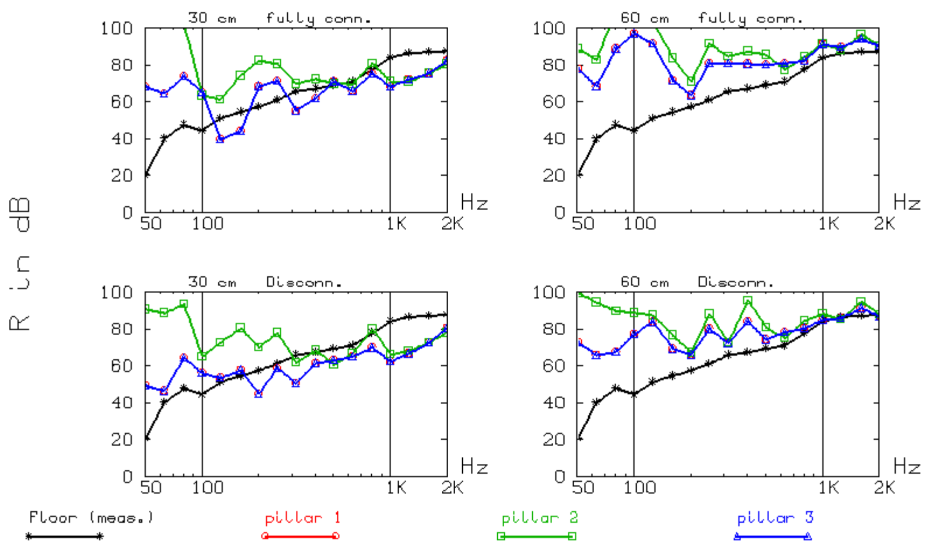

Figure 6 – Small volumes: contribution of the 3 posts (see Figure 2).

Table 1 gives the values of the global index R_A for the different cases as well as R_A for the floor insulated on both sides. No significant difference can be seen between connected and disconnected posts. The 30 cm posts show a lower R_A than the insulated floor (56 compared to 69) and should be treated if one does not want a significant degradation of the floor's performance by adding posts. For the 60 cm posts this is not necessary (76 higher than 69). The R_A index of the insulated floor is 69 dB and if we aim at 59 dB in all calculations for posts (grouped or separated) this is achieved only for the 60-cm posts.

In this case, connecting the posts to the floor (as would be expected in a real building) is associated to an improvement of the performance; the improvement being higher for the corner post (6-7 dB instead of 2-3 dB). When all posts are considered the effect of the connection between posts and floor almost disappears (only 1 dB difference).

Table 1 – R_A in dB for the different cases (small volumes).
4 cases: 2 post sizes (30 or 60 cm), 2 types of contact posts/floor.

	Post 1	Post 2	Post 3	All Posts
30/conn.	64	73	64	56
30/disc.	62	67	62	57
60/conn.	83	85	83	77
60/disc.	80	82	80	76
33 cm Floor	69			

3.3 Large volumes

Figures 7a et 7b show at 500 Hz and for the case of a simple 16-cm untreated wooden floor, a combined view of the incident acoustic pressure level (left side with a dynamic range of 60 dB) and on the right side the normal velocity level on all vibrating surfaces (dynamic range of 180 dB).

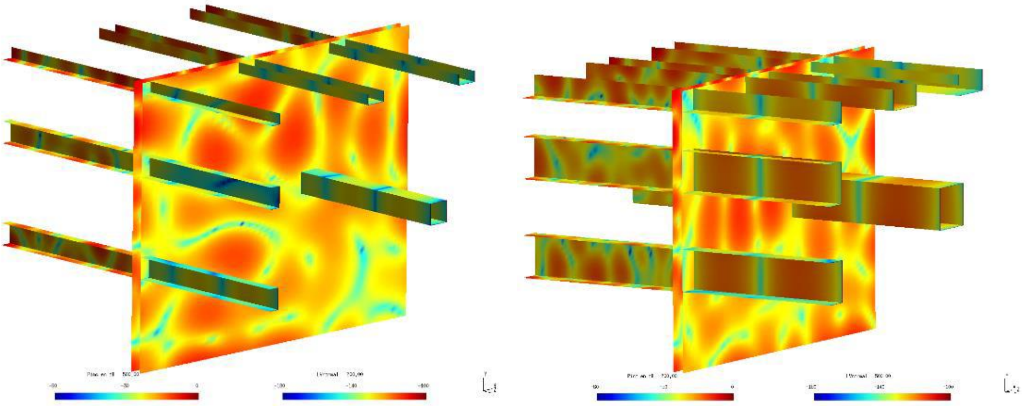

Figure 7 – Living rooms: incident pressure (dynamic range 60 dB) and normal velocity (dynamic range 180 dB) (resp. source and receiver volumes). Left) 30 cm square posts, right) 60 cm square post. 500 Hz.

Figure 8 shows the R spectra: measured for a 33 cm insulated floor without posts (*), for the simple 16 cm bare floor (posts insulated) (o), and for the 6 bare posts assuming no transmission by the floor. In this second case (larger volume and 6 posts instead of 3) Figure 8 shows for the 4 configurations lower values of R for the posts compared to the floor indicating the need to insulate the posts especially for the 30 cm posts if one does not want to degrade the efficiency of the floor.

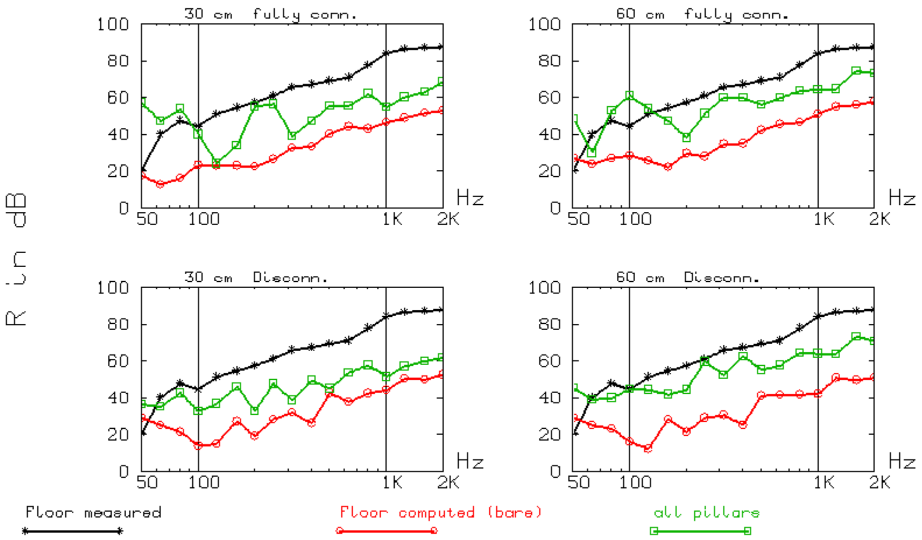

Figure 8 – Transmission Loss R in dB for the large volumes. Two post sizes, two types of floor/posts contact.

Figure 9 shows the contribution of the 6 posts. For each computation, all posts are insulated except the post considered. For the smaller posts, the transmission loss is mostly similar for all posts above 500 Hz. The influence of the posts' position is therefore not significative. The result for post 6, inside the room, is not different from the results for the other 5 posts on the facades. Post 3 (the corner post), again, shows the highest transmission loss.

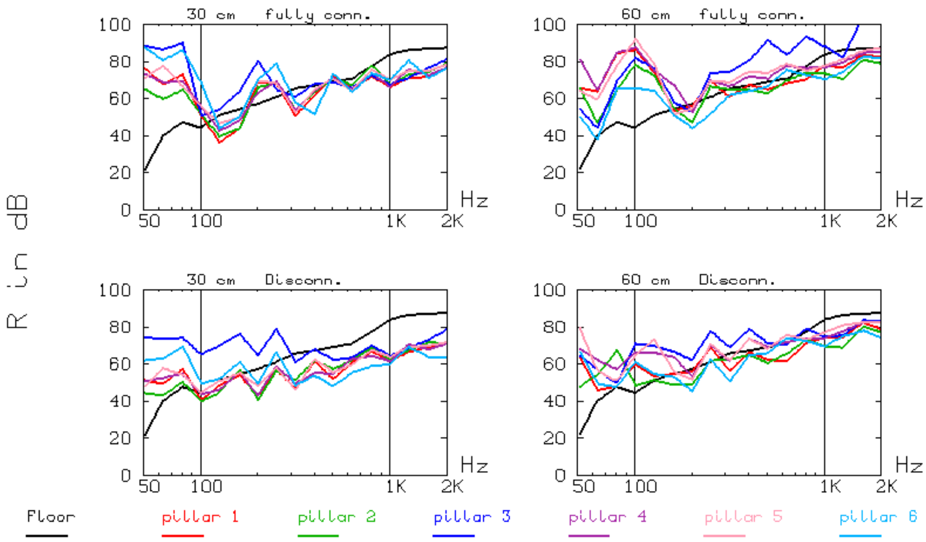

Figure 9 – Large volumes: contribution of the 6 posts (see Figure 2).

Table 2 gives the values of the global index R_A for the different cases as well as R_A for the insulated floor. For the 30 cm posts the value of R_A with all posts is much less (19 dB) to the value of R_A for the floor. For the wider posts (60 cm x 60 cm) the difference is still 10 dB.

For the 30 cm post, leaving even only one post bare leads to values lower than the 69 dB of the floor. So, in this case all posts should be insulated if one does not want to significantly degrade the performance of the insulated floor. For the 60 cm posts the objective of 59 dB is reached one might eventually leave the central post (or any other) bare. The R_A index of the insulated floor is 69 dB and if we aim at 59 dB in all calculations for posts (grouped or separated) this is achieved only for the 60-m posts.

In this case, connecting the posts to the floor (as would be expected in a real building) is associated in general to decrease of the performance; the decrease being higher for the 30 cm middle post (7 dB for 30 cm post 6). This decrease is lower for the 60 cm posts; no difference is obtained between connected or disconnected 60 cm middle post (post 6). The difference in behaviour associated to the posts and floor connection, between the small and large volumes is related to the size of the floor. Note that again when all posts are considered the effect of the connection between posts and floor disappears.

Table 2 – R_A in dB for the different cases (large volumes).
4 cases: 2 post sizes (30 or 60 cm), 2 types of contact posts/floor.

	Post 1	Post 2	Post 3	Post 4	Post 5	Post 6	All Posts
30/conn	62	64	69	64	66	64	50
30/disc	58	59	67	59	61	57	50
60/conn	69	68	78	74	73	65	59
60/disc	67	65	74	71	71	65	59
33 cm Floor	69						

4. Conclusions

Compared to a simple bare floor, sound transmission by wooden posts is clearly neglectable (R significantly higher).
However, the transmission loss of posts may become lower or comparable to a fully insulate floor (treated on both sides).

The results also show that the connection between floor and posts has an effect on the acoustic performance; this effect appears to depend on the position of the post and the size of the floor. However, when all posts are considered the effect of the posts and floor connection becomes rather insignificant. It should be mentioned that in a real building the posts and floor will be attached (the posts supporting the floor).

If one does not want to degrade the efficiency of the insulated floor here considered, one can conclude:

- for the smaller volumes with 3 posts, the 30 cm posts should all be insulated, and the 60 cm posts could be left bare.
- for the large volumes with 6 posts, the 30 cm posts should all be insulated while for the 60 cm posts it is advised to treat several posts: keeping the central post and eventually a corner post bare would be acceptable.

The R_A index of the insulated floor is 69 dB and if we aim at 59 dB in all calculations for posts this is achieved only for the 60-cm posts.

References

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