24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

APPARENT SOUND INSULATION IN COLD-FORMED STEEL-FRAMED BUILDINGS

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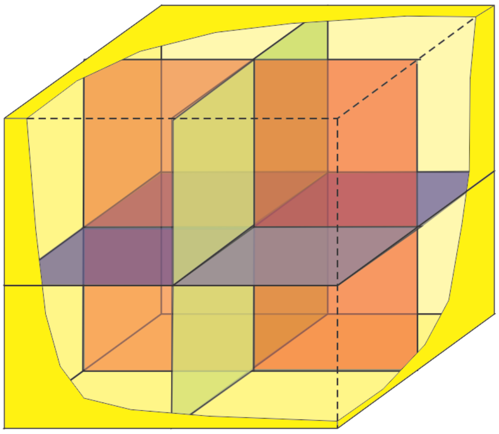
The sound transmission in buildings constructed from cold-formed steel-framed walls and floors was investigated in a large research project at the National Research Council Canada. Preliminary findings were presented at previous conferences. Comprehensive results of the study have now been published in the NRC Research Report RR-337, "Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings." The results are based on direct sound insulation tests of wall and floor specimens in NRC's transmission loss facilities, as well as measurements on a representative full-scale junction mock-up specimen in NRC's 8-room flanking transmission facility. Measurements of the flanking sound transmission were conducted according to the indirect method described in ISO 10848. The individual flanking paths were measured by a sequence of transmission loss measurements in which other transmission paths were suppressed by shielding. The paper presents some highlights of the results, including the importance of discontinuities in floor surfaces and wall gypsum board and the influence of fire blocking in joist cavities.

Keywords: building acoustics, flanking sound transmission

1. Introduction

In the 2015 edition of the National Building Code of Canada (NBCC), the sound insulation requirements for residential housing are given in terms of apparent sound transmission class (ASTC) [1]. The ASTC is the North American ASTM metric that is equivalent to the weighted apparent sound reduction index R'_w defined in ISO 717-1. It takes into account the sound transmission via the direct path (i. e. through the separating wall or floor) and via the flanking paths (e. g. via a shared floor or ceiling). Previous editions of the NBCC focused on the performance of the separating element only, with requirements given in terms of sound transmission class (STC) ratings [2]. The STC rating is the ASTM equivalent of the weighted sound reduction index R_w from ISO 717-1. The National Research Council Canada (NRC) is supporting the code change from STC to ASTC ratings through a number of joint projects with Canadian industry. The focus lies on collecting relevant flanking sound transmission data and on providing tools and guidelines to demonstrate code compliance and accelerate market acceptance [3].



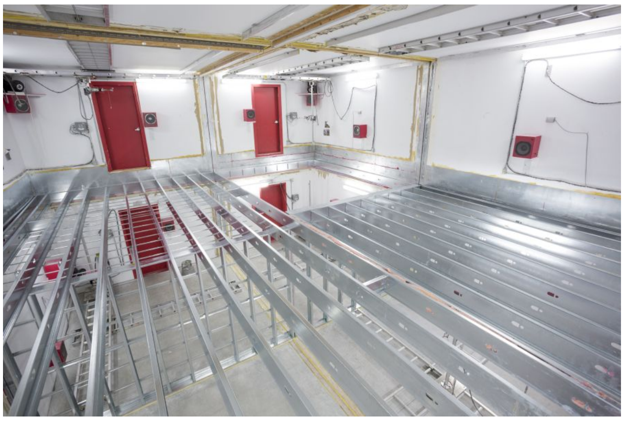


Figure 1: Schematic drawing (left) and image (right) of the NRC 8-room flanking facility. The yellow surfaces represent the permanent outer shell of the facility. The red surfaces indicate the loadbearing walls of the test specimen, the green surfaces indicate the non-loadbearing walls, and the blue surfaces indicate the floors.

In a joint research project between the NRC and the Canadian Sheet Steel Building Institute (CSSBI), the sound transmission characteristics of cold-formed steel-framed constructions were investigated. The objective of the project was to provide data on direct and flanking sound transmission for common construction details in cold-formed steel-framed buildings, particularly for the important mid-rise construction market. The project consisted of two stages: The first phase focused on the direct sound transmission through walls and floors. Extensive measurement series with a variety of steel-framed walls and floors were conducted. The results were published in previous papers [4, 5]. The second phase of the project focused on the characterization of flanking sound transmission in a laboratory test specimen. Some initial research findings were published in a previous paper [6]. Comprehensive results from both phases of the project have been incorporated into the NRC Research Report RR-337, "Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings", available for download from the NRC website [7].

2. Measurements in the Flanking Sound Transmission Facility

Measurements were conducted in the large 8-room flanking sound transmission facility at the NRC, depicted in Figure 1. Each room in the facility is equipped with four loudspeakers and one microphone which is positioned by a robot. The test specimen consists of eight walls, four floors, and six junctions. The permanent part of the facility (upper ceiling/roof, perimeter walls, and foundation floor) is constructed of high sound insulating elements that are resiliently isolated from each other and from the test specimens, with vibration breaks in the permanent surfaces where the specimens are installed. The upper rooms have a ceiling height of 2.7 m while the lower rooms have a height of 2.4 m. The volume of the rooms used to assess flanking transmission in this study ranged between 34 m^3 and 53 m^3.

The individual flanking paths between adjacent rooms (horizontally and vertically separated) were determined according to the indirect method described in ISO 10848 [9]. Transmission loss measurements were conducted in both directions, and the average was used as the final result. This procedure reduces errors associated with the microphone calibration. The source room was excited with pink noise using the four uncorrelated loudspeakers in each room. The sound pressure levels were recorded in the source room and the other seven rooms at nine positions each, using a microphone which was moved by a computer controlled robot in each room. The reverberation times were measured using the interrupted noise method. Background noise levels were measured in each room as part of the transmission loss measurements.

3. Specimen Descriptions

The test specimen in the 8-room flanking facility consisted of four loadbearing walls, four non-loadbearing walls, four floors, and six junctions. To take advantage of symmetries and to allow for redundant measurements, each of the four loadbearing walls were nominally identical in this study, as were the four non-loadbearing walls and the four floors.

3.1 Walls

The walls investigated in this study were double-leaf walls with cold-formed steel studs as framing members. Using a short code to describe the various wall parameters, the loadbearing walls were defined as follows: 2G16_SS152(406)_GFB152_RC13(406)_2G16. Here, 2G16 indicates two layers of 15.9 mm thick gypsum board (mass per area: 11.0 kg/m^2 per layer), 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 on centers at the perimeter and in the field. In addition to these elements, the loadbearing walls also included bridging channels and steel straps for bracing against lateral and shear loads.

The non-loadbearing walls in this study were similar to the loadbearing walls, except that the stud depth and cavity insulation thickness was reduced from 152 mm to 92 mm and that the steel which the studs were formed from was 0.54 mm thick. Using the same short code they can be described as 2G16_SS92(406)_GFB92_RC13(406)_2G16. The non-loadbearing walls did not include bridging channels and bracing steel straps.

3.2 Floors

The floors investigated in this study consisted of 38 mm lightweight gypsum concrete on a corrugated steel deck, fastened to steel joists with a gypsum board ceiling. The floor assembly was defined as the following: GCON38_CORSTE14_SJ254(406)_GFB92_RC13(305)_G16. Here, GCON38 indicates a layer of lightweight gypsum concrete with a maximum thickness of 38 mm, measured from the bottom of the corrugated steel deck (density: 1950 kg/m^3, average mass per area on corrugated steel deck: 60 kg/m^2). The gypsum concrete was poured onto the steel deck in-situ, and was left to cure for more than a month before testing. The strength of the cured gypsum concrete was determined to be 24.8 MPa. CORSTE14 indicates the corrugated steel deck (depth of corrugation: 14 mm, steel thickness: 0.76 mm), and SJ254(406) indicates 254 mm deep steel joists spaced 406 mm on centers (steel thickness: 1.37 mm). The floor also included blocking strips, installed at the center of the joists between the two last joists on each end and between the two joists in the floor center, and a steel strap connecting the three blocking strips with each other and with the other joists. The corrugated steel deck was fastened to the joists with screws spaced 203 mm on centers. As before, GFB92 indicates 92 mm thick glass fiber insulation, RC13(305) indicates 13 mm deep resilient metal channels spaced 305 mm on centers, and G16 indicates one layer of 15.9 mm thick gypsum board. The gypsum board was attached with screws spaced 305 mm on centers at the perimeter and in the field. The glass fiber insulation batts were resting on the resilient metal channels. Floor-ceiling assemblies with one or two layers of 15.9 mm thick fire-rated gypsum board on the ceiling were tested.

3.3 Junctions

Figure 2 shows sketches of the vertical wall-wall junction (left) and of the four different horizontal floor-wall junctions (right) that were investigated in this study. For the wall-wall junction, the loadbearing walls (left to right in Figure 2) were constructed first, and the non-loadbearing walls were attached to the loadbearing studs afterwards.

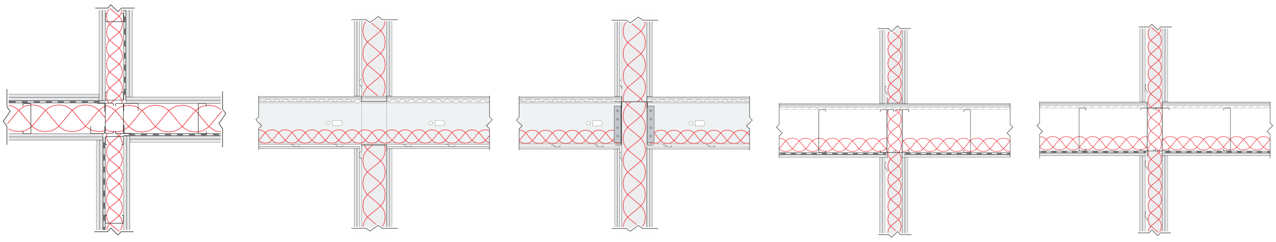


Figure 2: Details of the junctions tested in this study. From left to right: wall-wall junction (top view), floor-wall junction LBc (side view), floor-wall junction LBd (side view), floor-wall junction NLBc (side view), floor-wall junction NLBd (side view).

The four horizontal junctions (LBc, LBd, NLBc, NLBd) were designed to represent a variety of junction details encountered in practice:

- Junction LBc connected a loadbearing wall with joists that were running perpendicular to and continuous across the junction. The corrugated steel deck was installed after the walls and joists, and the gypsum concrete was poured through the bottom track of the upper loadbearing wall.
- Junction LBd connected a loadbearing wall with joists that were running perpendicular to the junction, but which were not continuous across the junction. The joists were attached to the lower loadbearing wall with joist hangers, and the subfloor between the two upper rooms was structurally disconnected.
- Junction NLBc consisted of joists running parallel to the junction and a non-loadbearing party wall standing on top of the subfloor. The subfloor was installed before the upper non-loadbearing wall, and was continuous across the junction.
- Junction NLBd connected a non-loadbearing wall with joists that were running parallel to the junction. The upper non-loadbearing wall was standing directly on top of the lower non-loadbearing wall. This configuration, which is not often found in practice, was chosen to allow the insertion of vibration breaks in the subfloor.

4. Results

Some of the practically most relevant findings from the study are presented here. The full set of results can be found in the NRC Research Report RR-337, “Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings”, available from the NRC website [7].

In order to save space, the focus in the following sections is on the Ff paths, for example floor-floor or ceiling-ceiling paths. Fd and Df paths (e.g. floor-wall or wall-ceiling paths) were also measured in this study, but in many cases the effects of construction details on the flanking sound transmission are most obvious for the Ff paths.

The results presented here have been normalized to the “Standard Scenario” described in NRC Research Report RR-331, “Guide to Calculating Airborne Sound Transmission in Buildings” [8], i. e. to a junction length of 2.5 m for a wall-wall junction and 5.0 m for a floor-wall junction, and to an area of the separating element of 12.5 m^2 for a separating wall and of 20.0 m^2 for a separating floor.

4.1 Effect of Continuous vs Discontinuous Joists and Subfloor

Figure 3 shows the floor-floor (Ff) and ceiling-ceiling (Ff) paths for the two loadbearing junctions investigated in this study. For Junction LBc, the floor joists were continuous across the junction, and the subfloor was continuous, with gypsum concrete poured into the bottom track of the upper loadbearing wall. For Junction LBd, the joists were interrupted at the junction and were connected to the lower loadbearing wall using joist hangers, and the subfloor was also interrupted at the bottom

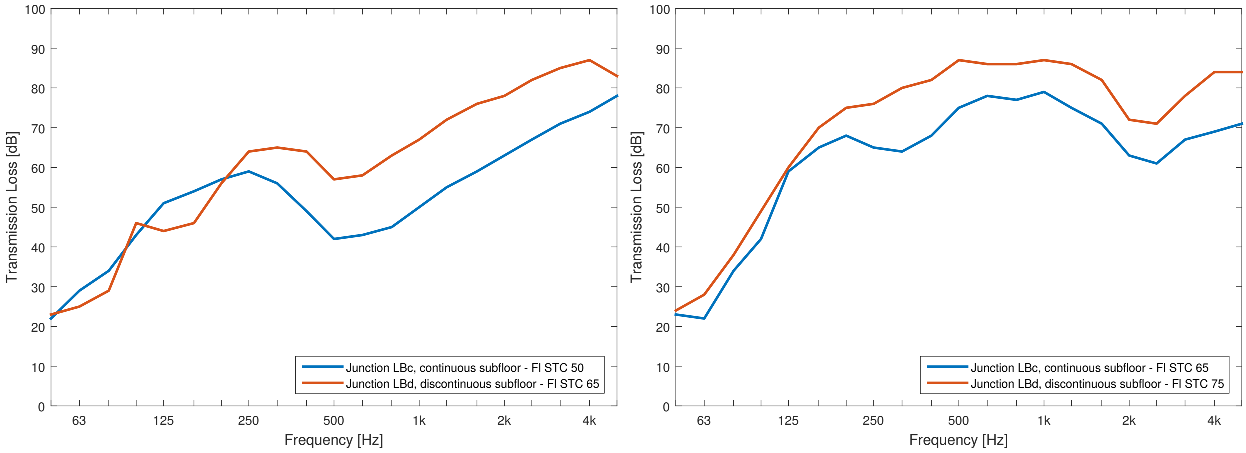


Figure 3: Floor-floor (left) and ceiling-ceiling (right) paths for the two loadbearing junctions.

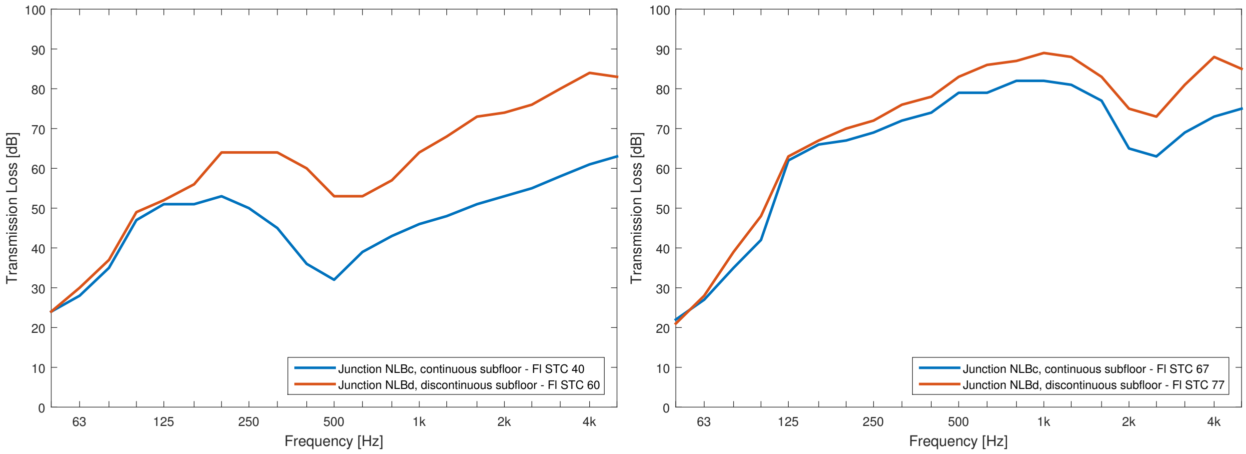


Figure 4: Floor-floor (left) and ceiling-ceiling (right) paths for the two non-loadbearing junctions.

track of the upper loadbearing wall.

Figure 4 shows the floor-floor (Ff) and ceiling-ceiling (Ff) paths for the two non-loadbearing junctions investigated in this study. For Junction NLBc, the subfloor was continuous across the junction, with the upper non-loadbearing wall installed on top of the cured gypsum concrete. For Junction NLBd, the subfloor was interrupted at the junction. The upper non-loadbearing wall was standing directly on top of the lower non-loadbearing wall.

The results in Figure 3 and Figure 4 highlight the importance of discontinuities to achieve good sound insulation performance. Structural breaks in the joists and subfloor improve the floor-floor paths by 15-20 Flanking STC points, and the transmission loss values by 15-20 dB above the coincidence frequency of the composite steel deck (at about 500 Hz). The Flanking STC value for the ceiling-ceiling paths for a loadbearing junction (Figure 3) with interrupted joists is 10 Flanking STC points higher than for the junction with continuous joists, and the transmission loss values are 10-15 dB higher over most of the frequency range of interest. For the non-loadbearing junctions (Figure 4), the floor joists have a lesser effect (since the sound transmission occurs perpendicular to the joists), but the sound transmission via a junction with continuous subfloor is nevertheless higher than the transmission via a junction with discontinuous subfloor.

4.2 Effect of Fire Blocking in Floor Cavities

The loadbearing junction that had joists running continuously across the junction (Junction LBc) was tested with and without fire blocking installed in the joist cavities. The fire blocking consisted of

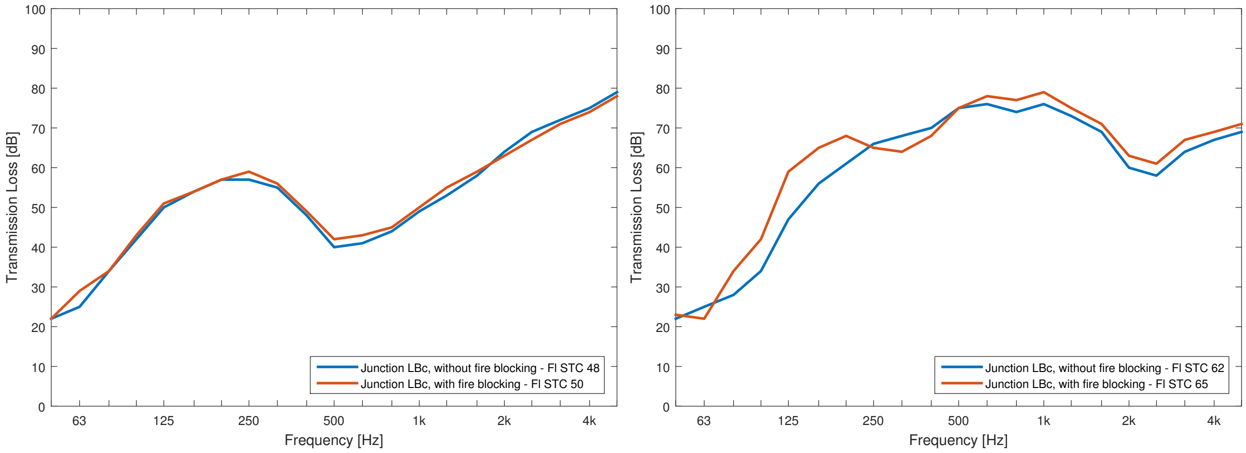


Figure 5: Floor-floor (left) and ceiling-ceiling (right) paths for Junction LBc, with and without fire blocking installed in the joist cavities at the junction.

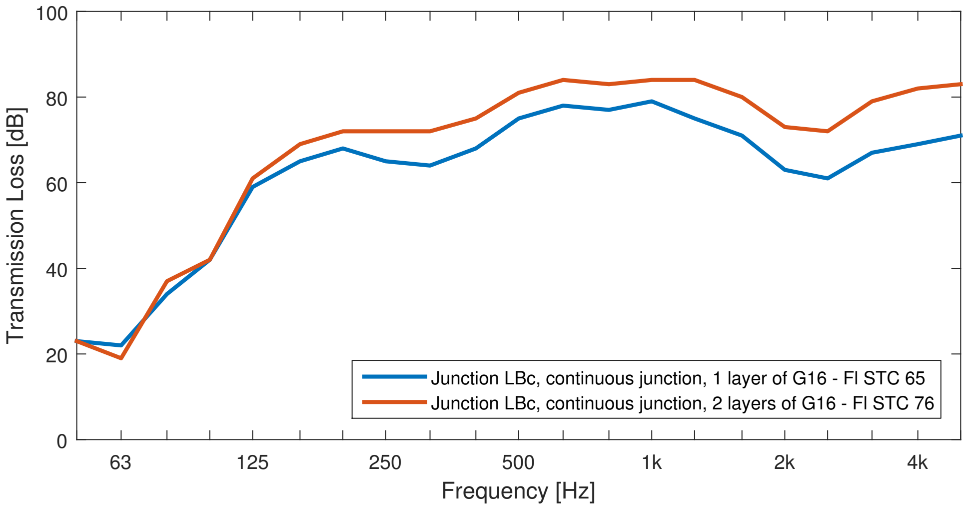


Figure 6: Ceiling-ceiling paths for loadbearing junction with continuous joists and subfloor.

strips of 15.9 mm fire-rated gypsum board attached to either side of a steel stud, which was installed between the steel joists on top of the lower loadbearing wall. Such fire blocking is required to prevent smoke and flame spread, but it can also have a beneficial effect on sound insulation.

Figure 5 shows the floor-floor (left) and ceiling-ceiling (right) paths for the loadbearing Junction LBc, with and without fire blocking installed in the joist cavities at the junction.

From Figure 5 it is observed that the effect of the fire blocking on the floor-floor path is relatively small – the transmission loss curves generally overlay. However, the improvement of 2 dB in transmission loss in the 500 Hz band leads to an improvement in Flanking STC by 2 points, from 48 to 50. The ceiling-ceiling path is affected more by the insertion of a fire block at the junction – the transmission loss values increase by 2-10 dB across the frequency range of interest, except for a dip around 315 Hz. It is likely that the two layers of gypsum board forming the fire blocking interact with the steel stud in between, thus creating a resonance at this frequency. The Flanking STC value for the ceiling-ceiling path increases by 3 points to 65.

4.3 Effect of Adding Gypsum Board Layers to Ceilings

Ceiling paths were tested with one or two layers of 15.9 mm fire-rated gypsum board installed on resilient channels below the floor joists. Figure 6 shows the transmission loss curves for the ceiling-ceiling path on the loadbearing junction with continuous joists and subfloor (Junction LBc).

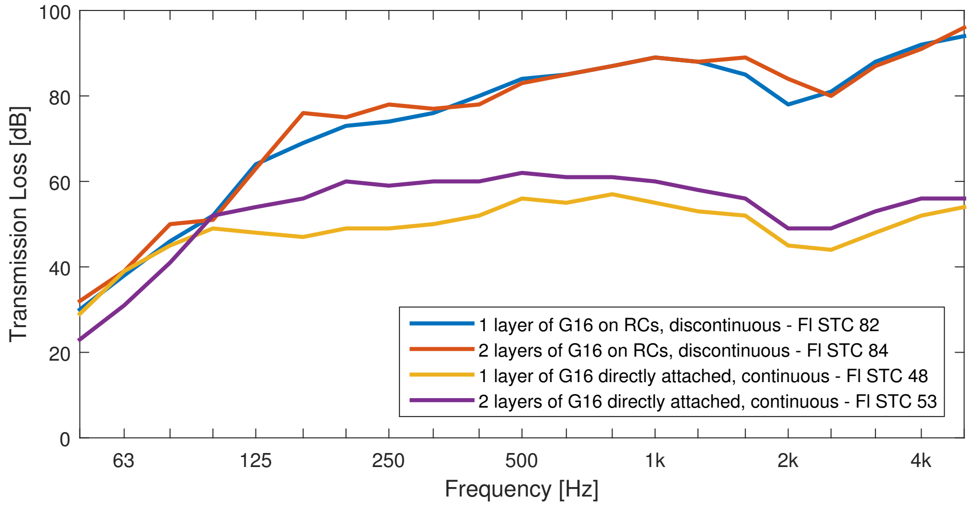


Figure 7: Wall-wall paths (Ff) for different attachment of gypsum board.

The additional layer of gypsum board on both ceilings yields an improvement of 11 Flanking STC points for the ceiling-ceiling transmission loss, with an improvement of 4-12 dB above 125 Hz.

4.4 Effect of Gypsum Board Attachment at the Junction

The influence of gypsum board that is continuous across a wall-wall junction was investigated by testing the flanking sound transmission loss for various configurations of wall gypsum board. Figure 7 shows the results.

The results in Figure 7 show a clear separation between the configurations where the wall gypsum board was continuous across the junction and the configurations where the wall gypsum board was interrupted at the junction. The number of gypsum board layers is of secondary importance compared with the continuity of the gypsum board. For one or two layers of gypsum board (on resilient channels) that are discontinuous at the junction, the Flanking STC rating exceeds 80. Transmission paths which have Flanking STC values this high will be negligible in most practical cases. It should be noted that in the tested junctions, the studs of the separating wall and the flanking walls were well-separated by a gap of at least 10 mm. When the gypsum board was continuous across the junction, the Flanking STC values dropped to 48 (for one layer directly attached) and 53 (for two layers directly attached). In many cases, such a wall-wall flanking path would be an important contributor to the apparent sound transmission and the sound level in the receive room.

5. Conclusions

The comparisons of sound transmission loss values presented in this paper and the tabulated Flanking STC values presented in NRC Research Report RR-337 clearly identify construction details with the potential to significantly improve or decrease the apparent flanking sound insulation:

- A break in the subfloor, for example by an intervening wall assembly without concrete filling the bottom track, can significantly reduce the flanking transmission via the floor surfaces. In this case study, the Flanking STC values for the floor-floor path for discontinuous subfloors were 15 points higher than for continuous subfloors in the case of a loadbearing junction, and 20 points higher in the case of a non-loadbearing junction.
- For loadbearing junctions, the continuity of the joists affects both the flanking sound transmission via the floor surfaces and the transmission via the ceiling surfaces. Joists that are continuous across the junction allow sound to travel uninterrupted, and hence should be avoided if possible. In this case study, the Flanking STC values for the ceiling-ceiling path for discontin-

uous joists were 10 points higher than for continuous joists.

- Fire blocking is usually inserted into the joist cavities at the junction to control smoke and flame spread, but it is also an efficient way to suppress airborne flanking transmission through the cavity. In this case study, the Flanking STC values for the floor-floor and ceiling-ceiling paths increased by 2 and 3 points respectively when fire blocking was installed. Care should be taken though to avoid additional rigid connections at the junction which could lead to higher structure-borne sound transmission.
- Adding a second layer of gypsum board to the ceiling was shown to improve the flanking transmission for paths involving the ceiling. The Flanking STC values for the ceiling-ceiling paths increased by 8-11 points for most junctions.
- Gypsum board that is installed continuous across a wall/wall junction can significantly decrease the apparent sound insulation. When the gypsum board and wall studs were well-separated, Flanking STC values above 80 were measured for the wall-wall path. When the gypsum board was installed continuous across the junction, the Flanking STC values dropped to 48 and 53 for one and two layers of gypsum board respectively.

Further results from this project can be found in the NRC Research Report RR-337, "Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings", available from the NRC website [7].

Acknowledgments

This project was funded by the Canadian Sheet Steel Building Institute (CSSBI) and the National Research Council Canada. The financial support is gratefully acknowledged.

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