Seoul
inter-noise
2020 23-26 AUGUST

A standardized measurement method to measure the vibration reduction index improvement by adding resilient strips at a wall-floor junction: preliminary exercise

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ABSTRACT

The application of a resilient strip at a wall-floor junction allows to improve the vibration reduction index, K_{ij}, by decreasing the structural transmissions. The improvement, named Δ_l in the standard ISO 12354-1, can be roughly estimated by an empirical formula. However, since these strips are now widely marketed, it is important to have a relevant measurement method for quantifying their effectiveness. For this purpose, many experimental measurements were exploited, and a conceptual analysis was performed leading to preliminary reflection on the possibility of establishing a standardized laboratory measurement procedure to include as a supplement in the standard ISO 10848.

1. INTRODUCTION

The application of a resilient strip at junctions gives an efficient acoustic solution to increase the sound insulation in lightweight masonry construction by treating the flanking transmission. In Belgium, it becomes part of common practice but what would be the criterion we could use to determine the effectiveness of these resilient strips? And how to evaluate this criterion?

A first answer can be found in the standard ISO 12354-1 [1]. In this standard, the attenuation of the flanking transmission is expressed by the vibration reduction index K_{ij} and its improvement by the application of a resilient strip is given by the index Δ_l (l for layer) but currently, this index can only be estimated roughly by an empirical formula.

This paper presents a possible normalised measurement procedure to quantify more precisely the Δ_l which could then be used to compare the performance of these elements and could also be used as input data in the ISO 12354-1 predictive models.

For now, the present proposal concerns only resilient strips inserted at a concrete floor/masonry wall junction.

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1 QUANTITY Δ_{LAYER}

Throughout the rest of the paper the name Δ_{layer} will be used instead of Δ_l in order to avoid any confusion with ΔL, the symbol for the reduction of impact sound pressure level. So, the quantity to be determined is the vibration reduction improvement, Δ_{layer}, in decibel, as a function of frequency.

For a path including the resilient strip, the Δ_{layer} is defined as the increase of the velocity level difference resulting from its application for a given junction and under a given load. It is thus defined as the difference between the vibration reduction index with and without the resilient strip. For « type A » elements (according to the terms of the standard ISO 10848-1 [2]), it can be given by the following formula:

$$\Delta_{layer} = K_{ij,s} - K_{ij,0} \tag{1}$$

where,

$K_{ij,s}$ is the vibration reduction index for the path "i-j" including the resilient strip for a given junction and under a given load;

$K_{ij,0}$ is the vibration reduction index for the same path "i-j" but without the resilient strip.

It shall be shown below that the Δ_{layer} is independent of the path and therefore the subscript "ij" should not be mentioned.

The Δ_{layer} is not an intrinsic characteristic of the resilient strip but depends on certain mounting conditions. To propose a standardised measurement procedure that allows to compare the effectiveness of the resilient strip these mounting conditions are studied below to determine the influencing factors.

2 FACTORS INFLUENCING THE Δ_{LAYER}

The factors which influence the Δ_{layer} were studied from two distinct measurement campaigns. The first campaign was made a few years ago on a real-scale test bench. The setup complied with the standard ISO 10848 dedicated to the measurement of the vibration reduction index K_{ij}. The floor was composed of hollow core concrete slabs (thickness = 0.20 m, ρ = 1575 kg/m³). Seven different types of vertical walls and sixteen resilient strips were used to study the improvement of the K_{ij} by their application [3]. The results of this campaign are expressed by third octave bands from 100 Hz to 5000 Hz.

The second measurement campaign was carried out on a half-scaled test bench [4]. In this case, the floor was composed of a reinforced concrete floor (thickness = 0.10 m, ρ = 2300 kg/m³). Six different types of vertical walls and six resilient strips were tested. Since the measurements were carried out on a half-scaled test bench, the results of this campaign are expressed by third octave bands from 250 Hz to 10000 Hz. These results are equivalent to the results on a full-scale test bench with double size elements in the frequency range of 125 – 5000 Hz.

2.1 Load dependency

A mounting composed of four hydraulic jacks inserted between a free beam and a fixed steel framework has allowed to apply a controlled compression on the resilient strips and to study the effect of the joint's compression on the Δ_{layer} [3]. Figure 1 presents the results obtained on a T-junction. The vertical walls were made of bricks (density: 1108 kg/m³, thickness :0.14m) and were interrupted by horizontal hollow core slabs. A resilient strip (a resinbonded rubber with a thickness of 0.01 m and a dynamic stiffness of 70 MN/m³ according to the standard EN 29052-1) was placed between the slabs and the lower wall.

The effect of the load on the resilient joint is well observed for all frequencies. When the load increases, the Δ_{layer} decreases. This is explained by the increase of the joint stiffness. Roughly, the curves decrease by 1 dB in each frequency band when the load is increased by 100 kN/m² for this strip but a more detailed analysis shows a slight dependence of the decrease with the frequency (slight difference of the slopes).

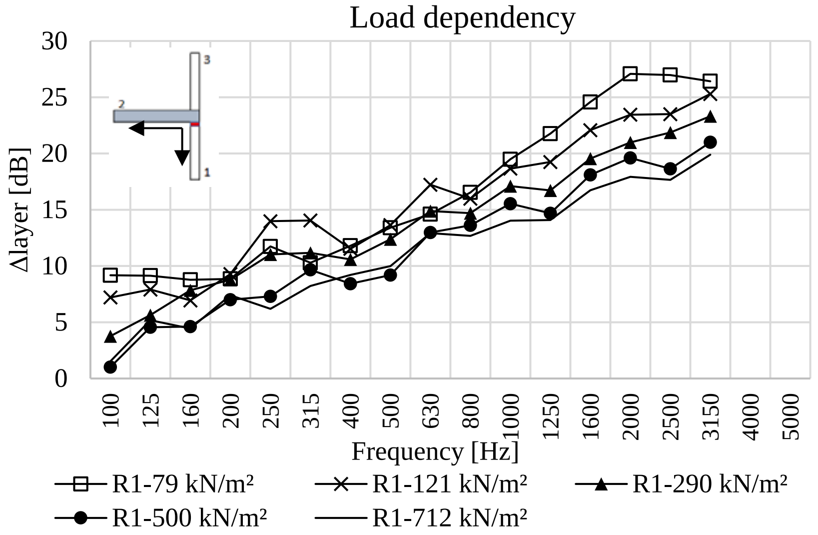

Figure 1: The effect of the load on the Δ_{layer}

2.2 Surface mass ratio dependency

Figure 2 shows that the Δ_{layer} depends on the ratio of the surface masses of the wall and the floor.The results come from the half-scale mock-up. The curves without the bullets compare the Δ_{layer} measured for a junction with a surface mass ratio of the elements of 1.13 (continuous line) and for a junction with a surface mass ratio of the elements of 1.97 (dashed line). In the two cases, the resilient strip is a resinbonded rubber with a thickness of 0.008 m and a dynamic stiffness s'_t of 60 MN/m³ which is compressed with a load of 64 kN/m² due to the mass of the concrete slab.

The curves with the bullets compare the Δ_{layer} measured for the same junctions than above but, in this case, the resilient strip is a resinbonded rubber with a thickness of 0.003 m and a dynamic stiffness s'_t of 187 MN/m³ which is compressed with a load of 64 kN/m².

The effect of the resilient strip is larger when the surface mass ratio is closer to 1. This can be explained by the fact the energy transfer between two rigidly connected elements with similar surface mass is larger, and thus the beneficial effect of the resilient strip will be larger. Oppositely, the weaker energy transfer caused by a high contrast in surface mass will be subject to a smaller reduction by the strip.

To be more exact, it should be shown that the Δ_{layer} depends on the ratio of the characteristic moment-impedances ψ/χ [5,6]. That means the ratio of the densities and the bending stiffnesses.

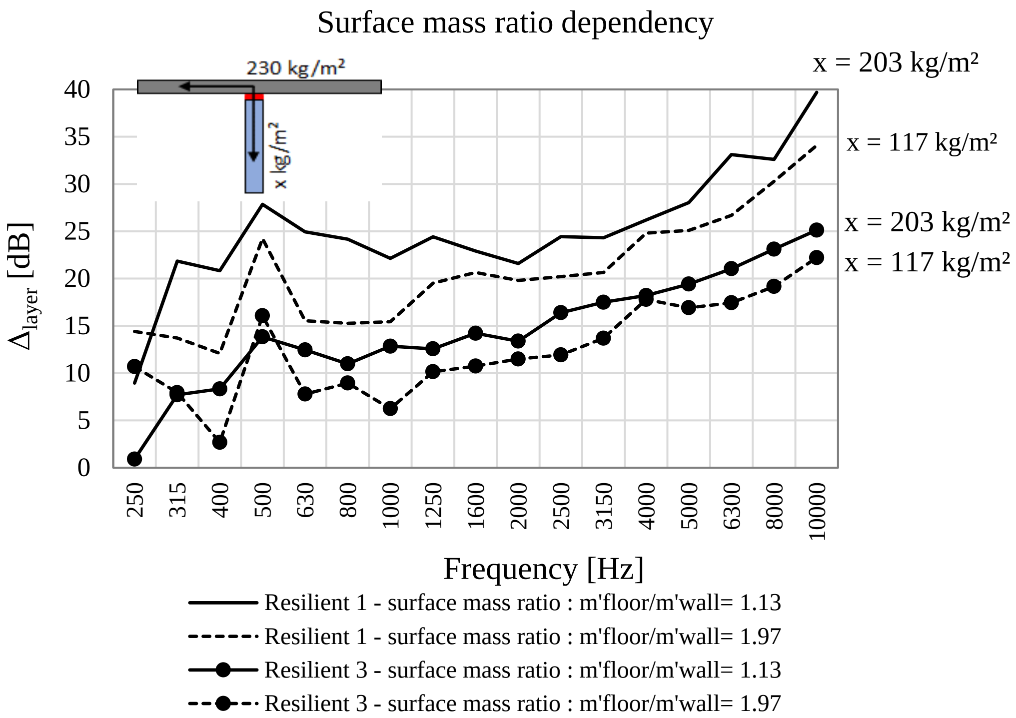

Figure 2: The effect of the surface mass ratio on the Δ_{layer}

2.3 Independence of the path

Figure 3 presents the Δ_{layer} measured for the transmission around the corner (path 1-2) and for the transmission across the straight section (path 1-3) for a T-junction.The results come from the full-scale mock-up. The vertical walls are composed of bricks (ρ’ = 155 kg/m²) and the resilient strip is a resinbonded rubber with a thickness of 0.01 m and a dynamic stiffness s'_t of 70 MN/m³. The Δ_{layer} measured across the path 1-2 is similar to the Δ_{layer} measured across the path 1-3. This could mean that the velocity level of wall 3 is only conditioned by the velocity level of floor 2. The vibration energy of wall 3 comes only from floor 2. The insertion of the resilient strip causes the decrease of the vibration energy in floor 2 and it affects wall 3 in the same proportion.

Figure 4 presents the Δ_{layer} measured for the transmission around the corner (path 2-3) and for the transmission across the straight section (path 1-3) for an X-junction.The results come from the half-scale mock-up. The vertical walls are composed of bricks (ρ’ = 195 kg/m²) and the resilient strip is a resinbonded rubber with a thickness of 0.003 m and a dynamic stiffness s'_t of 187 MN/m³. The same analysis as described above can be done for this X-junction. The Δ_{layer} measured across the path 2-3 is also similar to the Δ_{layer} measured across the path 1-3.

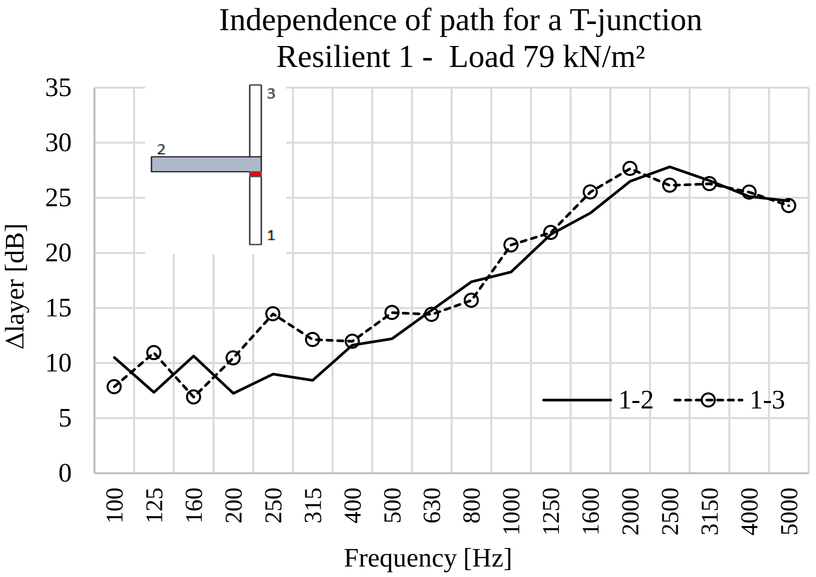

Figure 3: The effect of the path on the Δ_{layer} *for a T-junction*

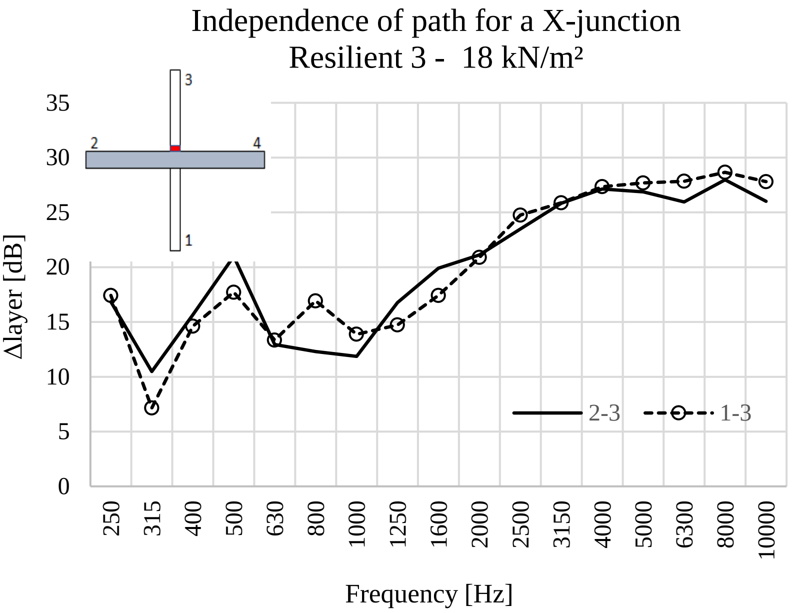

Figure 4: The effect of the path on the Δ_{layer} *for a X-junction*

For these configurations, the Δ_{layer} is thus independent of the path. Therefore, the name ΔK_{ij} which is mentioned in some papers doesn't seem appropriate and can be confusing assuming that it depends on the path "i-j"

2.4 Independence of the junction type

Figure 5 compares the Δ_{layer} measured from an X-junction and from a T-junction. Some differences are observed at low frequencies where the modal density is low. In this case, the floor was composed of a reinforced concrete floor (thickness = 0.10 m, ρ = 2300 kg/m³), the vertical walls were composed of cellular concrete (thickness = 0.07 m, ρ = 666 kg/m³). The resilient strip was a resinbonded rubber with a thickness of 0.003 m and a dynamic stiffness of 974 MN/m³ (according to the standard EN 29052-1). The results show that the Δ_{layer} is independent of the junction type.

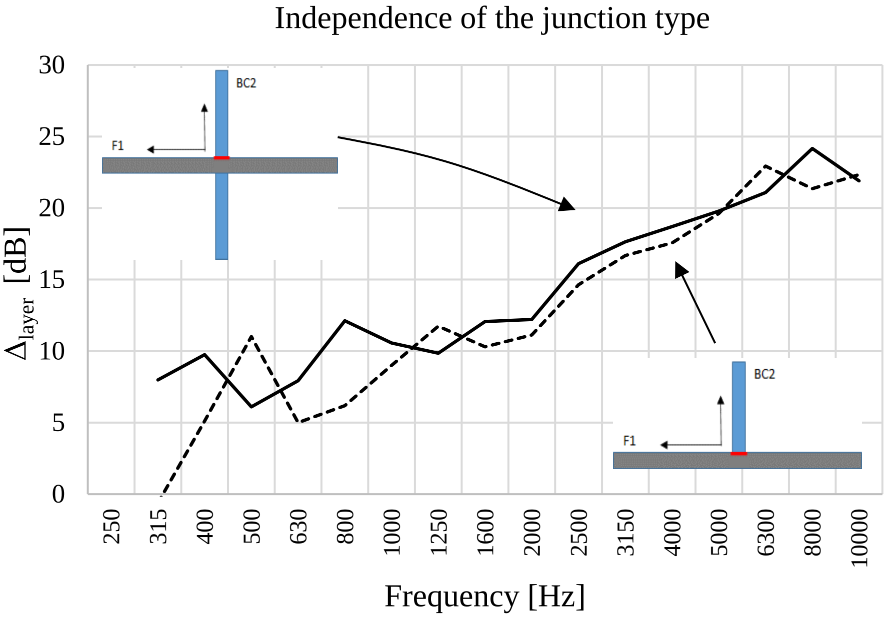

Figure 5: The effect of the junction type on the Δ_{layer}

3 Δ_{LAYER} AND $\Delta_{LAYER,REF,X\ LOAD}$

It has been shown above that the Δ_{layer} depends on the load applied on the resilient strip and on the surface mass ratio of the elements directly situated on the both sides of the resilient strip. In order to be able to compare the effectiveness of different resilient strips, the Δ_{layer} should thus be measured on some reference junctions and under standardised loads. In this case, the relevant quantity will be nominated:

$$\Delta_{layer,ref,x\ load} = K_{ij,s,ref,x\ load} - K_{ij,0,ref} \qquad (2)$$

where,

$K_{ij,s,ref,x\ load}$ is the vibration reduction index for the path "i-j" including the resilient strip for a reference junction and under a standardised load;

$K_{ij,0,ref}$ is the vibration reduction index for the same path "i-j" but without the resilient strip for a reference junction.

The reference junctions are the basic junctions in which the resilient strip is inserted for the normalised measurement. The reference junctions could be defined from the surface mass ratio of the elements disconnected by the resilient strip (or, for greater accuracy, from the ratio of the characteristic moment-impedances ψ/χ [5,6]) as follow:

1. A junction composed of a lightweight wall, i.e. a junction with a surface mass ratio "wall/floor" of 0.3: for example, a concrete floor/cellular concrete block junction
2. A junction composed of a medium-weight wall 1, i.e. a junction with a surface mass ratio "wall/floor" of 0.4: for example, a concrete floor/plaster block junction
3. A junction composed of a medium-weight wall 2, i.e. a junction with a surface mass ratio "wall/floor" of 0.6: for example, a concrete floor/brick wall junction

4. A junction composed of a heavy wall, i.e. a junction with a surface mass ratio “wall/floor” of 0.8: for example, a concrete floor/sand-limestone brick junction

The floor should be a reinforced concrete slab of 120 mm or 140 mm. It should be homogeneous with a uniform thickness.

A round robin measurement campaign should provide the standardized values of the vibration reduction indices, K_{ij}, for these reference junctions.

An additional index should indicate the reference junction used: “light”, “medium 1”, “medium 2” or “heavy” and the applied load. For example, $\Delta_{\text{layer,heavy, }70\text{kN/m}^2}$.

In order to specify the effect of resilient strips in specific situations, other junctions than those specified here could be used. In this case, the improvement values would include the particular characteristics of the laboratory and the basic elements, allowing a comparison of different strips under these particular conditions.

4 A PROPOSED SETUP FOR THE MEASUREMENT OF THE $\Delta_{\text{LAYER,REF,X LOAD}}$

The $\Delta_{\text{layer,ref,x load}}$ is independent of the path and an L-junction could be sufficient for the measurement. The following assembly (see Figure 6) could be proposed:

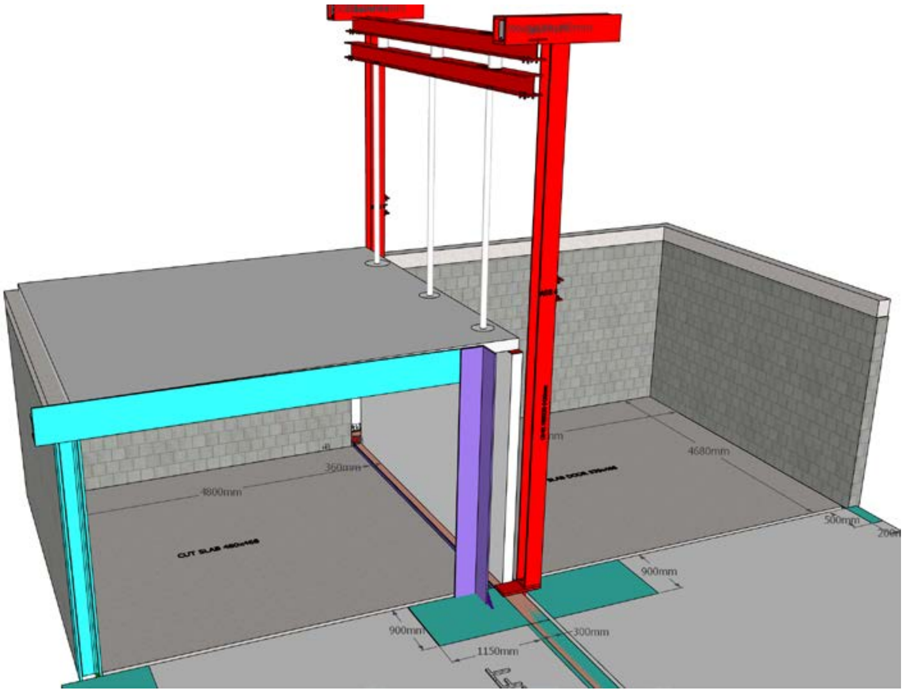

Figure 6: A proposed setup for the measurement

The dimensions of the elements are specified in the standard ISO 10848 [2]

4.1 The effect of the load

The effect of the load on the resilient strip could be obtained by a particular mounting where hydraulic jacks are inserted between a free beam and an upper steel framework attached to the ground without any connection to the setup. Five controlled pressures should be applied on the resilient strip in order to have five standardised loads: for example : 25 kN/m², 50 kN/m², 100 kN/m², 200 kN/m², 400 kN/m².

The $\Delta_{layer,ref,x\ load}$ obtained with these loads could allow to extrapolate for another given load.

4.2 Disturbing airborne noise

The K_{ij} measurement procedure is described in the standard ISO 10848 [2]. The generation of the vibration field by the multiple manual hits can produce airborne noise in the test cell producing a disturbing extraneous vibration field on the test walls.

The velocity level on the wall and on the floor constituting the junction with the resilient strip should be 10 dB higher than the velocity level caused by the disturbing airborne noise. To measure the extraneous velocity level, the concrete floor could be slightly raised so that there is no structural contact anymore with the lower wall. The velocity levels caused by the airborne noise generated by hits of the same force are measured on each element.

4.3 The sealing

During the test on the rigid junction, the quality of the sealing between the floor and the wall is important. A perfect connection must be ensured between the two elements. A mortar joint can be applied along the entire length of the junction (between the walls and the floor) for this issue (figures 7 and 8).

Figure 7: Application of a mortar joint

Figure 8: A perfect connection on the whole surface

The use of a plastic sheet seems to reduce the structural transmission in the high frequency range and it could thus underestimate the $\Delta_{layer,ref,x\ load}$ of the resilient strip under test (figures 9 and 10).

Figure 9: Picture of the use of the plastic sheet - The vertical walls are composed of cellular concrete (ρ’ = 46 kg/m²)

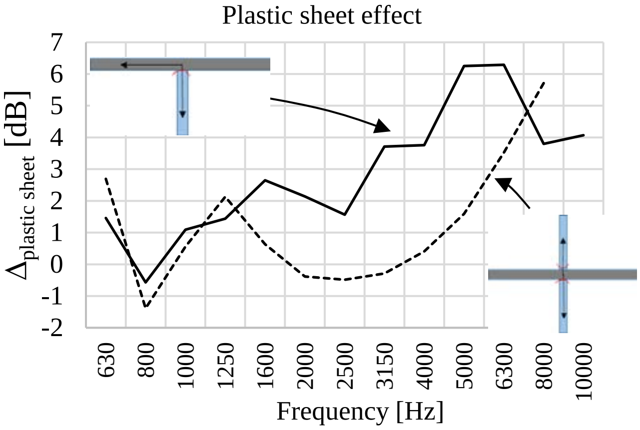

Figure 10: The effect of a plastic sheet

5 SINGLE-NUMBER RATING FOR IMPROVEMENT OF THE VIBRATION REDUCTION BY RESILIENT STRIP

The single-number quantity for the vibration reduction index, $\overline{K_{ij}}$, is the arithmetic average of K_{ij} within the frequency range 200 Hz to 1 250 Hz (one-third octave bands). The single-number quantity for the improvement of the vibration reduction index could then be:

$$\overline{\Delta_{\text{layer,ref,x load}}} = \overline{K_{ij,\text{s,ref,x load}}} - \overline{K_{ij,\text{0,ref}}} \tag{3}$$

However, the $K_{ij,\text{s,ref,x load}}$ varies considerably within the indicated frequency range. Therefore, care should be taken in applying this $\overline{\Delta_{\text{layer,ref,x load}}}$.

To provide input data relevant to the detailed models described in ISO 12354-1 and ISO 12354-2, the following single-values could be used:

$$\overline{\Delta_{\text{layer,ref,x load,low}}} = \overline{K_{ij,\text{s,ref,x load,low}}} - \overline{K_{ij,\text{0,ref,low}}} \quad [\text{dB}] \tag{4}$$

$$\overline{\Delta_{\text{layer,ref,x load,mid}}} = \overline{K_{ij,\text{s,ref,x load,mid}}} - \overline{K_{ij,\text{0,ref,mid}}} [\text{dB}] \tag{5}$$

$$\overline{\Delta_{\text{layer,ref,x load,high}}} = \overline{K_{ij,\text{s,ref,x load,high}}} - \overline{K_{ij,\text{0,ref,high}}} [\text{dB}] \tag{6}$$

where

- $\overline{K_{ij,\text{s,ref,x load,low}}}$ and $\overline{K_{ij,\text{0,ref,low}}}$ are the arithmetic averages of the one-third octave band values from 50 Hz to 200 Hz of the $K_{ij,s}$ with the resilient strip and the $K_{ij,0}$ without the resilient strip for a reference junction, respectively,
- $\overline{K_{ij,\text{s,ref,x load,mid}}}$ and $\overline{K_{ij,\text{0,ref,mid}}}$ are the arithmetic averages of the one-third octave band values from 250 Hz to 1000 Hz of the $K_{ij,s}$ with the resilient strip and the $K_{ij,0}$ without the resilient strip for a reference junction, respectively,

- $\overline{K_{ij,s,\text{ref,x load,high}}}$ and $\overline{K_{ij,0,\text{ref,high}}}$ are the arithmetic averages of the one-third octave band values from 1250 Hz to 3150 Hz of the $K_{ij,s}$ with the resilient strip and the $K_{ij,0}$ without the resilient strip for a reference junction, respectively.

6 Δ_{LAYER} AND $\Delta_{\text{LAYER,REF,X LOAD}}$ IN THE ISO 12354 PREDICTIVE MODELS

The measured $\Delta_{\text{layer,ref,x load}}$ can be used as input data in the detailed prediction models of the standards ISO 12354-1 and ISO 12354-2.

6.1 The prediction models

The standard ISO 12354-1 describes the use of the Δ_{layer} (Δ_l in the standard) to take into account the effect of a resilient strip in the prediction model for any junctions.

For masonry wall junctions and for common resilient joints (resilient layer with an apparent dynamic stiffness,s'_t between 50 and 100 MN/m³ according to EN 29052-1),

- if the transmission path crosses one joint:

$$K_{ij}=K_{ij,\text{rigid}}+\Delta_{\text{layer}}\ [\text{dB}] \tag{7}$$

- if the transmission path crosses two joints:

$$K_{ij}=K_{ij,\text{rigid}}+2\ \Delta_{\text{layer}}\ [\text{dB}] \tag{8}$$

But how to determine Δ_{layer} from $\Delta_{\text{layer,ref, x load}}$?

6.2 Application of the $\Delta_{\text{layer,ref, x load}}$ to other junctions than the reference junctions

Applying the laboratory results $\Delta_{\text{layer,ref, x load}}$ of a reference junction in the calculations for flanking transmission will be relevant for a concrete floor/masonry wall junction with a comparable surface mass ratio and a comparable load. If this is not possible, the laboratory results obtained with a reference junction having a higher contrast between the surface masses than the junction to model and with a higher applied load must be chosen to be on the safe side.

6.3 The path uninterrupted by the resilient strip

The results presented below show that the path that doesn't include the strip is also impacted by the insertion of this strip.

Figure 11 shows variations of the K_{ij} for the F1-F2 path of the X-junction for different types of strips. A variation curve is the difference between the $K_{F1\text{-}F2}$ of the junction including a strip and the $K_{F1\text{-}F2}$ of the rigid junction.

For this case, where the walls are composed of cellular concrete blocks with a density of 666 kg/m³ (the surface mass ratio with the floor is 0.2), $K_{F1\text{-}F2}$ decreases by about 2 dB between 800 Hz and 5000 Hz.

For the junction composed of bricks (figure 12) with a density of 1448 kg/m³ (the surface mass ratio with the floor is 0.8), $K_{F1\text{-}F2}$ decreases by about 5 dB between 800 Hz and 5000 Hz.

The decrease of the K_{F1-F2} is only slightly dependent on the strip type (see the difference between the curves of strips with a s'_t higher than 1000 MN/m³ and the curves of strips with a s'_t lower than 600 MN/m³

In conclusion, the paths that don’t include the strips are affected by their insertion in the other paths of the junction. The closer the surface mass ratio to one, the higher the negative impact. The decrease of the K_{ij} for this path is only slightly dependent on the strip type. To measure the influence of a resilient strip on a path not interrupted by the strip, it could be necessary to use a T or X-junction. An empirical formula determining a relation between the decrease of the K_{ij} for this path and the surface mass ratio of the elements on both sides the strip could be found.

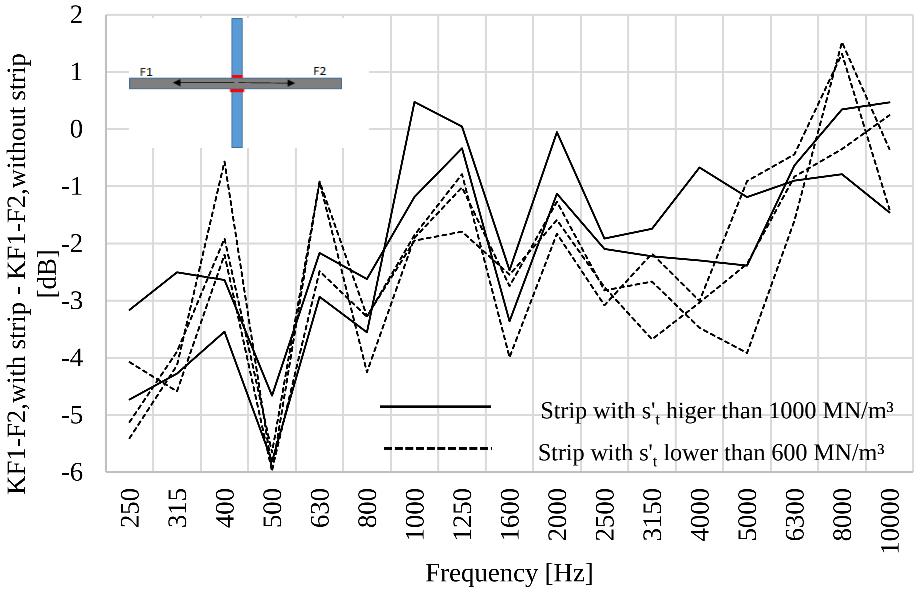

Figure 11: Impact of the resilient strips on the path uninterrupted: vertical walls are composed of cellular concrete, the surface mass ratio with the floor is 0.2

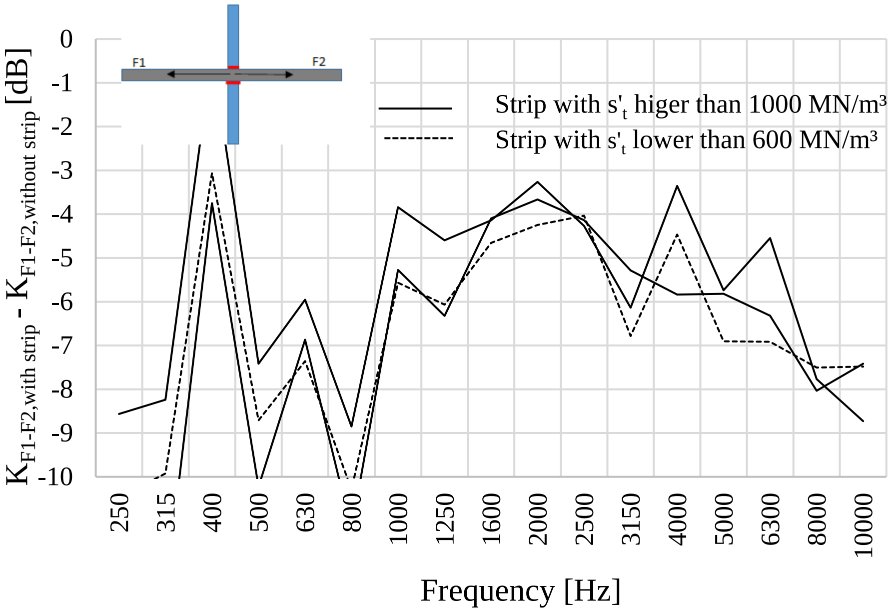

Figure 12: Impact of the resilient strips on the path uninterrupted: vertical walls are composed of bricks, the surface mass ratio with the floor is 0.8

7 CONCLUSIONS

This paper proposes some guidelines for the establishment of a standardized measurement procedure to quantify the effectiveness of a resilient strip used to improve the attenuation of the flanking transmisssion. The first part of this paper shows that the Δ_l (renamed Δ_{layer} in this paper), as defined in the standard IS0 12354-1, depends on the load applied on the resilient strip and on the surface mass ratio of the elements disconnected by the strip. It is then suggested to introduce a new standardised quantity, the $\Delta_{layer,ref,xload}$, which quantifies the effectiveness of the resilient strip under standardised conditions. It is later specified how to use this quantity in calculation models of the standards ISO 12354 to predict the impact of the resilient strip in other junctions than those standardized.

8 ACKNOWLEDGEMENTS

The results presented in this paper have been obtained within the frame of the projects “A-light II” (Integrating lightweight concepts in acoustical standardization) and the “Standards Antenna Acoustics”. The authors are grateful for the financial support from the Federal Public Service Economy of Belgium.

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