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Characterization of metallic studs used in gypsum board single frame walls

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This work aims to characterize metallic studs used in gypsum board single frame walls. The sound reduction index associated to the direct path (cavity path) of the double wall can be calculated using a wave based transfer matrix approach. In the mid-high frequency range, an SEA approach is preferred to model the frame between the two gypsum leaves, as point connections modeled by punctual springs defined by its translational stiffness located at the screws position on the frame. An experimental setup has been proposed to determine the equivalent stiffness of the stud at the screw positions. Based on these data predicted and measured sound reduction index are in fairly good agreement. In the present work, a finite element model corresponding to the experimental setup is developed to characterize metallic studs in order to perform a parametric study and investigate new studs shape. The effects of the material physical characteristic variations, the dimensions and metal thickness, and the shape of the studs as well as the type and number of gypsum board mounted on the frame are presented and discussed.

1 Introduction

Lightweight single frame double walls are very common solutions for partitioning in dwellings. They are typically composed of two leaves mounted on a wood or steel frame; the cavity between the two leaves being filled by absorbing material to improve the acoustic performance. When the double wall is mounted on a single frame, the presence of this frame, i.e. structural connections, is associated to a structural path that can have a great influence on the acoustic performance depending on its mechanical characteristics (stiffness of the connections).

Performance of lightweight double wall (see Figure 1) in terms of sound transmission has been studied both experimentally and analytically [1]. The sound reduction index of these lightweight double walls is calculated using the wave approach. In the wave approach, the metallic frame is considered by introducing translational springs to couple the plasterboards on each side of the frame. These springs are considered linear and are located at the studs position. They are modeled as normal line forces acting on the leaves and are characterized by their stiffness as well as their separation distance (periodicity). This approach is valid in the low frequency range. In the mid-high frequency range, the frame between the two leaves is considered as point connections modeled by punctual springs located at the screws position on the frame. An SEA approach is preferred in this frequency range. A difference is introduced to represent the studs and the boundary rails on which the double wall is mounted on. The transition between line connections to point connections appears when the half flexural wavelength of the panels is equal to the distance between screws. This evaluation of the sound reduction index of single frame partition is included in the commercially available software AcouSYS developed and sold by CSTB.

This work aims to characterize metallic studs used in gypsum board single frame walls. An experimental setup has been proposed to determine the equivalent stiffness of the stud at the screw positions [2]. Based on these data, predicted and measured sound reduction index are in fairly good agreement. In the present work, a finite element model corresponding to the experimental setup is developed to characterize metallic studs in order to perform a parametric study and investigate special studs shape. The effects of the material physical characteristic variations, the dimensions and metal thickness, and the shape of the studs as well as the type and number of gypsum board mounted on the frame are presented and discussed.

The first part of this paper presents the experimental setup developed to characterize partition studs with the

corresponding FEM approach. The second part consists in a parametric study.

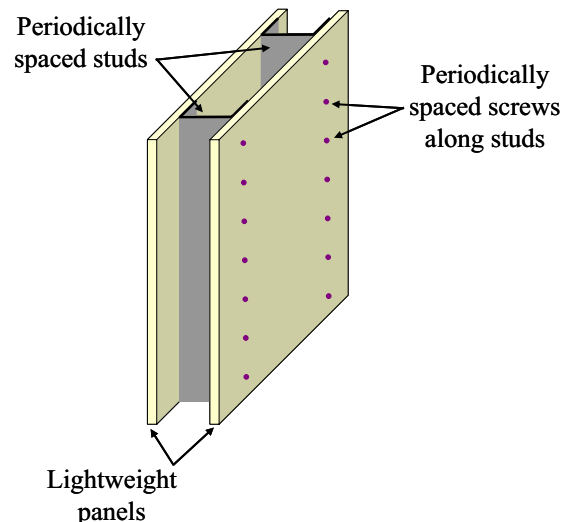


Figure 1: Description of lightweight single frame double wall.

2 Stud characterization

2.1 Experimental setup

A picture of the experimental setup is shown in Figure 2. In order to determine the spring stiffness associated to the studs/screws, the metallic stud to be characterized is placed centered between two gypsum boards and attached in the same way as used for the partition wall (screws separated by 30 cm and with same screwing torque). The top and bottom boards have the dimensions of 1.2x1.2 m² (1.2 m representing the standard gypsum board width). To maintain the gypsum boards on the peripheries parallel to the stud to be characterized, wood studs are used (with the same height as the studied stud). The system is then placed on the ground and the transfer function corresponding to the inverse of the input receptance is measured allowing to directly obtain an equivalent stiffness ($K=F/d$, where K is a stiffness in N/m, F the force in N and d the displacement in m). The excitation is obtained with an impact hammer. An example of such measured equivalent stiffness is presented in Figure 3. It can be observed that in the low frequency range (below 8 Hz), the system is not well excited by the impact hammer, and that in the high frequency range above 20 Hz, the modal behavior of the system becomes dominant. The equivalent stiffness for the studs is therefore deduced from the transitional frequency range (between 8 and 20 Hz)

where the measured transfer function is relatively flat. In this case the equivalent punctual stiffness for the characterized stud is about 265 kN/m.

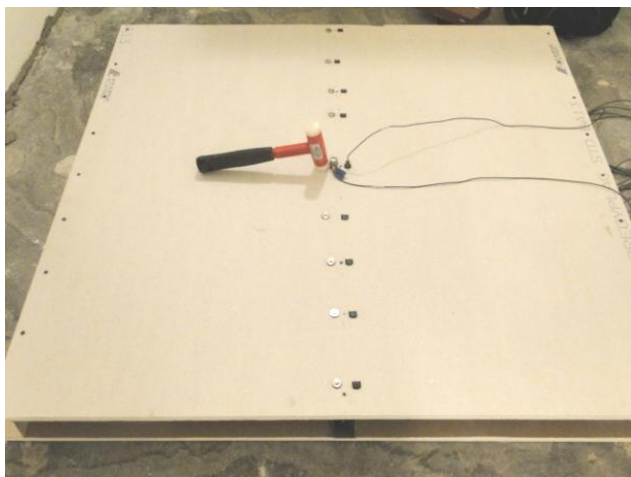


Figure 2: Experimental setup for characterizing metallic studs.

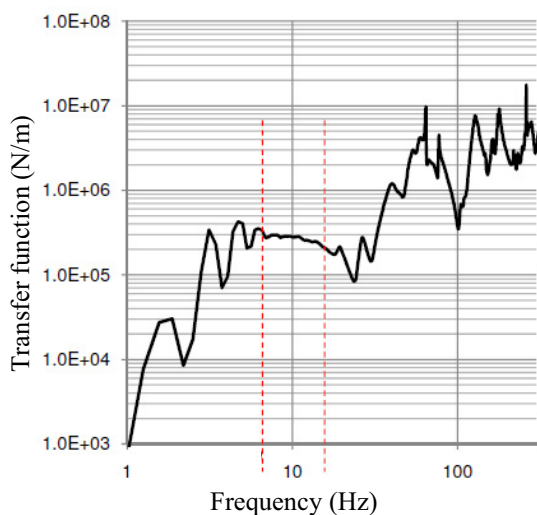


Figure 3: Example of measurement results.

2.2 Finite element modeling

A finite element modeling approach is proposed in order to avoid the characterization on the experimental setup. Indeed, in order to investigate new shapes for studs, it would be much more efficient to determine their equivalent stiffness by calculation before actually fabricating them. The experimental setup is then reproduced with the FEM approach as shown in Figure 4(a). The FEM software NASTRAN was used for these numerical calculations; shell elements are utilized for modeling the different components (gypsum boards and stud) since it was found to be easier to introduce elements merging associated to the screws presence. The boundary conditions on the bottom plate correspond to blocked vertical displacement and free in-plane rotation. The system is excited by a normal force acting on the top plate, at positions corresponding to a screw.

The investigated U-shaped stud section is represented in Figure 4(b). The stud has a height (a_2) of 70 mm, a width (b) of 38 mm and wings of 5 mm in length (a_1); it is made out of steel. The gypsum boards are 12.5 mm in thickness,

with density of 710 kg/m³ and elastic modulus of 2.1 GPa. As mentioned previously, each board is 1.2x1.2 m².

Figure 5 presents the transfer function calculated as well as the one measured. Two calculations are actually performed: the first one considers the input transfer function (force and displacement at the same location) and the second one considers a slightly different location for the excitation force and the displacement evaluation. Indeed, the experimental setup uses a force transducer and an accelerometer that are not collocated. It can be seen in Figure 5 that the evaluation of the non collocated transfer function allows matching the measured transfer function in the frequency range of interest. Using the FEM simulation, the evaluated equivalent punctual stiffness for the considered stud is 269 kN/m, which is quite close to that obtained from measurement (see Section 2.1). Furthermore it can be seen that the modal behavior above 20 Hz is different between the model and the experiment; this was expected since no optimization was performed in terms of figuring out the actual or more appropriate boundary conditions to be applied in FEM.

Figure 6 compares the stiffness averaged along the stud obtained from measurements and from FEM. The comparison is again good in the frequency range of interest. An averaged equivalent punctual stiffness for the considered stud is about 200 kN/m.

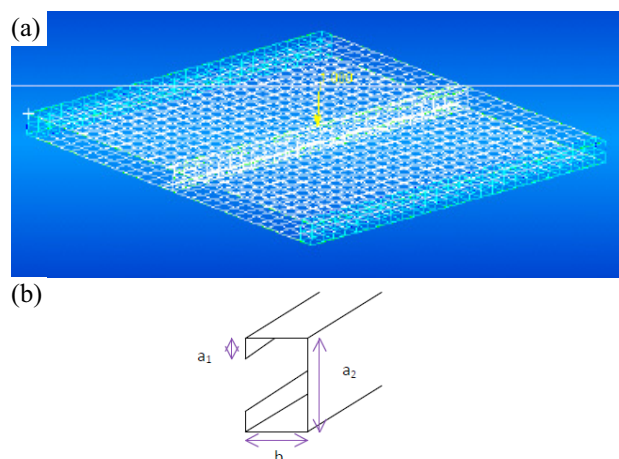


Figure 4: (a) Finite element modelling of experimental setup and (b) standard stud considered.

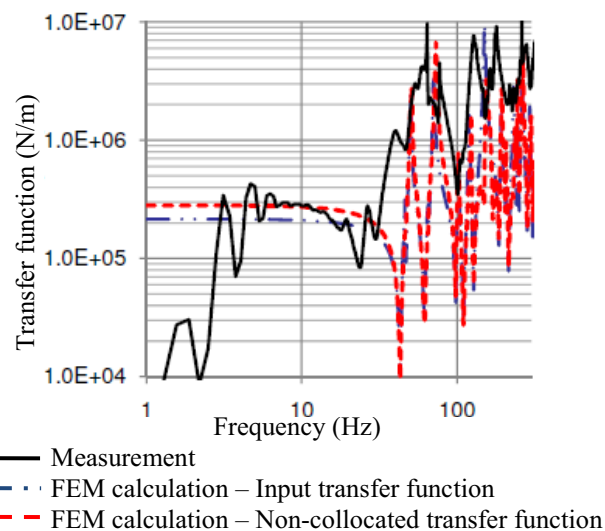


Figure 5: Comparison between measurement and FEM calculation.

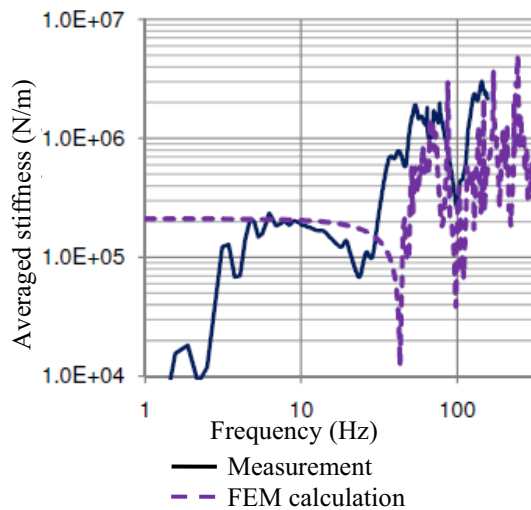


Figure 6: Comparison of averaged stiffness from measurements and FEM calculations.

These results show that it is possible to use FEM to evaluate the equivalent stiffness of studs. Without refining the finite element model (boundary conditions, etc...) it is possible to obtain equivalent stiffness close to the one measured. In order to evaluate the influence of different parameters on the equivalent stiffness, a parametric study was performed.

3 Parametric study

The influence of different parameters on the equivalent stiffness is investigated in this section.

3.1 Stud material

Studs are generally made out of steel; however it is possible that the steel physical characteristics could be different. Therefore, variations in terms of mass density (from 7700 to 7900 kg/m³ with 50 kg/m³ step), elastic modulus (from 180 to 240 GPa with 10 GPa step), and damping factor (1%, 1.5% and 5%) were investigated. The density and the damping factor were found to be without influence on the evaluated equivalent stiffness. However, the elastic modulus was found to have little effect as seen in Figure 7; the equivalent stiffness remains nevertheless in the same order of magnitude.

3.2 Gypsum boards

In this section, the effect on the equivalent stiffness of the characteristics and number of gypsum boards attached to the metallic stud is examined. Indeed, a partition with similar metallic frame can be mounted with a single layer or a double layer of gypsum boards on each side. Figure 8 presents the limited effect of a change in elastic modulus of the gypsum board.

Figure 9 shows the effect of changing the thickness of the gypsum board from 12.5 mm to 25 mm, the other characteristics of the gypsum board remaining constant. It can be seen that the gypsum board thickness has an effect on the stud equivalent stiffness: the stiffness being pretty much doubled when the board thickness is doubled.

The number of gypsum boards attached to the stud is finally studied. When considering two gypsum boards, each of thickness h , on one side of a partition, acoustic performance simulations are usually carried out using a single equivalent

gypsum layer having double thickness $2h$, the same density and an elastic modulus divided by 4, in order to have the same critical frequency independently of the number of boards. Figure 10 illustrates that the number of boards has a little influence of the evaluated equivalent stiffness.

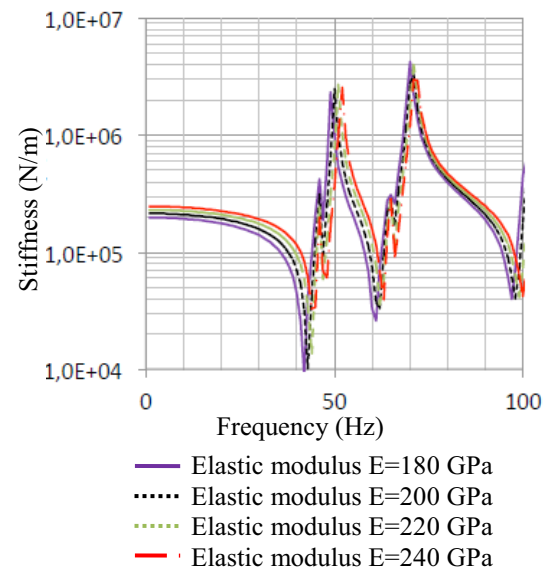


Figure 7: Effect of the steel elastic modulus on evaluated equivalent stiffness.

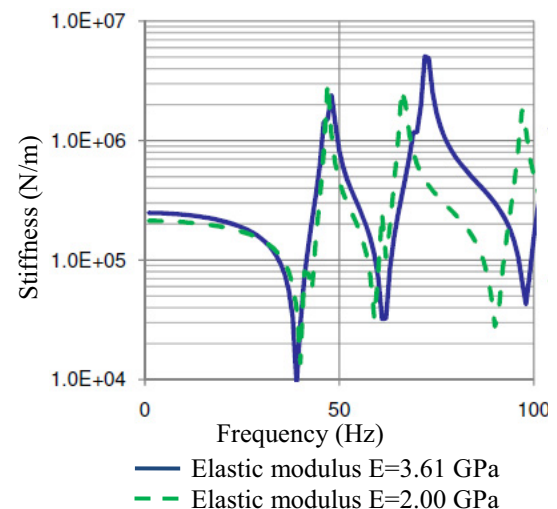


Figure 8: Effect of the gypsum board elastic modulus on evaluated equivalent stiffness.

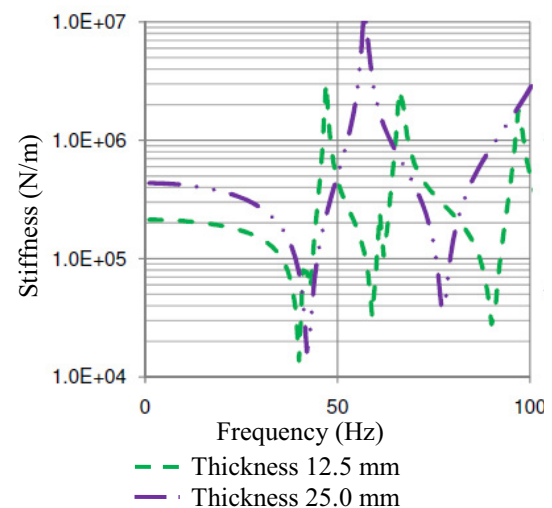


Figure 9: Effect of gypsum board thickness on evaluated equivalent stiffness.

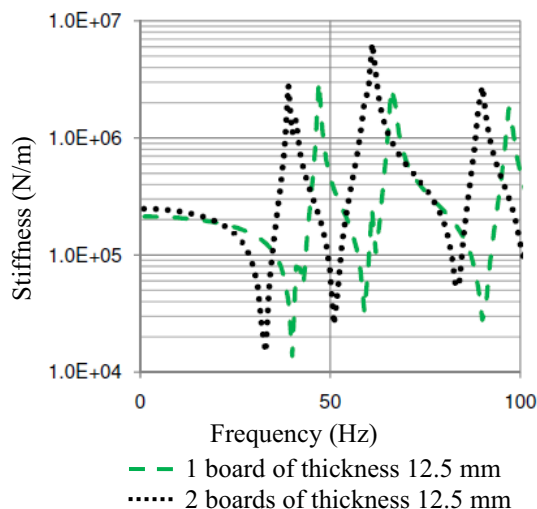


Figure 10: Effect of gypsum board number on evaluated equivalent stiffness.

3.3 Stud shape

In this section, the effect on the equivalent stiffness of the stud shape is inspected.

The first stud shape taken into account (Shape 1) is described in Figure 11. The dimensions given in bold correspond to the reference case. The effect of a variation in material thickness is shown in Figure 12, and the effect of a change in stud dimensions in Figure 13.

It can be seen that the material thickness of the stud has quite an influence on the evaluated equivalent stiffness: as expected, the thicker the stud the stiffer. The equivalent stiffness is augmented by a factor of more than 3 when the material thickness is increased from 0.6 to 1 mm. If this type of influence with respect to the stud material thickness was expected, it is still important to notice that it is essential to use less steel.

The change in the dimensions b_1 and b_2 has the largest influence on the equivalent stiffness. In fact, for this stud shape it was expected that the springiness was related to the stud portion defined by b_2 and a_2 . However, the modification of the dimension b_1 modifies the position of the screw with respect to stud back (the screws being considered centered with respect to the stud width b_1), bringing it closer to the stud portion defined by b_2 associated to springiness. It is surprising to notice that the increase in dimension a_2 has no influence on equivalent stiffness. These results also indicate that shape 1 studs of different heights, i.e. 70 or 48 mm, will be associated to the same equivalent stiffness.

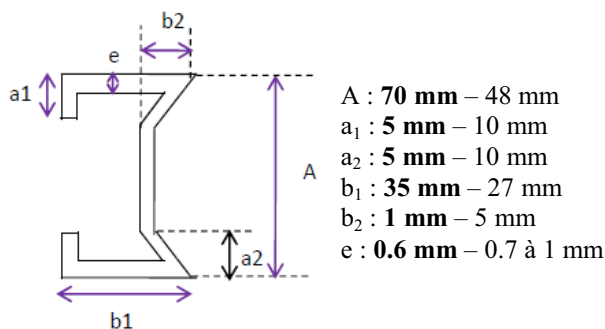


Figure 11: Stud geometry – Shape 1.

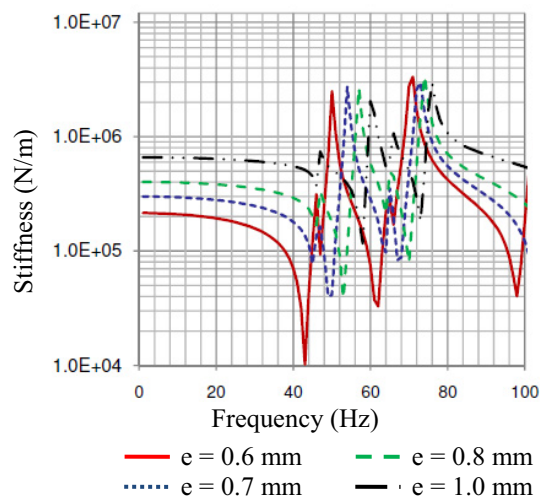


Figure 12: Effect of stud material thickness – Shape 1.

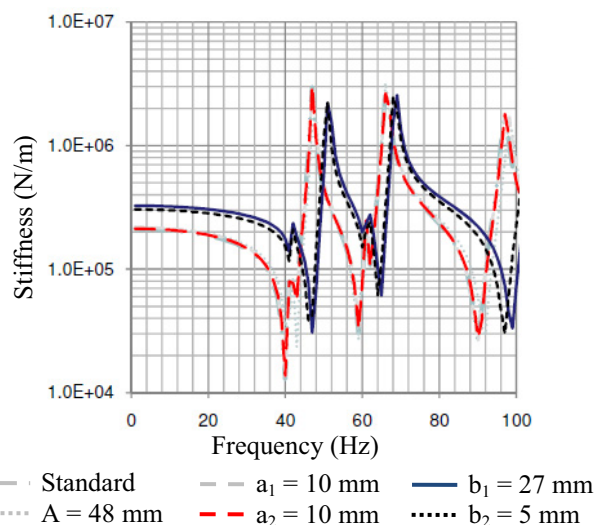


Figure 13: Effect of stud dimensions – Shape 1.

Finally different shapes to render the stud more resilient are studied. Figure 14 shows the different shapes considered and Table 2 indicates their dimensions. The studs with shape C and D are usually referred to “acoustic studs”. The stud height for the four different shapes is 48 mm.

Figure 15 presents the evaluated equivalent stiffness for the different shapes A, B, C and D considered. It can be observed that Shape A is associated to the largest stiffness, while Shape C and Shape D to the lowest. However, the change in stiffness is not extremely important: about a factor of 3 between the largest stiffness and the lowest. The reference to “acoustic studs” for Shape C and D is obviously understood as they are associated to a lower stiffness, therefore limiting the coupling between the two skins of the partition.

Finally, the sound reduction index for a single frame partition mounted with a single layer of gypsum boards (13 mm in thickness) on each side of metallic frame. Standard studs and studs with Shape C (or D being equivalent) are considered. The gypsum boards are assumed to be screwed every 30 cm on the metallic frame. Figure 16 shows the different transmission path as well as the sound reduction index evaluated with AcouSYS. The transmission path associated to the studs is greatly improved when using the C shaped studs instead of the standard studs. It can also be observed that the studs have an effect on sound transmission close to the partition resonant frequency

(around 100 Hz); indeed the studs are able to diminish this effect: the stiffer the stud the better to oppose the mass-cavity-mass resonance behavior. However, the change of studs only is just not enough to largely improve the sound reduction index (global index R_w+C remains identical at 36 dB) due to dominant transmission path through peripheral frame elements..

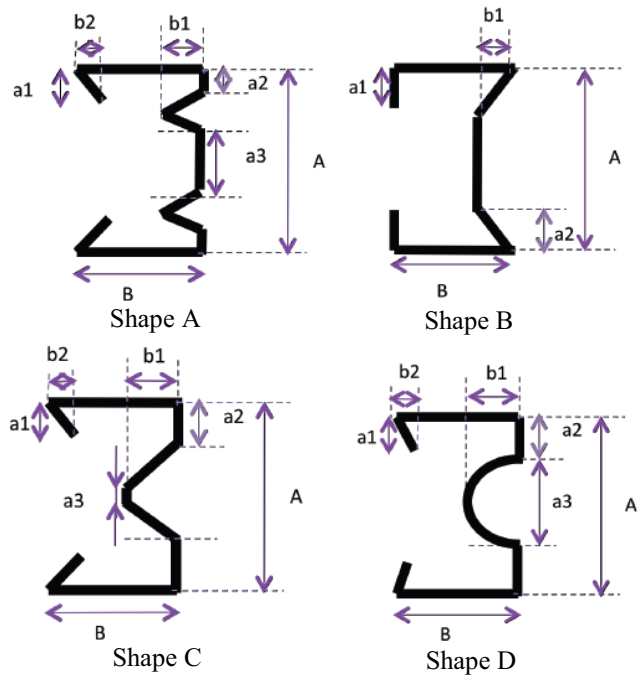


Figure 14: Different stud shapes considered.

Table 2: Dimensions of stud shapes considered.

	Values (mm)			
	Shape A	Shape B	Shape C	Shape D
A	48	48	48	48
a ₁	5	5	5	5
a ₂	5	5	12.5	12.5
a ₃	20	-	10	23
B	30	35	50	50
b ₁	2	1	25	17.5
b ₂	5	X	5	5

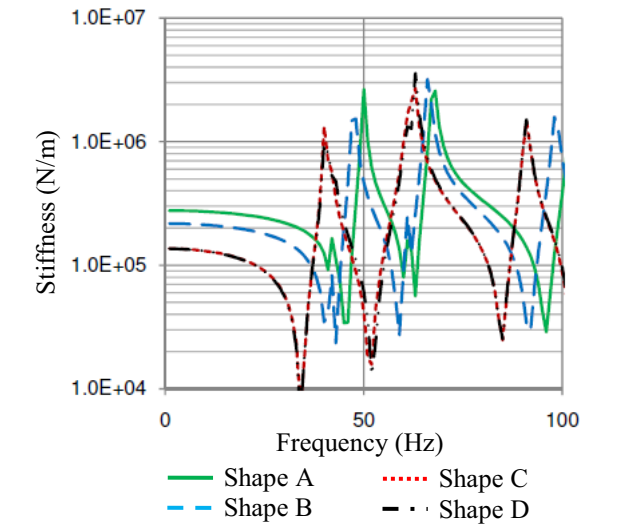


Figure 15: Effect of different stud shapes.

5 Conclusion

The goal of this work was to develop a finite element modelling approach to characterize metallic studs used in gypsum board single frame walls. The system modelled by finite element is based on an experimental setup previously designed to determine the equivalent stiffness of the stud at the screw positions. The effects of the material physical characteristic variations, the dimensions and metal thickness, and the shape of the studs as well as the type and number of gypsum board mounted on the frame were presented and discussed. The effect of a change in stud shape was also evaluated on the sound transmission index. Even if the transmission path associated to the studs can be greatly improved when using studs with lower equivalent stiffness, it was shown that it was just not enough to largely improve the sound reduction index. Thus, in order to improve single frame partition sound transmission index, this work has to be extended to evaluate to equivalent stiffness of the peripheral frame components (rails as well as studs connected to supporting building element) and defined their optimal shape.

Acknowledgments

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References

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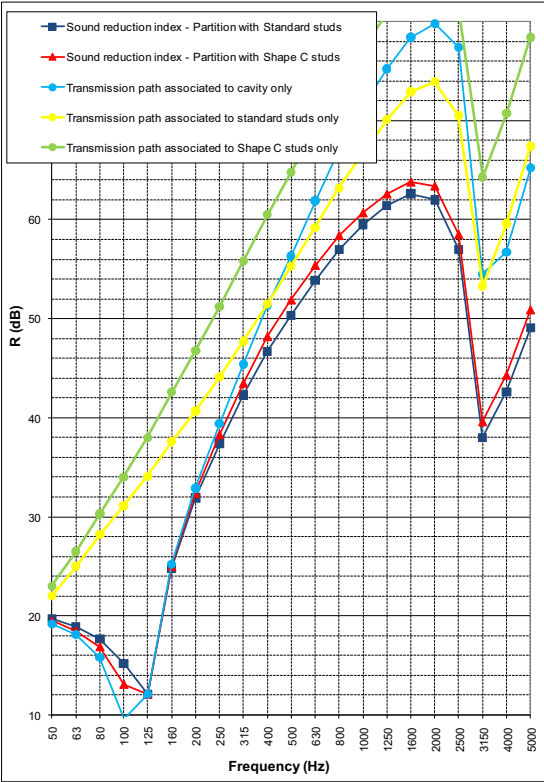


Figure 16: Sound reduction index for single frame partition.