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Innovative building systems to improve the acoustical quality in lightweight masonry constructions: Application of resilient joints at junctions - PART 2: Study cases modelled according to the standard 12354-1 (2000)

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An important brick manufacturer in partnership with the BBRI has succeeded to propose efficient acoustic solutions for this kind of lightweight materials by treating the flanking transmission using flexible interlayers at junctions and foundations. A large measurement survey has been carried out to study the efficiency of the resilient joint and to provide a prediction model on airborne sound insulation in brickwork constructions. The prediction model used is based on the standard 12354-1 but was adapted in order to take into account higher orders for the flanking transmission paths. This adapted model thus allowed studying different applications of the flexible joint and their contribution to the improvement of the global sound insulation. This paper presents a discussion on the calculation model, the input data and some early results.

1 Introduction

In Belgium, the standard NBN S01 400-1 (2008) which gives the minimum threshold values of acoustic insulation between dwellings is revised. The recommended insulation level is increased in order to satisfy 70% of the occupants for a basic comfort and 90% for a superior comfort. The new high requirements (for the superior comfort) demand a modification of the current construction methods. The Wienerberger Group asked us to help them in order to establish building guidelines for brick constructions. The BBRI has succeeded to propose efficient acoustic solutions for this kind of lightweight materials by treating the flanking transmission using flexible interlayers at junctions and foundations. A large measurement survey has been carried out in order to study and quantify the effect of the resilient joint on the global sound transmission. The results have been used also as input data for our prediction model from which the building guidelines are established. The prediction model is presented here with some results.

2 The prediction model

The prediction of the standardized level difference, D_{nT}, is performed according to the standard EN ISO 12354-1 (2000). This standard provides calculation models for the direct and the twelve flanking transmission paths. The general principle is to divide the total transmission factor into transmission factors related to each element in the receiving room and the elements and systems involved in the direct and indirect airborne transmission. Some adaptations have been performed to improve the prediction model to our building design.

2.1 The structure-borne path D-d

With a cavity wall as separating element, the structural transmission from one leaf to the other via the connections around the perimeter (figure 1) has to be taken into account for the prediction of the horizontal global sound transmission. The connections can be for example a continuous floor between two apartments or a common foundation at the ground floor. Measurements [3] made on a cavity wall supported on foundations show the importance of this path and explain why the cavity walls do not reach the expected performance.

According to the standard 12354-1, the effect of this transmission should be included in the sound reduction index but we have added it as a new flanking path to see its influence and its reduction when a resilient joint is inserted at the junction. This path is named: structure-borne path D-d.

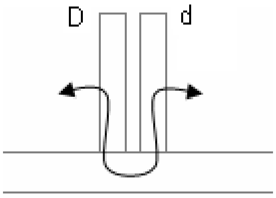


Fig.1 The structural transmission from one leaf to the other via the connections around the perimeter

The effect of common foundations on this structural path has been studied. Figure 2 presents the considered foundation types.

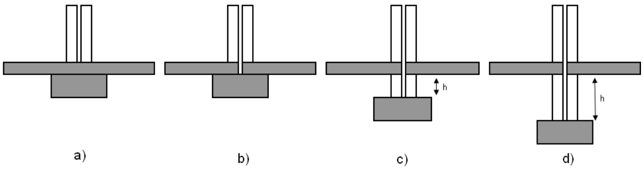


Fig.2 The different foundation design studied

For the last drawing (figure 2 d)), where the height h is higher than 0.6 m, the walls of the underfloor space (or cellar) must be considered as subsystems according to the SEA. The structure-borne path crosses then 3 junctions and the formula of the multiple K_{ij} given in the standard 12354-5 (2004) [5] has to be used.

$$K_{ij} = \sum_{k=i}^{j-1} K_{k,k+1} - 10\lg\sqrt{l_{i,i+1} l_{j-1,j}}\,\frac{\prod_{k=i+1}^{j-2} l_{k,k+1}}{\prod_{k=i+1}^{j-1} a_k} - \Delta K \quad \text{dB} \qquad (1)$$

Where,

$l_{m,n}$ is the coupling length between elements m and n, in meter;

a_m is the equivalent absorption length for element m, in meter;

ΔK is the adjustment term for the vibration reduction index to take into account reduced reduction due to other wave types than bending waves, in decibels. It could be estimated as 4 dB for two junctions and 6 dB for three junctions or more.

The K_{ij} multiple formula has been validated by confronting the calculation results with measurements.

2.2 Higher order flanking paths

When resilient joints are inserted at the junction cavity wall/floor, the inner lightweight walls (W1, w1, W2 and w2 in the graph), which is rigidly connected to the floor and cavity wall, represents a subsystem of horizontal higher order flanking paths which are significant (figure 3). The order of the structural path depends on the number of junctions crossed. The large number of these paths makes them absolutely not negligible. We have thus added these paths in our prediction model by using the multiple K_{ij} formula Eq. (1).

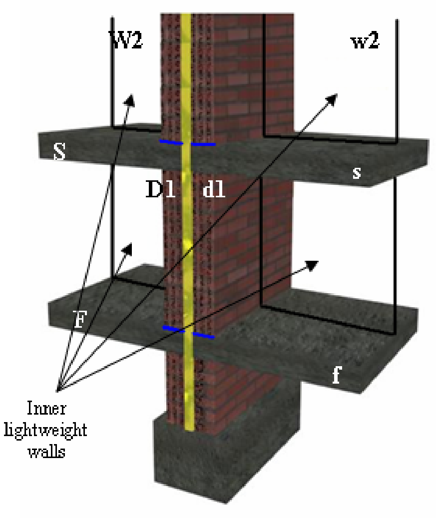


Fig.3 Inner lightweight walls rigidly connected to the structure

3 Input data

For the model, we assume the absence of indirect transmission paths and transmission paths by an element. Thus, the input data are the following:

- The sound reduction index of the party wall and the flanking walls : R_s, R_i, R_j ;
- The vibration reduction index for all flanking transmission paths: K_{ij} ;
- The sound reduction index improvement of walls or floor : ΔR_d, ΔR_i, ΔR_j;
- The structural reverberation time T_s;
- The geometry data: the surfaces (S_s, S_i, S_j), the junction lengths l_{ij}, the volumes.

The precision of the prediction depends on the accuracy of the input data.

3.1 The sound reduction index R

The sound reduction index used in the prediction model results from calculation even though we had the measured value for some cases [3]. In this way, we conserve consistency in the input data used. The sound reduction index of the cavity wall is the one of a perfect uncoupled cavity wall. For the calculation of the flanking reduction index including a leaf of the cavity wall, it is the sound reduction index of this single leaf which is taken into account.

3.2 The vibration reduction index K_{ij}

3.2.1 Rigid junction

The vibration reduction index K_{ij} used for the simulation is the one obtained according to the empirical formula from the standard 12354-1 to conserve consistency in the input data. The large number of measurements carried out on rigid junctions [2, 3] has showed a good agreement between the measurements and the predictions and thus the relevance to use the calculated value.

3.2.2 Junction with flexible interlayer

An important measurement survey has been carried out to measure the K_{ij} for a transmission path crossing resilient joints [3]. The original setup permitted to compress the joint to simulate different storeys. The results of these measurements have lead to an empirical formula dedicated to the joint used (a resinbonded rubber from CDM, thickness = 0.01m and E=0.32MN/m² with a load of 200kg/m²) i.e the empirical formula given in the annex E of the standard 12354-1 (2000) but with an adapted value for f_l Eq. (2.a to 2.e).

$$K_{13} = 5,7 + 14,1M + 5,7M^2+2\Delta_l \text{ dB} \qquad (2.a)$$

$$K_{24} = 3,7 + 14,1M + 5,7M^2;\ 0\leq K_{24}\leq - 4 \text{ dB};\ 0 \text{ dB/oct.} \qquad (2.b)$$

$$K_{12} = 5,7 + 5,7\,M^2 +\Delta_l\ (=K_{23}) \qquad (2.c)$$

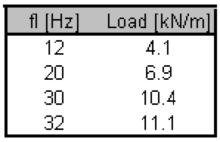
$$\Delta_l = 10\lg(f/f_l) \text{ dB} \quad \text{for } f>f_l \qquad (2.d)$$

$$M=\lg(m'_{per,i}/m'_i) \qquad (2.e)$$

Where, m'_i is the surface mass of the element i in the transmissiohn path ij, [kg/m²].

$m'_{per,i}$ is the surface mass of the perpendicular element to iI constituting the junction, [kg/m²].

The f_l depends on the load (number of storeys) applied on the resilient joint. The table below (table 1) gives the f_l used according to the load.



fl [Hz]	Load [kN/m]
12	4.1
20	6.9
30	10.4
32	11.1

Table 1 f_l used according to the load

A supplementary study is carried out to find the right empirical formula which links the stiffness of the joint to the K_{ij}. For this study, we have developed an original setup to measure the dynamic stiffness of the resilient joint with heavy loads (to simulate storey) and for the audio frequencies (50 to 5000 Hz). This setup is inspired by the standard ISO 10846 (Part1 to 5)

3.2.3 Special cases

Some special cases cannot be predicted with empirical formula as the vibration reduction index through foundations (see figures 2 b) to d)). For these cases only the measurement results are used in the prediction model. The details of these measurements can be read in the article on the measurement survey [3].

4 Validation of the prediction model

The $D_{nT,w}$ measurements of a special construction simulating a field set-up and built in the experimental site of Beerse have been confronted to the prediction results in order to validate the model. The construction is composed of a cavity wall (2x150 kg/m²). The floor and the ceiling pass continuously through this cavity wall (see figure 4). There are resilient joints below and above each bricks wall. The measurement results showed a good agreement with the predicted values.

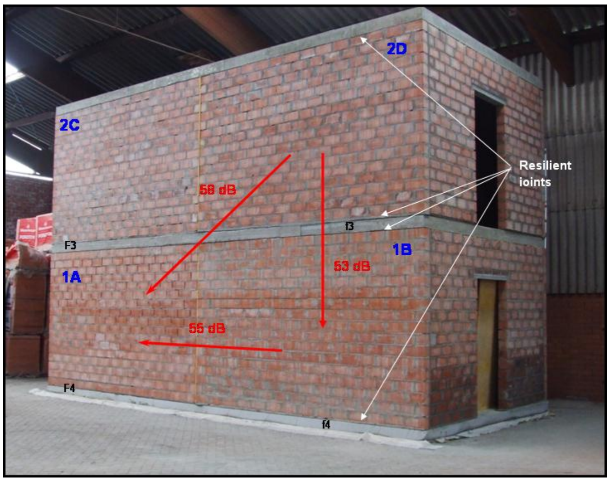
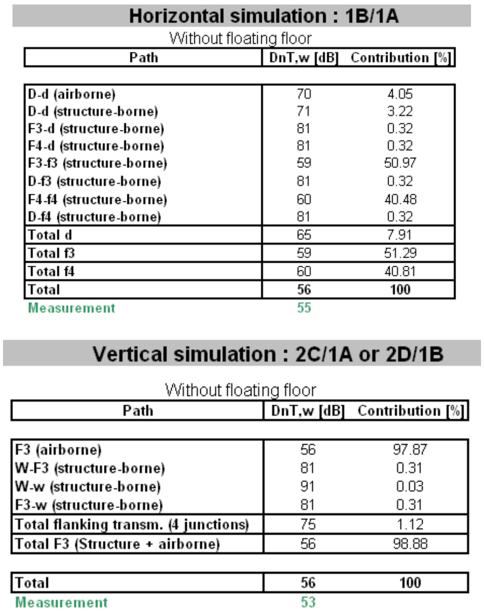


Fig.4 Construction of rooms to validate the prediction models and measurement results without floating floors

The analysis of the contribution for each transmission paths show that for the horizontal transmission at the ground level without floating floor, the structural transmission paths via the ceiling (F3 to f3) and the floor (F4 to f4) are dominant as expected since they are continuous. For the vertical transmission between rooms, we can see that the transmission through the floor (F3) is most dominant due to the lack of the floating floor. These results show the great efficiency of the structural cut by resilient joints.



Horizontal simulation : 1B/1A

Without floating floor

Path	DnT,w [dB]	Contribution [%]
D-d (airborne)	70	4.05
D-d (structure-borne)	71	3.22
F3-d (structure-borne)	81	0.32
F4-d (structure-borne)	81	0.32
F3-f3 (structure-borne)	59	50.97
D-f3 (structure-borne)	81	0.32
F4-f4 (structure-borne)	60	40.48
D-f4 (structure-borne)	81	0.32
Total d	65	7.91
Total f3	59	51.29
Total f4	60	40.81
Total	**56**	**100**
Measurement	55	

Vertical simulation : 2C/1A or 2D/1B

Without floating floor

Path	DnT,w [dB]	Contribution [%]
F3 (airborne)	56	97.87
W-F3 (structure-borne)	81	0.31
W-w (structure-borne)	91	0.03
F3-w (structure-borne)	81	0.31
Total flanking transm. (4 junctions)	75	1.12
Total F3 (Structure + airborne)	56	98.88
Total	**56**	**100**
Measurement	53	

Table 2 Prediction results

5 Study cases

The model has been validated on a real construction built in the experimental site of Wienerberger (Belgium) and a lot of predictions have been carried out. Some of them are presented here. The complete report and details of the simulations are property of the Wienerberger Group and can be consulted on request. The results of the prediction model give the $D_{nT,w}$ per path and their contribution to the global sound transmission in %. So, It is easy to investigate the most dominant paths and the improvements.

5.1 Apartment with continuous floor

5.1.1 Rigid junction

The vertical separating construction is a cavity wall composed of bricks (2x150 kg/m²). The separating floor is continuous (425kg/m²). There is a floating floor (figure 5).

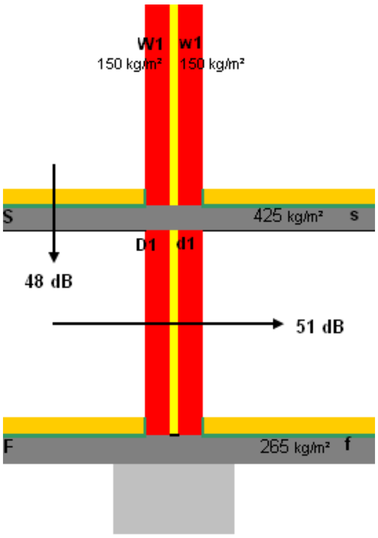
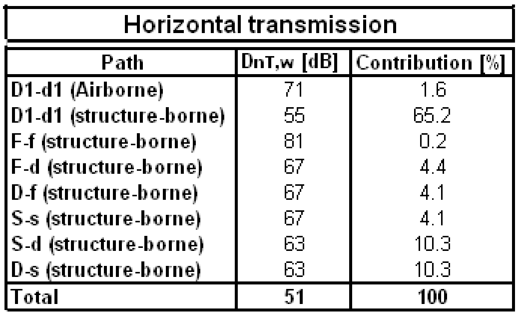


Fig.5 Apartment with continuous floors and rigid junctions

Table 3 presents the $D_{nT,w}$ for each transmission each path as well as the overall horizontal $D_{nT,w}$. The global sound transmission is mainly conditioned by the structure-borne sound transmission D1-d1 through the leaves of the cavity wall via the connecting floor and ceiling. The contribution of these 2 paths is of 65.2%. The $D_{nT,w}$ of the total transmission is **51 dB**. The removal of the structure-borne paths D1-d1 will allow a considerable increase of the acoustic insulation (see the next case).



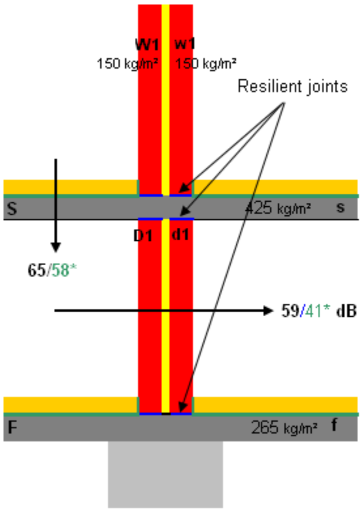
Horizontal transmission

Path	DnT,w [dB]	Contribution [%]
D1-d1 (Airborne)	71	1.6
D1-d1 (structure-borne)	55	65.2
F-f (structure-borne)	81	0.2
F-d (structure-borne)	67	4.4
D-f (structure-borne)	67	4.1
S-s (structure-borne)	67	4.1
S-d (structure-borne)	63	10.3
D-s (structure-borne)	63	10.3
Total	**51**	**100**

Table 3 Results for the horizontal sound transmission between apartments with a continuous floor and rigid junctions cavity walls/floor

5.1.2 Junction with flexible interlayers

The same building design as in paragraph 4.1.1 but, in this case, there are resilient joints under and above the floor slab at each junction (figure 6).



* Result with inner lightweight walls rigidly connected to the structure without resilient joints

Fig.6 Apartment with continuous floor and 2 resilient joints at junctions

The table below (table 4) presents the results when the inner lightweight walls are completely disconnected.

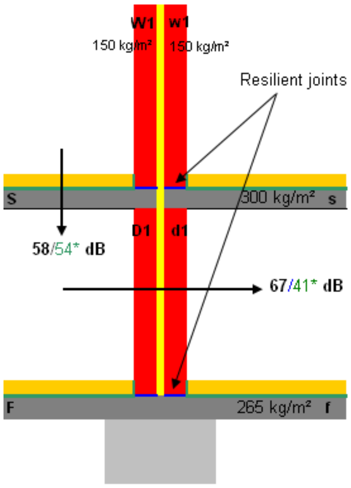
Horizontal transmission		
Path	**DnT,w [dB]**	**Contribution [%]**
D1-d1 (Airborne)	71	6.7
D1-d1 (structure-borne)	73	4.2
F-f (structure-borne)	74	3.4
F-d (structure-borne)	91	0.1
D-f (structure-borne)	91	0.1
S-s (structure-borne)	60	84.7
S-d (structure-borne)	83	0.4
D-s (structure-borne)	83	0.4
Total	59	100

Table 4 Results for the horizontal sound transmission between apartments with a continuous floor and flexible interlayers at the junctions with the cavity wall

As we can see on table 4, the $D_{nT,w}$ for the horizontal transmission (including all paths) is **59 dB**. As expected, it is the structural path S-s which is dominant (84.7% on the global transmission). The other paths are restricted by the resilient joint or/and the floating floor. The $D_{nT,w}$ falls dramatically when the inner walls are rigidly connected to the structure. For the vertical transmission, we reach **65 dB** if the inner wall W2 (figure 3) is uncoupled and 58 dB if the inner lightweight partition is rigidly coupled to the structure. In this last case, it is the interior wall (W2) connected to the floor (S) which determines the global sound transmission (75%).

5.2 Apartment with interrupted floor

The cavity wall is composed with bricks (2x150 kg/m²) and the floor is interrupted (300 kg/m²). There is a floating floor and there are resilient joints at the upper section of each junction (figure 7).



* Result with inner walls connected to the structure without resilient joints

Fig.7 Apartment with interrupted floor and 1 resilient joint at junctions

Table 5 presents the results when the inner lightweight walls are completely disconnected.

Horizontal transmission		
Path	**DnT,w [dB]**	**Contribution [%]**
D1-d1 (Airborne)	71	38.8
D1-d1 (structure-borne)	76	12.3
F-f (structure-borne)	73	24.5
F-d (structure-borne)	76	12.3
D-f (structure-borne)	76	12.3
Total	67	100

Table 5 Results for the horizontal sound transmission between apartments with an interrupted floor

The $D_{nT,w}$ for the horizontal transmission (including all paths), at the ground floor, is **67 dB**. For this case, the structure-borne path S-s, S-d and D-s are inexistent. The structure-borne paths F-f, F-d and D-f are protected by the floating floor and the resilient joint. So, the dominant path is D1-d1. The $D_{nT,w}$ falls to 41 dB when the inner lightweight walls are rigidly connected to the structure. At the first storey and higher, the $D_{nT,w}$ does not depend anymore of structural paths resulting in the actual performance of the cavity wall (71dB).

For the vertical transmission, we reach **58 dB** and 54 dB when an inner lightweight wall is coupled to the structure. This value is mainly conditioned by the path W2-S firstly (56.4%) followed by the airborne transmission through the floor (17.8%).

5 Conclusion

From the prediction model, we can draw some solutions for the different comfort levels required by the new Belgian standard NBN S01-400-1 (2008) i.e $D_{nT,w}$ 54, 58 and 62 dB. The possible solutions are presented for different surface masses of walls used. We have to keep in mind that these solutions depend on the geometrical data and assume that the lightweight inner partitions are totally disconnected from the structure by resilient joints. The tables are valid for rooms with a depth of 3m and the floating floor must have a minimum ΔR of 7 dB.

Table 6 shows the results to reach 54 dB in horizontal direction.

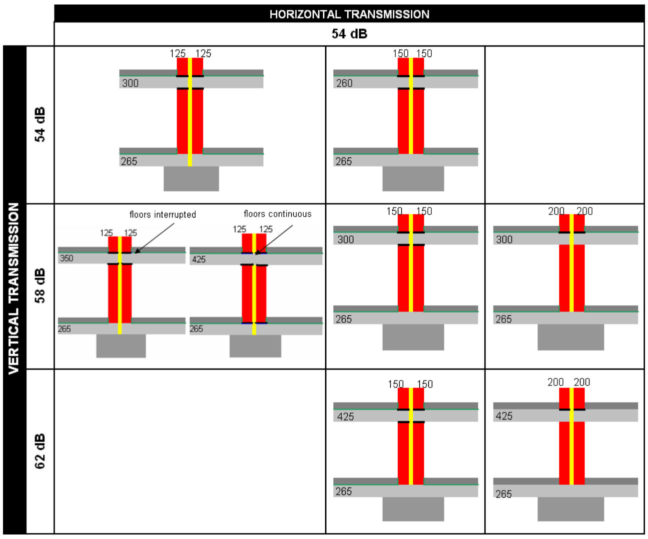


Table 6 Guidelines to reach 54 dB for the horizontal transmission

Table 7 shows the results to reach 58 dB for the horizontal transmission. We can see that the ground floor slab is, in this case, not continuous on the foundation. A resilient joint is added in case of lighter walls and in case of a continuous floor at the upper levels. This detail permits to decrease the horizontal transmission by reducing the structural transmission through the ground floor slabs.

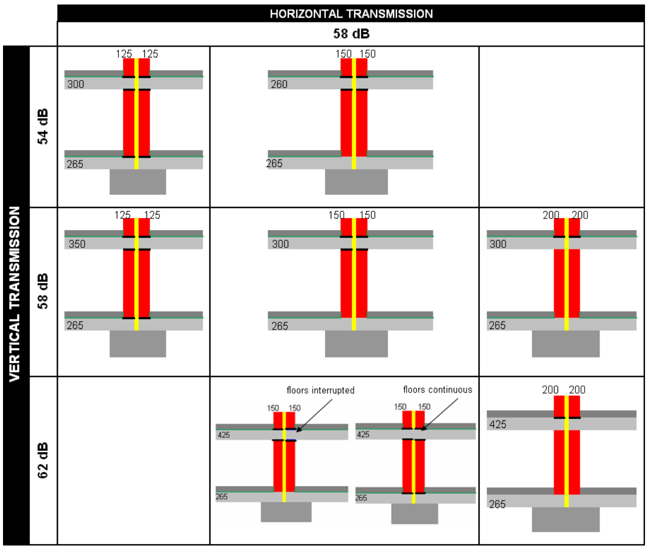


Table 7 Guidelines to reach 58 dB for the horizontal transmission

To increase the horizontal sound insulation in order to reach 62 dB, a resilient joint has to be placed at the foot of walls. In this way, the structural path is completely removed and the airborne-sound transmission through the cavity walls becomes dominant. We have drawn disconnected ground floor slabs on the foundation but, for these solutions (with resilient joints), the ground floor slabs can be continuous.

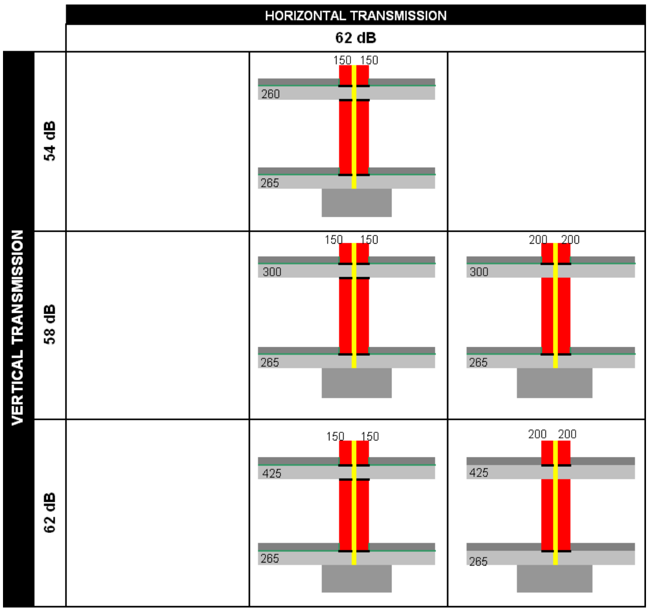


Table 8 Guidelines to reach 62 dB for the horizontal transmission

Acknowledgments

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