Direct Sound Transmission Loss of Heavy Gauge Steel Stud Walls

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Summary
In a recent study at the National Research Council of Canada, the direct sound transmission loss of heavy gauge steel stud walls was investigated. Mid-rise buildings (4 to 6 stories) using steel stud walls are becoming more and more common in North America. In addition to the steel studs, the walls typically include bridging channels and steel straps for bracing against lateral and shear loads. The sound transmission losses of more than thirty of the steel stud walls were measured in this study. The parameters that were varied between walls included the stud spacing, stud gauge, stud depth, cavity insulation, and sheathing. In addition to the standardized transmission loss tests, structural measurements were performed to investigate the effect of stud stiffness and other parameters.

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1. Introduction

In the North American market, mid-rise buildings (four to six stories high) are currently in high demand as a consequence of increased urban densification. Canadian manufacturers of construction products want to access this growing market, and are seeking to provide mid-rise builders with cost-effective products that have validated performance. In collaboration with Canadian industry, the National Research Council of Canada is leading various projects in developing, improving and adopting building products and assemblies for the mid-rise building market.

In an ongoing joint research project between the National Research Council Canada (NRC) and the Canadian Sheet Steel Building Institute (CSSBI), the sound transmission characteristics of heavy-gauge steel-framed constructions are being investigated. The project consists of two stages. The first focuses on the direct sound transmission through walls and floors, while the second focuses on flanking sound transmission. In this paper, some results of the first phase are presented, namely the sound transmission loss characteristics of heavy-gauge steel stud walls. Future publications will provide details on the direct sound transmission through floor assemblies with steel joists, and on the flanking sound transmission in steel-framed buildings.

As part of the first stage of the project, the sound transmission losses of thirty steel-framed wall assemblies were tested. In collaboration with CSSBI, a reference assembly was defined, and the effects of various construction parameters were investigated. In addition to the standardized transmission loss tests, some structural measurements were performed to investigate the stud stiffness and other parameters. The results presented in this paper and further details will be incorporated in the NRC Research Report RR-337, “Apparent Sound Insulation in Steel-Framed Buildings”, to be published in 2016.

2. Specimen Descriptions and Measurement Setup

The walls investigated in this study were double-leaf walls with heavy gauge steel studs as framing members. The reference assembly was defined as the following: G16_SS152(406)_GFB152_RC13(406)_G16. Here, G16 indicates one layer of 15.9 mm thick gypsum board (mass per area: 11.0 kg/m^2), SS152(406) indicates 152 mm deep steel studs spaced 406 mm on centers (steel thickness: 1.37 mm), GFB152 indicates 152 mm thick glass fiber insulation, and RC13(406) indicates 13 mm deep resilient metal channels spaced 406 mm on centers. The gypsum board was attached with screws spaced 305 mm apart at the perimeter and in the field. In addition to the above named elements, the walls also included bridging channels and steel straps for bracing against lateral and shear loads. Figure 1 shows a picture of the assembly without sheathing.

The Sound Transmission Loss tests were conducted in NRC's direct wall transmission facility, and were

Figure 1. Reference wall assembly in test frame, with sheathing removed. The flat strap cross and bridging channel in the center of the wall brace against lateral and shear loads.

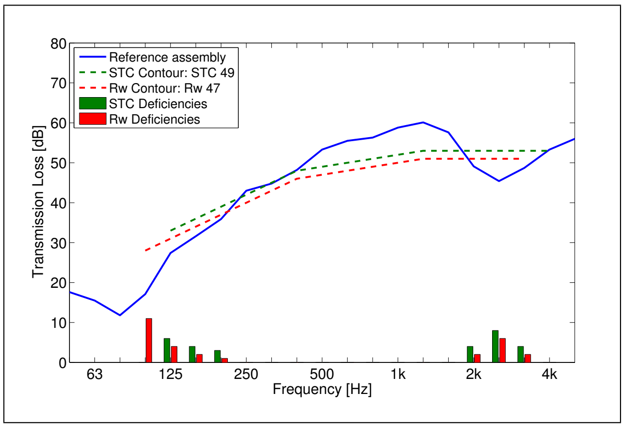

Figure 2. Sound Transmission Loss of reference assembly: G16_SS152(406)_GFB152_RC13(406)_G16

performed according to ASTM E90 [1]. The area of the wall specimen was 8.92 m^2, and the room volumes were approximately 250 m^3 and 140 m^3. The temperature and relative humidity in the rooms were about 21 C and between 55% and 65%, respectively. The Sound Transmission Loss was measured in both directions, and the average was taken as the final value. This reduces any errors associated with the microphone calibration. The source room was excited with pink noise using four uncorrelated loudspeakers, and the sound pressure levels were recorded in source and receiver room at nine positions each, using one microphone which was moved by a computer controlled robot in each room. The reverberation times were measured using the interrupted noise method. The Sound Transmission Loss curves of all walls presented here were well below the facility flanking limit.

3. Parametric Study

Starting with the reference assembly, a parametric study was conducted investigating several important specimen parameters. Table I lists the investigated parameters together with the options considered. The first column in Table I indicates the values for the reference assembly. Not all possible combinations were tested. Instead, one parameter was varied at a time, and selected additional tests were performed with more than one parameter modified.

The Sound Transmission Loss of the reference assembly is shown in Figure 2. Single number quantities STC and R_w were calculated from the Sound Transmission Loss curves according to ASTM E413 [2] and ISO 717-1 [3]. The assembly achieves an STC rating of 49 and R_w of 47. The deficiencies occur at low frequencies and in the region of the coincidence frequency. The R_w value in particular is dominated by the deficiencies in the 100 Hz band (11 dB).

The Sound Transmission Loss curve follows the characteristic pattern of double-panel walls. The mass-spring-mass resonance frequency lies in the 80 Hz band (calculated: 56 Hz, assuming air spring). The coincidence dip of the gypsum board occurs in the 2500 Hz band (calculated: approx. 2200 Hz). The coincidence frequency of the gypsum board was also measured using structural drawaway measurements (see Section 4), and was determined to be around 2600 Hz. The reference wall assembly falls just short of the minimum requirement for partition walls between units in the 2010 National Building Code of Canada, STC 50.

3.1. Influence of Sheathing

The influence of the sheathing layers was investigated by adding and/or removing gypsum board from the wall. The reference assembly had one layer of 15.9 mm thick gypsum board (type X) on both sides. Additional layers of gypsum board increase the mass of the wall leafs, which in turn leads to a lower mass-spring-mass resonance frequency, which in turn leads to better sound insulation performance in the frequency range of interest.

Figure 3 shows the effect of adding gypsum board to the reference assembly. The mass-spring-mass resonance frequency shifts from the 80 Hz band into the 63 Hz band and further into the 50 Hz band. Each additional layer of gypsum board increases the STC value by 4 points, and the R_w value by 5 points. For assemblies without cavity insulation, the improvement in STC is slightly higher, with 5 points per additional layer (not shown). For assemblies without resilient channels, the improvement in STC is only 3 points per additional layer (not shown). For walls with 92 mm studs, the improvement is 6 points per additional layer (not shown).

3.2. Influence of Cavity Insulation

The wall cavity of the reference assembly was filled with 152 mm thick glass fiber batts. The main effect

Table I. Specimen parameters.

Parameter	Option 1	Option 2	Option 3
Sheathing	G16 on each side	G16 on one side, 2G16 on other side	2G16 on each side
Cavity	GFB152	GFB92	No insulation
Resilient channels	With RCs	Without RCs	
Stud spacing	406 mm o.c.	610 mm o.c.	
Stud depth	152 mm	92 mm	
Steel thickness	1.37 mm	1.09 mm	

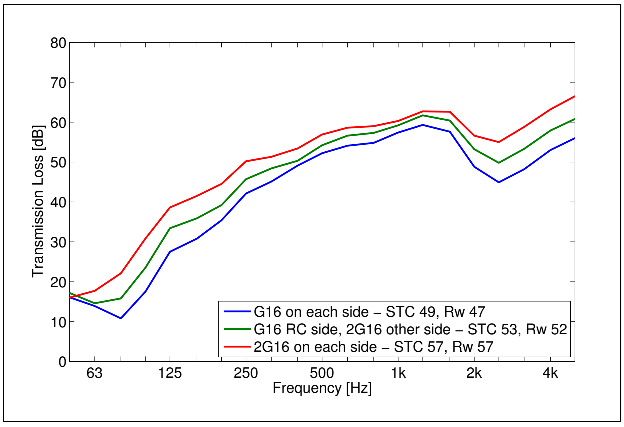

Figure 3. Influence of sheathing. For additional layers of gypsum board, the mass-spring-mass resonance shifts from the 80 Hz band into the 63 Hz band and further into the 50 Hz band.

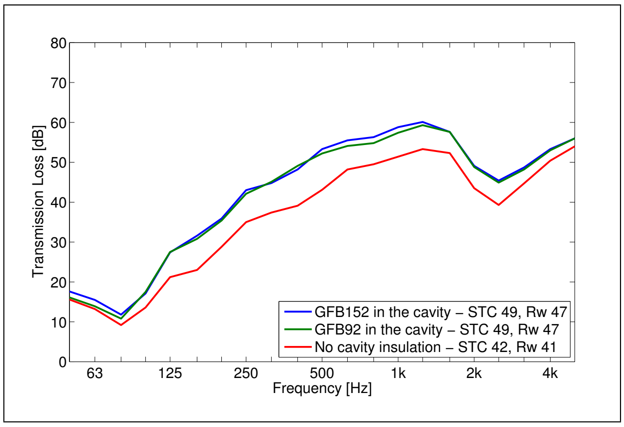

Figure 4. Influence of cavity insulation. Removing the cavity insulation from the reference assembly has a signficant effect on the Sound Transmission Loss curve. The thickness of the insulation material tested here is of minor importance.

of the insulation material in terms of sound insulation performance is to increase the air flow resistivity inside the cavity [4]. This reduces the effective stiffness of the cavity, which leads to a downward shift of the mass-spring-mass frequency. The insulation batts also increase absorption by dissipating sound energy inside the cavity into heat.

Removing the insulation material from the reference assembly significantly decreases the Sound Transmission Loss values, as shown in Figure 4. The STC value drops from 49 to 42, the R_w value from 47 to 41. However, Figure 4 shows that reducing the thickness of the glass fiber insulation from 152 mm to 92 mm only has limited effect on the Sound Transmission Loss. The STC remains at 49, the R_w at 47 points. This is in contrast to an earlier report on gypsum board walls [4].

If two layers of gypsum board are attached on both sides, the effect of removing the insulation material from the cavity is reduced, but still significant (not shown). The STC value in this case drops by 4 points, the R_w by 5 points. Once again, changing the thickness of the insulation material from 152mm to 92mm only has limited effect (ΔSTC -1, ΔR_w ± 0).

3.3. Influence of Resilient Channels

Resilient metal channels have been shown to be very effective for sound insulation [5]. They effectively decouple the sheathing layer on one side from the studs by adding a new mass-spring resonator. This reduces the structural transmission across the stud, and shifts down the mass-spring-mass frequency of the assembly.

Figure 5 shows the influence of resilient channels. The mass-spring-mass resonance frequency shifts upwards in frequency when removing the resilient channels, decreasing the sound insulation performance above 80 Hz. Also visible in the TL curve for the wall without resilient channels is a pronounced dip in the 315 Hz band. This is likely due to the coincidence frequency of the steel stud, see Section 4. If the studs are not decoupled from the sheathing layers, the stud can “force” its motion onto the sheathing layers. This is particularly important at its coincidence frequency, at which the stud radiates very efficiently.

The STC value in this case drops by 7 points, the R_w value by 6 points. For assemblies with two layers of gypsum board on each side, the degradation is even larger (10 points in STC and R_w, not shown). Given these significant changes, the use of resilient channels is recommended.

3.4. Influence of Stud Spacing

The stud spacing is often determined by structural and/or fire resistance considerations. The smaller the stud spacing, the stronger the wall structurally, and the higher the fire resistance. These considerations

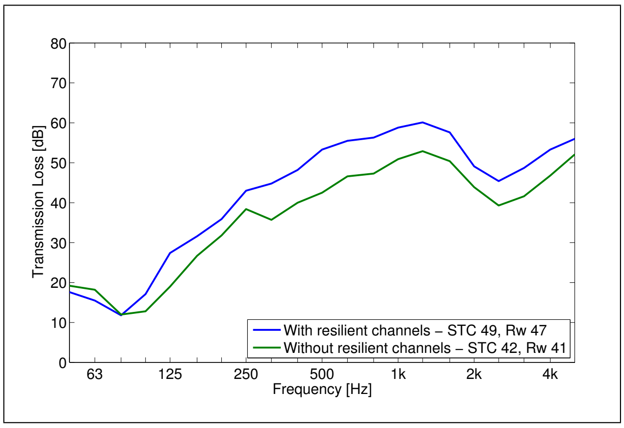

Figure 5. Influence of resilient channels. Resilient channels are among the most effective devices to improve sound insulation performance. The improvement is even higher for walls with more than one layer of gypsum board on each side.

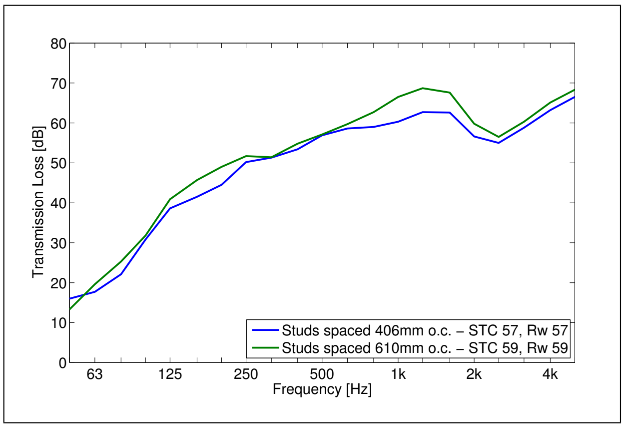

Figure 6. Influence of stud spacing. Increasing the stud spacing improves the sound insulation performance due to less structural connections between the two sides and due to decreased stiffness of the wall.

are particularly important for mid-rise buildings. For sound insulation performance, a larger stud spacing is desirable, to decrease the number of studs and thereby limit the structural transmission, and to decrease the stiffness of the entire wall assembly.

Two different stud spacings were investigated in this study: 406 mm on centers and 610 mm on centers. The results are shown in Figure 6, for walls with two layers of gypsum board on each side. The change in stud spacing has a notable effect on the Sound Transmission Loss curves. It increases over the entire frequency of interest. The STC and R_w values increase by 2 points each.

3.5. Influence of Stud Depth

Figure 7 shows the influence of the stud depth. Two stud depths were investigated: 152 mm and 92 mm. For both types of stud, the steel thickness and the stud spacing was the same (406 mm on centers and

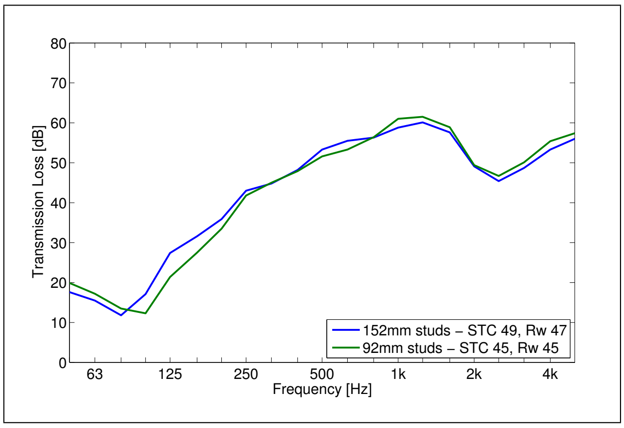

Figure 7. Influence of stud depth. Decreasing the stud depth without changing other parameters degrades the sound insulation performance, because the smaller air gap between the two sides leads to an upward shift of the mass-spring-mass resonance frequency.

1.37 mm, respectively). As would be expected, decreasing the stud depth decreases the sound insulation performance. The smaller air gap between the two sides leads to an upward shift of the mass-spring-mass resonance frequency. The STC value drops from 49 for 152 mm studs to 45 for 92 mm studs, the R_w value drops from 47 to 45. If more layers of gypsum board are used, the change between walls with different stud depth gets smaller (not shown). The influence of the stud depth was not investigated for wall assemblies without resilient channels. It is expected that without resilient channels, the increased stiffness of deeper studs could increase the radiation efficiency at low frequencies, leading to a decrease in sound insulation performance.

3.6. Influence of Steel Thickness

The walls investigated in this study were heavy-gauge steel stud walls, intended to be load-bearing walls in mid-rise constructions. The studs in the reference wall assembly and in all the walls presented so far had a steel thickness of 1.37 mm (16 gauge). Several walls with slightly thinner steel thickness were tested as well, namely 1.09 mm (18 gauge).

Figure 8 shows the Sound Transmission Loss of the reference assembly, and of the same wall with studs with smaller steel thickness. There are some differences between the curves, but they are not very significant. The STC and R_w values improve by 1 point for the wall with thinner steel thickness. While the observed effects between walls with different stud steel thickness are not very significant for the cases studied, it is expected that using light gauge studs (0.455 mm, 25 gauge) would show more pronounced effects. Also, the differences between walls with studs of different steel thickness might be larger for walls without resilient channels.

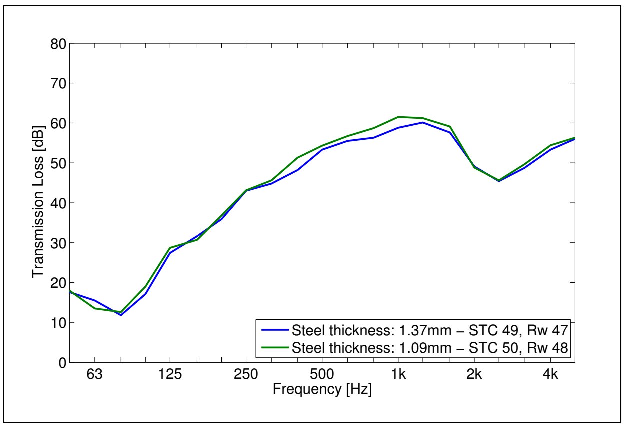

Figure 8. Influence of steel thickness. The steel thickness was found to be of minor importance in this study. However, light gauge walls will show different behaviour in terms of sound insulation.

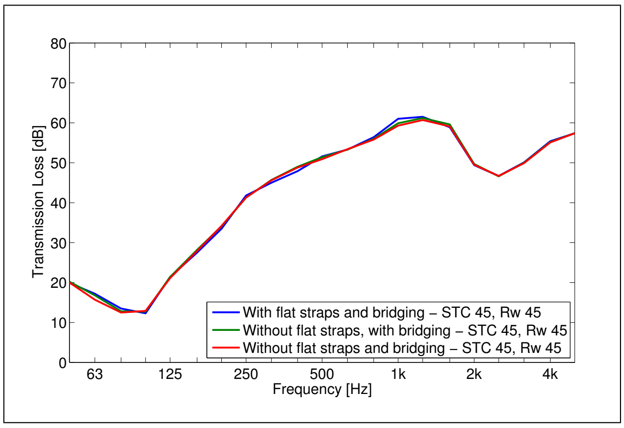

Figure 9. Influence of flat straps and bridging channel. The flat straps and bridging channels do not have a measurable influence on the direct sound insulation of the walls. They may however contribute to flanking sound transmission.

3.7. Influence of Flat Straps and Bridging

It was investigated whether the flat straps and the bridging channels used for bracing against lateral and shear loads had an effect on the direct sound insulation performance of the wall assemblies. To this end, an additional set of measurements was conducted in which the bridging channel and the flat straps were removed from the wall one at a time. A wall assembly similar to the reference assembly, but with 92 mm studs and 92 mm insulation, was used for this investigation: G16_SS92(406)_GFB92_RC13(406)_G16.

As shown in Figure 9, there is little difference between the three measurements. It is assumed that using the reference assembly (with 152 mm deep studs) would show similar results. The flat straps and the bridging channel do not have a significant effect on the direct sound insulation performance of heavy-gauge steel stud walls. However, they may contribute to the flanking sound transmission in buildings. The bridging channel in particular offers a path for vibrations to travel through the wall assembly horizontally and parallel to the wall surface.

4. Structural Measurements

In addition to the Sound Transmission Loss tests, structural drawaway measurements were performed on the reference assembly. The wall was excited by a shaker (PCB K2007E01), and the acceleration response was measured at 20 positions spaced every 5 cm along a straight line. The wavenumbers were then calculated according to the procedure described in [6]. The phase differences between the 20 response signals are used to estimate the bending wave on the structure.

The measurements were performed in-situ: for the gypsum board wavenumbers, the accelerometers were attached on the resilient channel side of the wall; for the stud measurement, the resilient channels and the gypsum panels on both sides were taken off the wall. The insulation batts remained in place, and the stud was also connected to the wall headers and footers, and to the bridging channel and the cross brace.

Figure 10 shows the wavenumbers measured on the gypsum board, and measured directly on the steel stud. Unfortunately, it was not possible to determine the stud wavenumbers below 200 Hz. The first bending modes of the stud are below this frequency, and standing waves made the evaluation of phase differences between the response signals difficult. The horizontal line in Figure 10 indicates the aliasing limit of the calculation, as determined by the spacing between the response positions. Also shown in Figure 10 are the theoretical wavenumbers of the gypsum board and in air. The agreement between the theoretical curve for gypsum board and the measured values is quite good.

The vertical line at 2640 Hz indicates the measured coincidence frequency of the gypsum panels, at which the bending wavelength of the panels equals the wavelength in air. The gypsum board radiates very efficiently at and above this frequency, resulting in the coincidence dip that can be observed in all the Sound Transmission Loss curves presented in this paper.

The vertical line at 270 Hz indicates the measured coincidence frequency of the steel studs, at which the bending wavelength of the stud equals the wavelength in air. The coincidence frequency of the stud also results in a dip in the Sound Transmission Loss curve. This can be observed in Figure 5, for the wall without resilient channels. For walls with resilient channels, the effect of the stud coincidence dip is mitigated.

5. Conclusions

A test series investigating the direct sound transmission loss of heavy gauge steel stud walls was conducted. More than thirty walls were measured, and

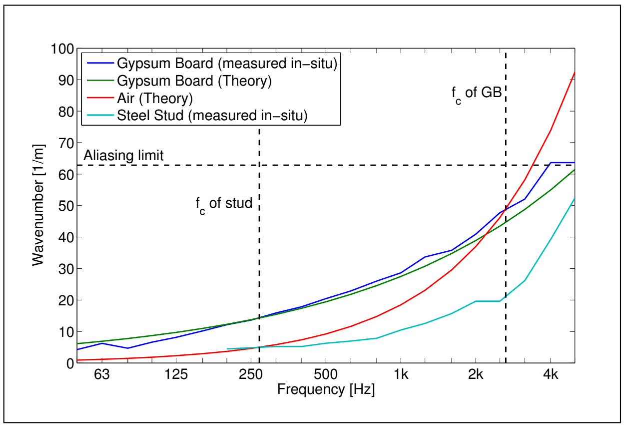

Figure 10. Wavenumbers measured on reference assembly. The cross-over points between the gypsum board/steel stud wavenumbers and the theoretical wavenumbers in air indicate the coincidence frequency of the gypsum board/steel stud, at and above which the gypsum board/steel stud radiates very efficiently.

the effects of some important specimen parameters were studied. It was found that adding additional layers of gypsum board, using resilient channels, and using cavity insulation are the most important steps for achieving improvements in sound insulation. Stud spacing, stud depth, steel thickness, and the thickness of the insulation batts were shown to be less important for the cases studied in this investigation. Other parameters such as screw spacing which were not investigated in this study may also have an effect on the sound insulation performance of the walls. The results of this test series will be incorporated in the NRC Research Report RR-337, "Apparent Sound Insulation in Steel-Framed Buildings", to be published in 2016. The report will also contain the results of the direct sound transmission tests of floors with steel joists, and of flanking sound transmission tests in steel-framed buildings.

Acknowledgement

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