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# Sound Insulation of Load Bearing Shear Resistant Wood and Steel Stud Walls

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# EXECUTIVE SUMMARY

The IRC Acoustics Laboratory has completed the measurement phase of a study of sound transmission through gypsum board walls, which is part of the project "Fire Resistance and Sound Performance of Wall Assemblies - Phase II"

The project was supported by a consortium that included:

- Canadian Home Builders Association (CHBA),
- Canadian Sheet Steel Building Institute (CSSBI),
- Canadian Wood Council (CWC),
- Cellulose Insulation Manufacturers Association of Canada (CIMAC),
- Forintek Canada Corp. (FORINTEK),
- Gypsum Manufacturers of Canada (GMC),
- Institute for Research in Construction of the National Research Council Canada (IRC/NRCC),
- Owens Corning (OC), and
- Roxul Inc. (ROXUL).

A linked study of fire resistance of wall assemblies has also been completed. The results have been published as a series of IRC Internal Reports: IR-729 and IR-806 for wood-framed assemblies, and IR-833 for steel-framed assemblies.

This report presents the sound transmission class (STC) data for a series of walls constructed with industry-standard details. Although some of the specimens were chosen by individual clients to demonstrate performance of specific products, these were combined with a structured series established collectively by the consortium.

The combined set of 58 constructions from this project, together with a similar set of specimens evaluated in a preceding project completed in 1995, provide a database for consistent comparisons of the sound transmission through gypsum board wall systems.

This set of data also provides a basis for empirical prediction methods and for development of improved constructions. More immediately, they provide STC data needed by builders and regulators to select constructions suitable for party walls in multi-family dwellings.

# INTRODUCTION

The purpose of this report is to provide information on the airborne sound insulation of load-bearing gypsum board wall assemblies, most of which had shear-resistant elements. These were divided almost equally between wood- and steel-stud framing. These types of assemblies extend the range considered in the earlier study of gypsum board walls, which was documented in IRC Internal Reports IR-693 and IR-761.

A Consortium Steering Committee was formed to ensure that the construction details and materials employed were typical of normal practice. A total of 58 different wall assemblies were examined in this study. The sound transmission class (STC) ratings for these assemblies are given in the section *Measurement Results.*

Midway through the project, IRC/NRC performed a necessary renovation of the test facility. This had the effect of breaking the project into two parts, each with fully self-consistent data. In the short term, the renovations have made it more difficult to compare results between the wood- and steel-framed specimens. This complication has been overcome through systematic re-testing of several types of wall assemblies, to provide a framework for harmonizing the results.

Throughout the project a number of reference walls were built using nominally identical materials and using the same contractor for construction. This served three important purposes:

1. The reference specimens provided a measure of the repeatability of results (assuming the same laboratory but a complete rebuild of the specimen) for assemblies that were typical of this study, thereby providing an estimate of what constitutes a significant difference when comparing measured results. This is discussed in the section *Measurement Process and Precision*.
2. Since the reference specimens were measured both before and after the chamber renovations they could also be used to quantify the systematic bias introduced by the changes to the facility. This facilitated adjustments to compensate for facility effects, when creating the harmonized data set for regression analysis, as discussed in *Analysis of Trends in the Results*.
3. By comparing specimens in the same stud set, effects due to small changes (such as replacing the gypsum board or the cavity insulation without altering the studs and shear membrane) could be more accurately assessed. This provides the basis for the section *Analysis of Individual Variables*. For this reason the stud set associated with each construction is indicated in the tables of measured data for the wood-framed specimens.

Regression expressions have been developed for the harmonized set of data, in which data measured before chamber renovation have been adjusted to reflect the systematic change in measured transmission loss for similar constructions. The regression results can be thought of as being estimates that are harmonized to a common facility; the renovated chambers.

The regression expressions may be used to estimate the single number ratings for consistent constructions that were not tested. Due to the limited scope of the experimental study, it is not possible to provide estimates for all similar constructions. The regression expressions should be applied only within the range of parameters for the set of specimens that were evaluated.

Measured STC values from this report should not be used to estimate performance of an assembly unless the material properties - especially surface density - of the gypsum board used in the proposed construction is similar to that used in this study (see Table A2 and its footnotes). Given the gypsum board surface density, the regression expressions presented on pages 18 and 21 should be used to estimate expected performance.

The report is organized as follows:

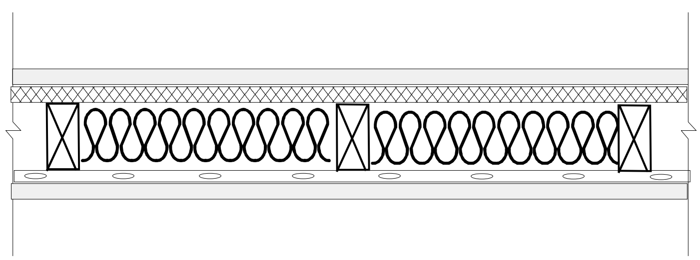
# MEASUREMENT RESULTS

The following tables present brief descriptions of the specimens evaluated, together with the measured Sound Transmission Class (STC) value for each construction. In some cases, more than one test was made for a given wall design. In those cases, the mean value for the group of tests is presented.

As discussed in the following section on Measurement Process and Precision, some uncertainty in the experimental results is inevitable, because of variations in the construction and because of the inherent precision limits of the test method. The subsequent section on Analysis of Trends in the Results explains the process to systematically minimize such variability and to provide a self-consistent set of estimates of expected performance for walls matching these generic details. Some of those adjusted estimates differ slightly from the experimental results listed in this section. It should be stressed that all the values tabulated in *this* section are legitimate test results conforming to all requirements of the pertinent technical standards.

## Wood-Framed Assemblies

*Table WSS-1: Wood studs with a shear bracing element plus one layer of gypsum board on one side, and resilient furring channels plus one layer of gypsum board on the other side*



one layer of gypsum board,
shear bracing element (as noted),
38x89 mm wood studs at 406 mm o.c.,
absorptive material (as noted) in stud cavity
13 mm resilient steel furring channels
spaced at 610 or 406 mm o.c.
one layer of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

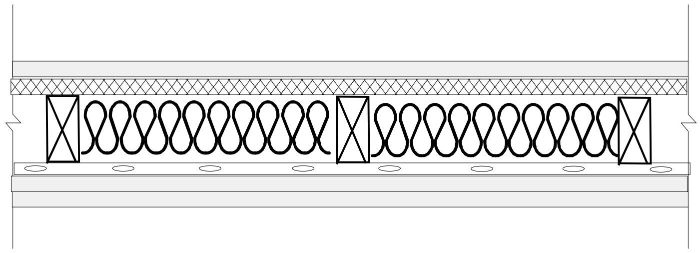
| Gypsum Board[1] | Shear Bracing | Absorptive Material | Stud Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm regular | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-059/060 | 42 |
| 12.7 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-047/048 | 47 |

**b) Resilient channels spaced at 610 mm o.c.**

| | | | | | |
|---|---|---|---|---|---|
| 12.7 mm regular | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-055/056 | 48 |
| 12.7 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-051/052 | 52 |
| " | 9.5 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 4 | TLA-97-062/063 | 50 |
| 15.9 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-041/042 | 53 |
| " | " | glass fibre, 89 mm R13 batt | 5 | TLA-97-078/079 | 53 |
| " | " | rock fibre, 90 mm R13 batt | 5 | TLA-97-074/075 | 52 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Significance of stud set is discussed in following section on Measurement Process & Precision.

*Table WSS-2: Wood studs with one layer of gypsum board plus a shear bracing element on one side, and resilient furring channels plus two layers of gypsum board on the other side*



one layer of gypsum board,
shear bracing element (as noted),
38x89 mm wood studs at 406 mm o.c.,
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 610 or 406 mm o.c.,
two layers of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

| Gypsum Board[1] | Shear Bracing | Absorptive Material | Stud Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm regular | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-057/058 | 48 |
| " | 12.7 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 2 | TLA-96-107/108 | 49 |
| 12.7 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-045/046 | 50 |
| " | 12.7 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 2 | TLA-96-113/114 | 53 |
| 15.9 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 3 | TLA-96-146M | 50 |
| " | 12.7 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 3 | TLA-96-152/153 | 50 |

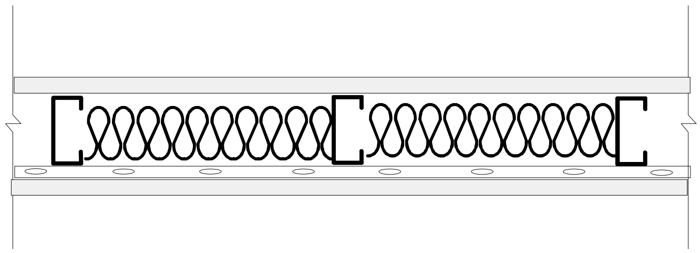
**b) Resilient channels spaced at 610 mm o.c.**

| | | | | | |
|---|---|---|---|---|---|
| 12.7 mm regular | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-053/054 | 52 |
| | 12.7 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 2 | TLA-96-109/110 | 51 |
| 12.7 mm Type X | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 1 | TLA-96-049/050 | 57 |
| | 12.7 mm plywood (nailed) | glass fibre, 89 mm R12 batt | 2 | TLA-96-111/112 | 56 |
| 15.9 mm Type X | 12.7 mm OSB (nailed) | rock fibre, 65 mm R9 batt | 1 | TLA-96-037M | 54 |
| " | " | glass fibre, 65 mm R8 batt | 1 | TLA-96-035M | 55 |
| “ | “ | cellulose fibre, 89 mm blown | 5 | TLA-97-082/083 | 59 |
| " | " | rock fibre, 90 mm R13 batt | 5 | TLA-97-072/073 | 56 |
| " | " | glass fibre, 89 mm R13 batt | 5 | TLA-97-076M | 56 |
| " | 12.7 mm OSB (nailed) | glass fibre, 89 mm R12 batt | 3 | TLA-96-144M | 55 |
| “ | 12.7 mm OSB (screwed) | " | 6 | TLA-97-090M | 57 |
| " | 12.7 mm OSB (screwed, applied horizontally) | " | 6 | TLA-97-092/093 | 56 |
| " | 12.7 mm plywood (nailed) | " | 3 | TLA-96-158/159 | 54 |
| " | 12.7 mm plywood (screwed) | " | 2 | TLA-96-099/100 | 55 |
| “ | 11 mm OSB (nailed) | " | 4 | TLA-97-058/059 | 56 |
| " | 11 mm OSB (screwed) | " | 4 | TLA-97-056/057 | 55 |
| " | 9.5 mm plywood (nailed) | " | 4 | TLA-97-060/061 | 56 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Significance of stud set is discussed in following section on Measurement Process & Precision.

## Steel-Framed Assemblies

*Table LBSS-1: 41x92 mm load-bearing steel studs spaced 406 mm o.c., with one layer gypsum board on one side, resilient steel furring channels spaced 406 or 610 mm o.c. plus one layer gypsum board on other side*



one layer of gypsum board,
41x92 mm load-bearing steel studs of
16 gauge (1.52 mm), 18 gauge (1.22 mm), or
20 gauge (0.91 mm),
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 610 mm o.c.,
one layer of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

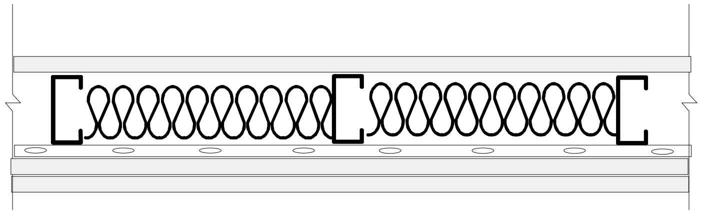
| Gypsum Board[1] | Stud Details | Absorptive Material | Stud Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | 20 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-105/106 | 45 |

**b) Resilient channels spaced at 610 mm o.c.**

| | | | | | |
|---|---|---|---|---|---|
| 12.7 mm Type X | 20 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-022 | 48 |
| " | 20 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-095/096 | 47 |
| 15.9 mm Type X | 16 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-93-355 | 49 |
| " | 18 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-93-354 | 50 |
| " | 20 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-025 | 49 |
| " | 20 gauge at 406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-089/090 | 49 |

Notes: 1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.

*Table LBSS-2(a): 41x92 mm load-bearing steel studs (spaced 406 or 610 mm o.c.), 16 gauge (1.52 mm) or 20 gauge (0.91 mm), with one layer gypsum board on one side, resilient steel furring channels (spaced 406 or 610 mm o.c.) plus two layers gypsum board on other side*



one layer of gypsum board,
41x92 mm load-bearing steel studs
16 gauge (1.52mm) or 20 gauge (0.91 mm),
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 406 or 610 mm o.c.,
two layers of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

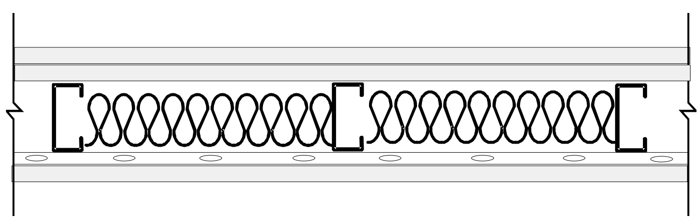
| Gypsum Board[1] | Stud Details | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-103/104 | 51 |
| " | 20 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | A | TLA-99-127/128 | 51 |
| " | 20 gauge @406 mm o.c. | cellulose fibre, 92 mm blown | A | TLA-00-067/068 | 51 |
| 12.7 mm Type X | 20 gauge @610 mm o.c. | rock fibre, 90 mm R13 batt | A | TLA-99-137/138 | 55 |
| 15.9 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-083/084 | 50 |
| | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-069/070 | 51 |

**b) Resilient channels spaced at 610 mm o.c.**

| Gypsum Board[1] | Stud Details | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-018 | 53 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-021 | 54 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-097/098 | 54 |
| " | 20 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | A | TLA-99-123/124 | 52 |
| 15.9 mm Type X | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-091/092 | 54 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.

*Table LBSS-2(b): 41x92 mm load-bearing steel studs (spaced 406 mm o.c.), 16 gauge (1.52 mm) or 20 gauge (0.91 mm), with two layers of gypsum board on one side, resilient steel furring channels (spaced 610 mm o.c.) plus one layer of gypsum board on other side*

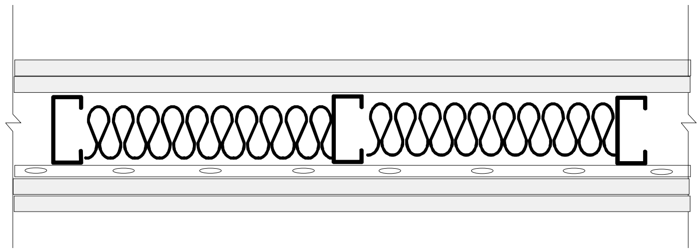


two layers of gypsum board,
41x92 mm load-bearing steel studs
16 gauge (1.52mm) or 20 gauge (0.91 mm),
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 610 mm o.c.,
one layer of gypsum board.

| Gypsum Board[1] | Stud Details | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL94-016 | 53 |
| " | 16 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | B | TL94-013 | 53 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL94-019 | 54 |
| " | 20 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | B | TL94-023 | 54 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.

*Table LBSS-3: 41x92 mm load-bearing steel studs spaced at 406 mm o.c., 16 gauge (1.52 mm) or 20 gauge (0.91 mm), with two layers gypsum board on one side, resilient steel furring channels spaced 406 or 610 mm o.c. plus two layers gypsum board on other side*



two layers of gypsum board,
41x92 mm load-bearing steel studs
16 gauge (1.52mm) or 20 gauge (0.91 mm),
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 406 or 610 mm o.c.,
two layers of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

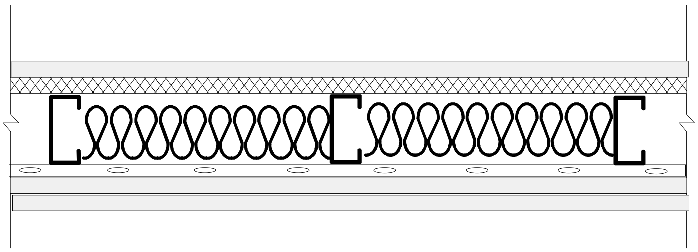
| Gypsum Board[1] | Stud Details | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-079/080 | 57 |
| " | 16 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | A | TLA-00-081/082 | 56 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-065/066 | 57 |
| 15.9 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-085/086 | 57 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-071/072 | 58 |

**b) Resilient channels spaced at 610 mm o.c.**

| | | | | | |
|---|---|---|---|---|---|
| 12.7 mm Type X | 16 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-017 | 59 |
| " | 16 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | B | TL-94-014 | 59 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | B | TL-94-020 | 60 |
| " | 20 gauge @406 mm o.c. | rock fibre, 90 mm R13 batt | B | TL-94-024 | 60 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-099/100 | 59 |
| " | 20 gauge @406 mm o.c. | none | A | TLA-00-063/064 | 50 |
| 15.9 mm Type X | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-073/074 | 59 |
| " | 20 gauge @406 mm o.c. | glass fibre, 89 mm R12 batt | A | TLA-00-093/094 | 59 |
| " | 20 gauge @406 mm o.c. | none | A | TLA-00-075/076 | 51 |

Note:
1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.
3. TLA-00-093/094 is a rebuild of TLA-00-073/074 to assess construction and measurement reproducibility.

*Table LBSS-4: 41x92 mm load-bearing steel studs, 20 gauge (0.91 mm), spaced at 406 mm o.c., with one layer of gypsum board and a shear bracing element on one side, resilient steel furring channels spaced 406 mm o.c. plus two layers gypsum board on other side*



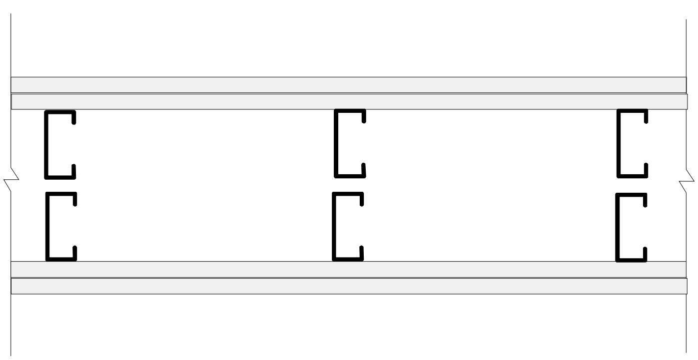
one layer of gypsum board,
shear bracing element (as noted),
41x92 mm load-bearing steel studs
20 gauge (0.91 mm) spaced 406 mm o.c.,
absorptive material (as noted) in stud cavity,
13 mm resilient steel furring channels
spaced at 406 mm o.c.,
two layers of gypsum board.

**a) Resilient channels spaced at 406 mm o.c.**

| Gypsum Board[1] | Shear Bracing | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | steel X-bracing straps + end cavities blocked at mid-height | rock fibre, 90 mm R13 batt | A | TLA-99-129/130 | 52 |
| " | steel X-bracing straps | rock fibre, 90 mm R13 batt | A | TLA-99-131/132 | 51 |
| " | 11.7* mm OSB panel | rock fibre, 90 mm R13 batt | A | TLA-99-135/136 | 57 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.
3. See Appendix, Figures A-4 to A-6 for more information about specimen details.
* Denotes nominal thickness.

*Table LBSS-5: 2 rows 41x92 mm load-bearing 20 gauge (0.91 mm) steel studs, spaced at 406 mm o.c., the two rows are spaced 25 mm apart, no absorptive material in stud cavity and two layers of gypsum board on the exposed faces*



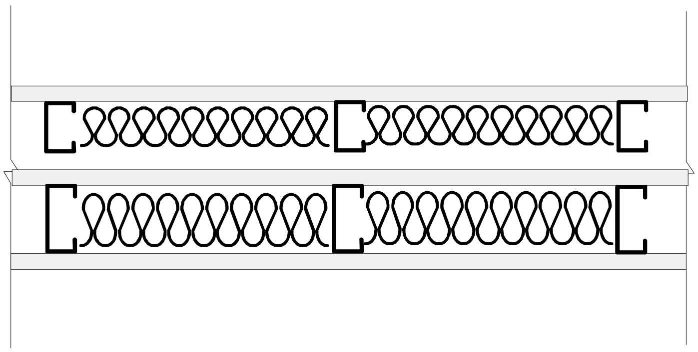
two layers of gypsum board,
41x92 mm loadbearing 20 gauge (0.91 mm) steel studs
25 mm airspace.
41x92 mm loadbearing 20 gauge (0.91 mm) steel studs
two layers of gypsum board.

**a) Both sets of steel studs spaced at 406 mm o.c.**

| Gypsum Board[1] | Shear Bracing | Absorptive Material | Set[2] | Test Number | STC |
|---|---|---|---|---|---|
| 12.7 mm Type X | None | None | A | TLA-00-061/062 | 52 |

Note: 1. See note on classification and properties of gypsum board on page 40
2. Set A or B denotes measurement results from after or before the facility modification, respectively.

*Table LBSS-6: 41x92 mm load-bearing 20 gauge (0.91 mm) steel studs, spaced at 406 mm o.c., with one layer of gypsum board on each side, with an adjacent furring section comprising non-load-bearing 25 gauge (0.50 mm) steel studs spaced 406 mm o.c. with absorptive material in stud cavity and one layer of gypsum board on the exposed face*



Furring section comprising:
one layer of gypsum board,
65 mm non-load-bearing 25 gauge (0.50 mm) steel studs
with absorptive material in stud cavity,
25 mm airspace.

Structural section comprising:
one layer of gypsum board,
41x92 mm load-bearing 20 gauge (0.91 mm) steel studs
with absorptive material in stud cavity,
one layer of gypsum board.

**a) Both sets of steel studs spaced at 406 mm o.c.**

| Structural Section | | Furring Section | | Test Number | STC |
|---|---|---|---|---|---|
| Gypsum Board[1] | Absorptive Material | Gypsum Board[1] | Absorptive Material | | |
| 15.9 mm Type X (both sides) | Glass fibre, 89 mm R12 batt | 12.7 mm Regular (exterior face only) | Glass fibre, 89 mm R12 batt | TLA-00-077/078 | 48 |

Note: 1. See note on classification and properties of gypsum board on page 40

# MEASUREMENT PROCESS AND PRECISION

The acoustical measurements were made in the suite of reverberation chambers in building M-27 of IRC/NRCC. Wall specimens are mounted in a removable test frame between two chambers, without rigid contact to either reverberation chamber. Tests are conducted in accordance with the requirements of ASTM E90, Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

In presenting and evaluating the results of this series of measurements, three basic aspects must be considered:

1. Repeatability of sound transmission results when specimens are replicated with nominally equivalent materials.
2. The effect on the sound transmission results due to modifications to the test facility, during the course of this project.
3. The design of the measurement series and the analysis of the experimental results to provide a basis for accurate estimates of the effect of specific changes in specimens.

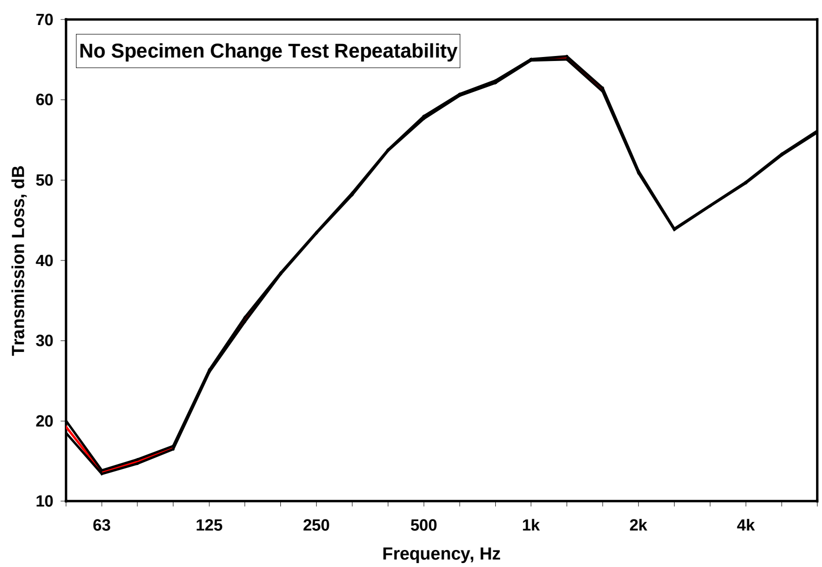
This section of the report presents information primarily on the first two of these issues. All three are addressed further in later sections on analysis of results.

## Precision, Repeatability, and Significance of Observed Differences

As shown in the preceding project on gypsum board walls (documented in IRC Internal Report IRC-IR-693, October 1995), the acoustical effect of specific changes in wall details can be assessed most precisely by making a series of small modifications to a wall specimen.

With this approach, meaningful effects can be shown, if the changes exceed a repeatability criterion based on the variability in results when a given specimen is repeatedly tested over a short period of time. Figure 1 presents the variability in sound transmission loss observed in repeated testing of a gypsum board wall, with no modifications to the specimen.

*Figure 1: Variability observed in repeated testing of a specimen over several days, with no modifications to the specimen. The curves for 10 tests are presented here to illustrate the small range in the results. The results vary by only a few tenths of a decibel at most frequencies (standard deviation from 0.2 to 0.8 dB). This is believed to be independent of specimen type.*



The variability in the measurement results depends on implementation of the test method - number of microphone and sound source positions and consistency of their locations, calibration effects, temperature stability, etc. These data presented in Figure 1 represent the characteristic repeatability for the automated system used for all the measurements reported here.

The standard deviation in most frequency bands is only a few tenths of a decibel. Thus, variability due to random effects in the measurement process would not interfere with identifying a change of 1dB or greater and smaller changes can also be identified in detailed comparisons (as in the section on Analysis of Individual Variables) where consistent deviations are observed in several adjacent frequency bands.

In addition to measurement uncertainty, however, a second aspect of repeatability needs to be considered in assessing which differences are significant. In practice, the variability observed when nominally identical specimens are constructed (even with materials from the same batches) is much greater than the repeatability in the measurement process. This variation seems to depend to some degree on the type of construction, and on the type of changes.

When the changes in construction were small, then the uncertainty associated with the change was rather small. To facilitate reliable evaluation of parametric effects, and to support interpolation to wall designs other than those actually tested, the set of specimens for each type of studs was structured so that only one component was changed while others were held constant. For example, the effect due to different types of insulation was evaluated in a wood stud wall where the studs, shear membrane, and the type and attachment of the gypsum board were all held constant. Changes were implemented without altering the more sensitive elements of the construction, such as the studs and shear membrane. A similar methodology was used for the steel-framed assemblies, although the parametric variations were more limited. This provided the basis for evaluating the effect of specific parameters, as discussed further in the section on Dependence on Individual Variables.

For such comparisons (where neither the specimen framing nor the laboratory was changed) the uncertainty is only slightly greater than the test repeatability discussed above. The consistency of trends in such comparisons suggests that when changes in excess of 1 dB are observed in a number of adjacent bands, they are physically meaningful.

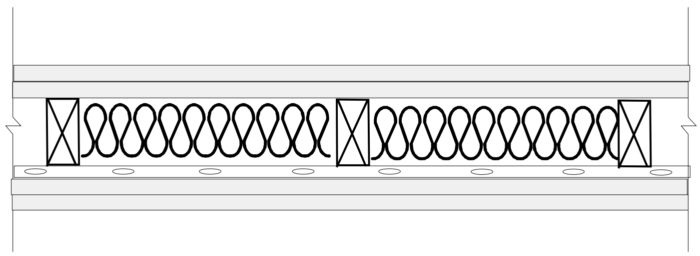
Greater uncertainty was inherent in more significant changes. In this project, variability in the individual measurement results was introduced both by changes in the specimen construction, and by changes to the test facility part way through the evaluation of the steel-framed specimens. Because such variations might mask systematic changes due to construction details, reference specimens with nominally identical construction were included in the set of wall variants tested for each set of studs, to provide an estimate of the variation due to replacing the framing. A second set of comparison specimens was used to assess the effect of facility changes.

The largest variability was observed for the wood-framed specimens.

### *Rebuild Repeatability for Wood-Framed Walls*

In the case of the wood-framed walls, an extensive set of data was gathered. To avoid cumulative effects due to stud damage when attaching the shear membranes and gypsum board, six sets of wood studs were used. The test results are presented both in Table WSR-1 and in Figure 2 below.

*Table WSR-1: Reference specimen, with wood studs, two layers of gypsum board (in place of shear bracing element and face layer of gypsum board on that side), and resilient furring channels plus two layers of gypsum board on the other side.*



two layers of gypsum board,
38x89 mm wood studs at 406 mm o.c.,
absorptive material in stud cavity,
13 mm resilient steel furring channels
spaced at 610 mm o.c.,
two layers of gypsum board.

| Stud Set | Gypsum Board | Absorptive Material | Test Number | STC |
|---|---|---|---|---|
| 1. | 15.9 mm Type X | glass fibre, 89 mm R12 batt | TLA-96-023 | 59 |
| 2. | " | " | TLA-96-095M[1] | 56 |
| 3. | " | " | TLA-96-160 | 56 |
| 4. | " | " | TLA-97-048M[2] | 56 |
| 5. | " | " | TLA-97-064 | 57 |
| 6. | " | " | TLA-97-088 | 59 |
| Mean | | | | 57 |

*Note: 1. Mean result from two tests was used (TLA-96-093, 96-095).*
*2. Mean result from three tests was used (TLA-97-048, 97-052, 97-054))*

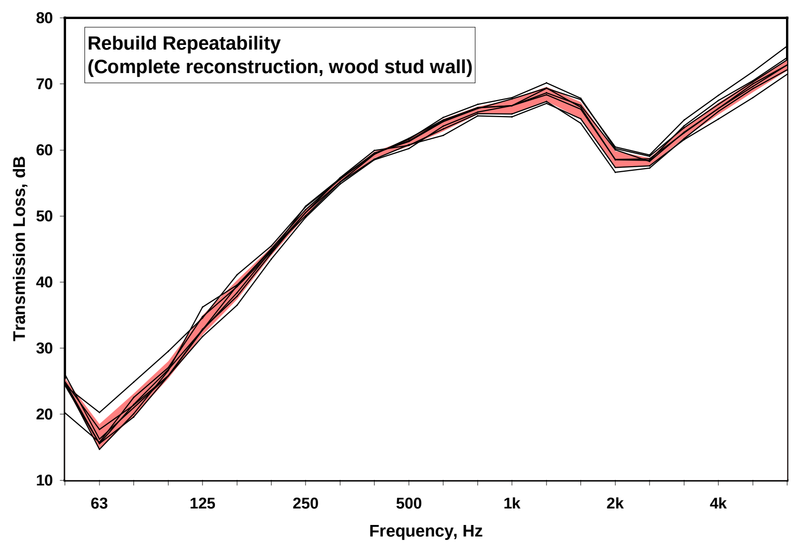



*Figure 2: Variability in repeated tests of a specific wood stud wall design, with complete rebuild of the specimen each time, using nominally identical components. The shaded area represents the range of one standard deviation about the mean value. The STC ratings are controlled by performance in the 125 Hz band, and the standard deviation of 1.3 dB at that frequency is responsible for the range of 3 dB observed in the STC*

Although the general shape of the sound transmission results is very similar for all six of the reference specimens with wood studs, the differences evident in

Figure 2 are clearly greater than the range expected due to variability in the measurement process shown in Figure 1.

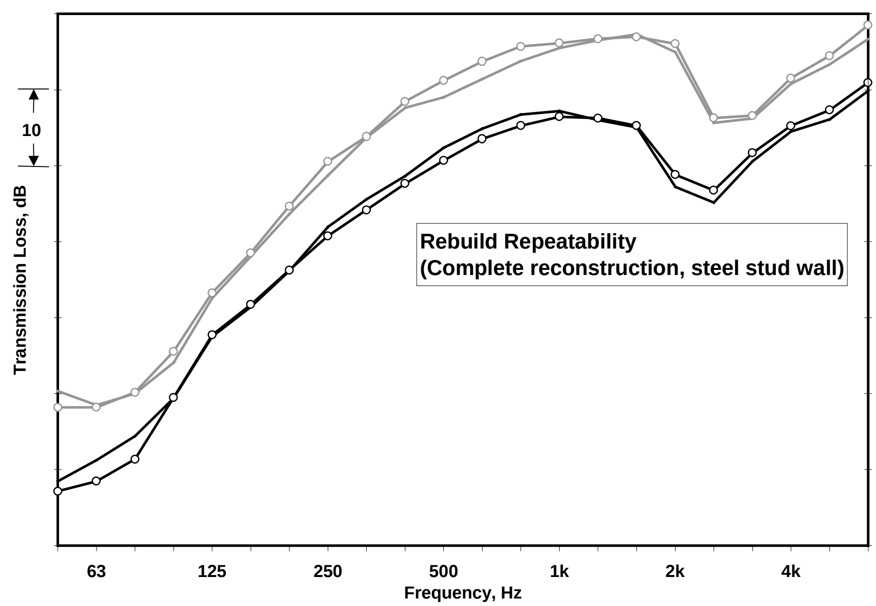
The STC ratings for these reference wood-framed specimens are controlled by the performance in the 125 Hz band, and the standard deviation of 1.3 dB at that frequency is responsible for the range of 3 dB observed in the STC ratings for nominally identical wood-framed specimens.

### *Rebuild Repeatability for Steel-Framed Walls*

In the case of the steel-framed assemblies, the modification of the facility midway through the series complicates assessment of the variability due to replicating specimens. Two constructions were rebuilt and tested to directly assess the "rebuild repeatability." Similar results were observed in both cases; the data are shown in Figure 3. The STC values were the same, and the curves agreed quite well at most frequencies. These data were insufficient for statistical evaluation of the rebuild repeatability, but the mean absolute difference of 1.0 dB was significantly smaller than the variance exhibited by the wood-framed specimens in Figure 2.

The observed variation seems slightly smaller for rebuild of the steel-framed walls, but the data are too limited for a serious quantitative comparison.

*Figure 3: Variability observed in repeat testing of matching steel stud wall specimens in the same laboratory, with complete rebuild of the specimen using nominally identical components. The transmission loss axis for the two cases was arbitrarily offset to permit comparison of the two sets of data on one graph. Note that STC values were the same.*




A more substantial basis for evaluating the repeatability is obtained by combining these results with those for the four steel-framed constructions that were tested both before and after the facility renovation, using nominally identical materials. The STC results are listed in Tables LBSS-1 to LBSS-3. In two cases the STC changed by 1, but in all other cases the STC was unchanged. Thus a change of 1 in the listed STC value should not be interpreted as significant, but a change of 2 or more should indicate a meaningful difference for the steel-framed constructions.

A similar criterion seems reasonable for the STC values of wood-framed specimens based on the same set of wood studs. However, for specimens chosen at random from the tables, even a difference of 3 in the STC is not clear evidence of meaningful change. It is more reliable to use the regression expressions presented in the following section of the report as a basis for assessing the significance of changes.

## Establishing a Harmonized Set of STC Ratings:

At the heart of the plan for this project was the acquisition of a consistent set of data, which could be used to predict the STC values for a larger set of wall designs.

As noted before, the study dealt with two sets of specimens – one with wood studs and the other with load-bearing steel studs. There were specific barriers to obtaining a consistent set of data:

1. For the wood-framed specimens, it was expected that variability among the stud assemblies would introduce differences between the sound transmission results for sets of specimens. On the assumption that the same bias would apply to all specimens constructed on a given set of studs, nominally identical reference specimens were included in the series for each stud set. It was found, however, that correcting for this expected bias provided negligible improvement in the regression expressions. Therefore no relative adjustment was made within the set of data for all the wood-framed specimens.
2. For the steel-framed specimens, it was intended to combine the sound transmission data for a new set of set of specimens with the data for nine specimens studied in the previous project. Unfortunately, there were major delays in the project, and IRC proceeded with a much-needed renovation of the acoustics facility in 1998. Part of the acoustics measurements for steel-framed specimens in this project were performed after the renovation. Thus to establish a coherent set of data for steel-framed specimens, it was necessary to determine how the renovation affected sound transmission results, and then apply appropriate adjustments to one of the two sets of data. For consistency with future studies, it was decided that the data from the preceding project should be adjusted to conform to the new "facility signature", as discussed on the next page.
3. Harmonizing data for the two sets of specimens posed an additional problem. It was also necessary to have the final estimates for wood-framed and steel-framed specimens directly comparable. All of the former specimens had been evaluated before the laboratory renovation. For purposes of developing consistent regression expressions, all the results for the wood-framed specimens were therefore adjusted by adding the correction to allow for the change in facility bias.

In practice, the adjustment to allow for facility signature had only marginal effect on the STC ratings and the subsequent regression expressions – in most cases the predicted STC was unchanged, and in no case did the change exceed 1 dB. However, in the interest of minimizing sources of bias, the harmonization process described above was used.

The details of the bias associated with the facility change are presented below, and the following section on Analysis of Trends in Results presents the regression expressions obtained after these adjustment were used in the data processing.

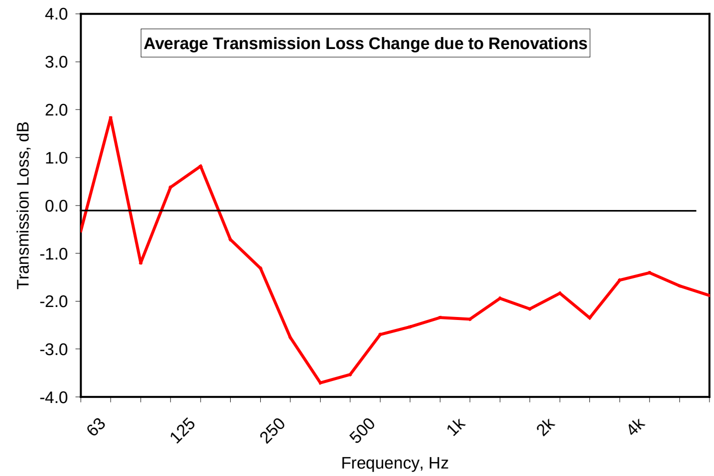
### *The Facility Signature Adjustment*

The details of the changes in the facility and pertinent qualification testing are presented in the report, "Renovations of the IRC/NRC transmission loss facility for walls, and their effects", IRC Internal Report IR-826.

The change in facility signature was determined by building and testing a set of wall assemblies that replicated specimens evaluated before the renovation, and included a cross-section of the wall designs for this project. Although there is some variability, which may depend partly on the type of specimen, consistent trends were observed.

Figure 4 presents the mean difference between results observed before the renovation in 1998 and the corresponding results for nominally identical specimens tested after the renovation. This comparison has been restricted to cases where there was good assurance of equivalent materials for all components of the replicate constructions.

*Figure 4:*
*Mean change observed between sound transmission for a set of wall specimens evaluated after renovation of the IRC laboratory, versus corresponding pre-renovation results for nominally identical specimens.*




This adjustment has been developed specifically for analysis of the data for this project, with emphasis on specimen designs of concern in this project, and should not be blindly applied to all previous data from the IRC laboratory.

Note that where traceable test results are required, either configuration of the IRC/NRCC laboratory (pre- or post-renovation) provides acceptable sound transmission loss results that fully conform to the applicable ASTM standards, and fall within the range established in round robin testing by the major North American laboratories.

# ANALYSIS OF TRENDS IN THE RESULTS

Trends in the data were analyzed using multi-variate linear regression. Two general constraints must be noted:

1. Representative regression equations that are generally applicable are obtained only when there is a reasonably uniform distribution of the values of each predictor (independent variable). This was not always possible in this study, so some anomalous results are to be expected. To minimize such effects, the application of the regression equations should be restricted to conditions matching the range of variables that was tested.
2. A regression analysis of all the measured results as one collection of data would not be fruitful. The variations in construction that are included have too great an influence on sound insulation, and the range of variables was not consistent between sets for wood-framed and steel-framed walls. Therefore, the steel-framed assemblies were analyzed as one set, and the wood-framed walls were treated as a separate set.

The regression analysis was performed using commercial software (SigmaStat Version 2.03). The specific technical criteria and process should be noted:

- All analyses used multiple stepwise regression, in a two-pass process. The first pass was an analysis of variables (ANOVA) to determine the most important independent variables and identify variables that are correlated. If correlation between variables was significant, second-pass regressions were used to determine the most appropriate variable to be included.
- In the first-pass, the F-statistic was used to gauge the contribution of the independent variables in predicting the dependent variable, STC. The criterion for considering the variable significant was "F>4.0". Typically the ANOVA indicated that STC was most highly dependent on the mass of the surface layers, but other variables were also significant. This did not always identify all the variables that were known to be important. This could occur because the range in the values tested for that variable was too small.
- Where basic theory suggested variables were important, but they marginally failed the F-statistic test, a second set of criteria was used. These included the VIF (variance inflation factor), P-value (probability of being wrong), "R-squared" and the standard error. VIF greater than 1.5 indicates variables that are correlated. (An example would be thickness, bending stiffness and surface density of the shear membrane - all depend directly or indirectly on the thickness, so only one should be included). Once the correlated variables have been identified using the VIF, the P-value is used to identify the variables most likely to be wrong. The variable with the lowest P-value is retained. No variables with P-values in excess of 0.20 were retained.
- After using the P-value and VIF criteria to choose the most appropriate independent variables, a second multi-variate regression was conducted to determine the variable coefficients. In this second-pass, the quality of estimate of the regression expression is judged by the R-squared and standard error estimates. The final regression was determined by the

expression that offered the lowest standard error while also satisfying the criteria for F, VIF, and P-value.

***Regression Estimates for Wood-Framed Specimens***

For the specimens with a single row of wood studs and an attached shear membrane, the data for regression analysis were obtained from the experimental results by application of the corrections for facility signature. The subsequent regression analysis yielded the following equation:

STC = 36.07 + 7.16Log(***DirectDensity***) + 13.40Log(***ResGypDensity***) + 0.045(***InsThick***) – 1.842(***RCContacts***)

Standard error = 1.19 dB
R-squared =0.902
Valid only within specified range of variables (see Table 1 on next page)

The variables in the regression equation were dependent on specific properties of the components of the specimen (identified in Figure 5) as follows:

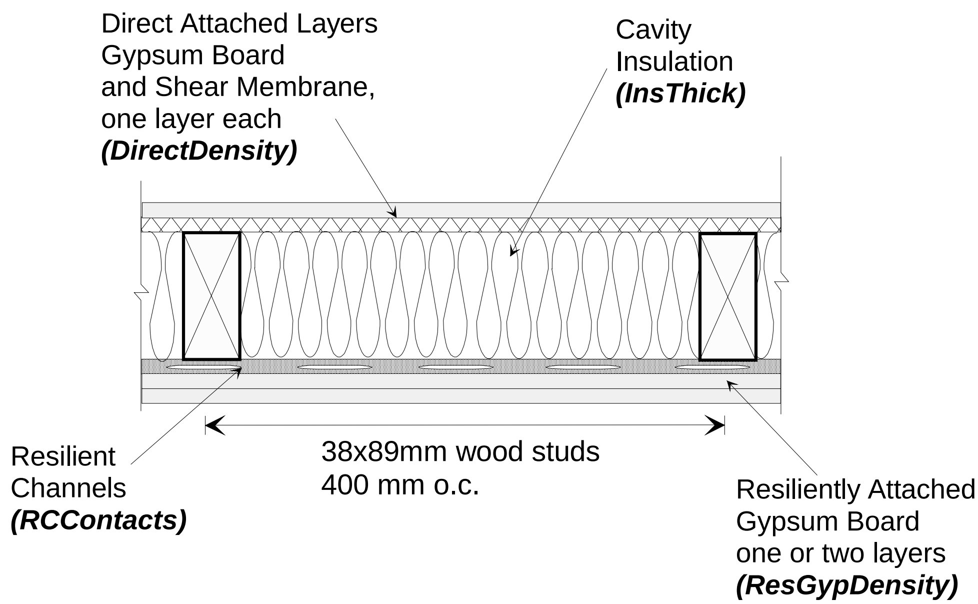
*DirectDensity* = total surface density of the shear membrane layer and gypsum board layer that are directly attached to the studs (kg/$m^2$). There was a single layer of each.

*ResGypDensity* = total surface density of the gypsum board that is resiliently attached to the studs (kg/$m^2$). There may be one or two layers.

*InsThick* = thickness of the fibrous cavity insulation (mm)

*RCContacts* = total number of points at which the resilient channels were fastened to the studs divided by the total area of the wall (number/$m^2$)

*Figure 5: Variables in the multi-variate expression for the STC are associated with important physical properties of specific components of the wall specimens.*



The linear regression expression is a simple first-order representation of a complex non-linear problem, and must be applied with care. The regression expression is valid only to estimate STC for specimens of the same basic type, whose components fall within the range of properties of the specimens tested.

| Independent Variable | Minimum Value | Intermediate Values | Maximum Value |
|---|---|---|---|
| **Resilient Channel** | | | |
| Spacing (mm o.c.) | 406 | 610, 1220 | 2440 |
| Number of contacts per square meter | 2.4 | 3.6, 6.1 | 8.5 |
| **Cavity Absorption** | | | |
| Type | | Glass, Rock, Cellulose | |
| Thickness (mm) | 65 | none | 90 |
| Surface Density (kg/m$^2$) | 0.67 | 0.87, 1.16, 3.02 | 4.65 |
| **Direct-Attached Gypsum Board** | | | |
| Type | | Regular, Type X | |
| Number of Layers | 1 | none | 1 |
| Total Surface Density (kg/m$^2$) | 7.4 | | 13.3 |
| **Resiliently-Attached Gypsum Board** | | | |
| Type | | Regular, Type X | |
| Number of Layers | 1 | none | 2 |
| Total Surface Density (kg/m$^2$) | 7.4 | | 22.9 |
| **Studs** | | | |
| Spacing (mm o.c.) | 406 | none | 406 |
| Depth (mm) | 89 | none | 89 |
| **Shear element** | | | |
| Type | | OSB, Plywood | |
| Surface Density (kg/m$^2$) | 4.5 | | 8.2 |
| Thickness (mm) | 9.5 | 11, 12, 12.5, 12.7 | 13 |
| Fastener spacing (mm o.c.) | 75 | none | 152 |
| Fastener type | | nails, screws | |

*Table 1: The variables and their range that were considered in the regression analysis for the specimens with a single row of wood studs and an attached shear membrane.*

It should be noted that in conducting the regression analysis it was found that the range in shear membrane thickness or surface density was insufficient to determine a meaningful functional dependence. (This is discussed in greater detail in the section entitled Analysis of Individual Variables). Consequently, the shear element is not treated independently, but is considered as contributing to the total surface density of the direct attached layers.

| Resilient Channel | Shear Membrane | Absorption | 12.7mm 1S&R1 | 12.7mm 1S&R2 | 12.7mm Type X 1S&R1 | 12.7mm Type X 1S&R2 | 15.9mm Type X 1S&R1 | 15.9mm Type X 1S&R2 |
|---|---|---|---|---|---|---|---|---|
| 406 mm o.c. | 12.7mm OSB nailed | 90mm rock fibre R13 | | | | | | |
| | | 90mm glass fibre R12 | -2 | 0 | 0 | 0 | | -1 |
| | 12.7mm Plywood nailed | | | 1 | | 3 | | -1 |
| 610 mm o.c. | 12.7mm OSB nailed | blown cellulose | | | | | | 3 |
| | | 65mm rock fibre R9 | | | | | | -1 |
| | | 65mm glass fibre R8 | | | | | | 1 |
| | | 90mm rock fibre R13 | | | | | 0 | 0 |
| | | 90mm glass fibre R13 | | | | | 1 | 0 |
| | | 90mm glass fibre R12 | -1 | -1 | 1 | 2 | 2 | -1 |
| | 12.7mm OSB screwed | | | | | | | 1 |
| | 12.7mm OSB – perpendicular | | | | | | | 0 |
| | 12.7mm Plywood nailed | | | -1 | | 1 | | -1 |
| | 12.7mm Plywood screwed | | | | | | | 0 |
| | 11mm OSB nailed | | | | | | | 1 |
| | 11mm OSB screwed | | | | | | | 0 |
| | 9.5mm Plywood | | | | 0 | | | 0 |

*Table 2: Regression residuals for the specimens with a single row of wood studs and an attached shear membrane. Residuals are the difference between measured STC values and those predicted by the regression expression. Wall configuration is summarized by the identifier at the top of each column, 1 or 2 denotes the number of layers of gypsum board, S denotes a shear membrane, & denotes the framing, and R resilient channels.*

The regression expression for the wood stud shear walls was determined using a population of 44 walls. This population included two walls with the resilient channels spaced at 1220 and 2440 mm o.c. These non-standard constructions, which are not shown in the table above, allowed for a more accurate determination of the dependence on channel spacing. This population also included approximately 7 assemblies that were complete rebuilds where materials from different batches introduced a significant variation in one or more of the dependent variables. For these constructions, the mean residual is indicated in Table 2. (Note that since some cells contain an average, and others do not, one cannot simply sum the residuals listed in Table 2 and expect zero.)

The accuracy of the regression expression can be gauged by comparing the residuals (measured STC minus the regression estimate). The predicted result should be within a range of 2 standard deviations of the prediction (i.e. 2.4 dB), nineteen times out of twenty. Inspection of the individual residuals indicates that only two of the 44 predictions are outside this range. One exception is the wall with cellulose fibre insulation which is shown in Figure 16 to exhibit a small and localized improvement in the 125 Hz one-third octave band, causing the larger single number rating. The other case is the wall with studs 406 mm o.c. and 1+2 layers of 12.7 mm Type X gypsum board, for which perhaps second order effects such as stiffness of the gypsum board may be of importance.

The data indicate that there is no consistent over or underestimation associated with a particular variable. Thus the expression is a reasonable predictor for the walls in this study.

### *Regression Estimates for Steel-Framed Specimens*

For the steel-framed specimens, the data for regression analysis were obtained from the experimental results by application of the corrections for facility signature to the pre-renovation data. The subsequent regression analysis yielded the following equation:

STC = 10.40 + 18.75Log(***DirectGypDensity***) + 15.26Log(***ResGypDensity***) + 0.0969(***InsThick***) – 0.901(***RCContacts***)

Standard error = 1.41 dB
R-squared =0.891
Valid only within specified range of variables (see Table 3 on next page)

The variables in the regression equation were dependent on specific properties of the components of the specimen (identified in Figure 6) as follows:

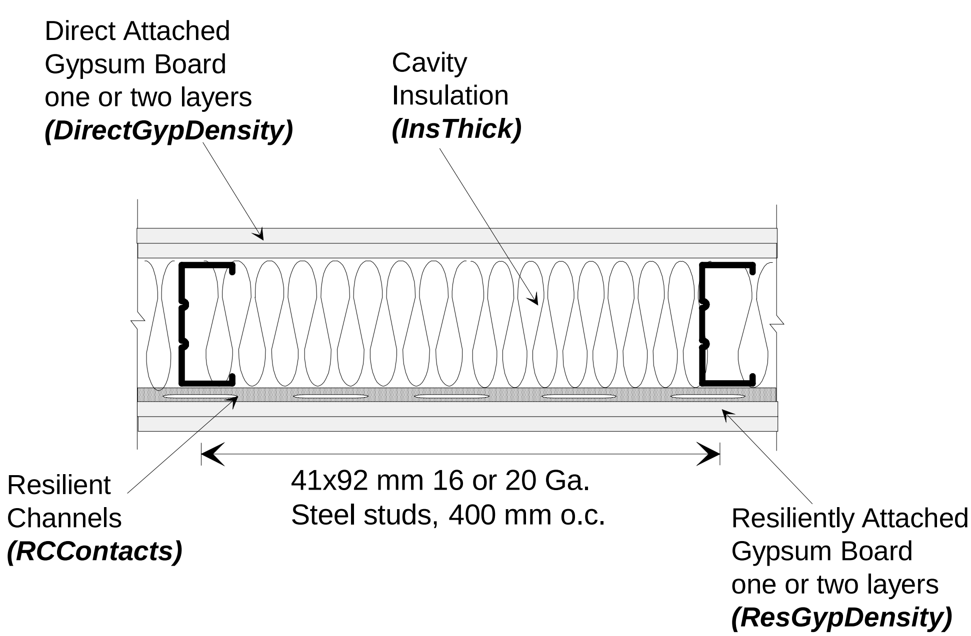
*DirectGypDensity* = total surface density of the gypsum board that is directly attached to the studs (kg/m$^2$). There may only be one or two layers;

*ResGypDensity* = total surface density of the gypsum board that is resiliently attached to the studs (kg/m$^2$). There may only be one or two layers.

*InsThick* = thickness of the fibrous cavity insulation (mm);

*RCContacts* = total number of points at which the resilient channels are fastened to the studs divided by the total area of the wall (number/m$^2$).

*Figure 6: Variables in the multivariate expression for the STC are associated with important physical properties of specific components of the wall specimens.*



The linear regression expression is a simple first-order representation of a complex non-linear problem, and must be applied with care. The regression expression is valid only to estimate STC for specimens of the same basic type, whose components fall within the range of properties of the specimens tested.

| Independent Variable | Minimum Value | Intermediate Values | Maximum Value |
|---|---|---|---|
| **Resilient Channel** | | | |
| Spacing (mm o.c.) | 406 | none | 610 |
| Number of Contacts per square meter | 5.6 | none | 7.8 |
| **Cavity Absorption** | | | |
| Type | | Glass, Rock, Cellulose | |
| Thickness (mm) | 0 | 65 | 92 |
| Surface Density (kg/m$^2$) | 0 | 0.87, 1.16, 3.02 | 4.80 |
| **Direct-Attached Gypsum Board** | | | |
| Type | | Type X | |
| Number of Layers | 1 | none | 2 |
| Total Surface Density (kg/m$^2$) | 10.0 | | 22.5 |
| **Resiliently-Attached Gypsum Board** | | | |
| Type | | Type X | |
| Number of Layers | 1 | none | 2 |
| Total Surface Density (kg/m$^2$) | 10.0 | | 22.8 |
| **Studs** | | | |
| Thickness (mm), [Gauge] | 0.92, [20] | 1.22, [18] | 1.52, [16] |
| Spacing (mm o.c.) | 406 | none | 406 |
| Depth (mm) | 92 | none | 92 |
| **Shear Element** | | | |
| Type | | X-bracing, OSB | |

*Table 3: The variables and their range that were considered in the regression analysis for the specimens with load-bearing steel studs.*

**16 Gauge Steel Studs 406 mm oc**

| Resilient Channel | Shear Membrane | Absorption | 12.7mm Type X 1&R1 | 12.7mm Type X 1&R2 | 12.7mm Type X 2&R2 | 15.9mm Type X 1&R1 | 15.9mm Type X 1&R2 | 15.9mm Type X 2&R2 |
|---|---|---|---|---|---|---|---|---|
| 406 mm o.c. | none | 90 mm glass fibre R12 | | | 0 | | -3 | -1 |
| | | 90 mm rock fibre R13 | | | -1 | | | |
| 610 mm o.c. | none | 90 mm glass fibre R12 | | 1 | 1 | 0 | | |
| | | 90 mm rock fibre R13 | | | 1 | | | |

**20 Gauge Steel Studs 406 mm oc**

| Resilient Channel | Shear Membrane | Absorption | 12.7mm Type X 1&R1 | 12.7mm Type X 1&R2 | 12.7mm Type X 2&R2 | 15.9mm Type X 1&R1 | 15.9mm Type X 1&R2 | 15.9mm Type X 2&R2 |
|---|---|---|---|---|---|---|---|---|
| 406 mm o.c. | none | 90 mm glass fibre R12 | -2 | -1 | 0 | | -2 | 0 |
| | | 90 mm rock fibre R13 | | 0 | | | | |
| | | none | | | | | | |
| | | 90 mm blown cellulose | | 0 | | | | |
| | Cross brace - blocking | 90 mm rock fibre R13 | | 1 | | | | |
| | cross brace | | | 0 | | | | |
| 610 mm o.c. | none | 90 mm glass fibre R12 | -2 | 0 | 0 | -1 | -1 | -1 |
| | | 90 mm rock fibre R13 | | -1 | 3 | | | |
| | | none | | | 0 | | | 0 |
| | | | | | | | | |

Table 4: *Regression residuals, the difference between measured STC values and those predicted by the regression expression for the steel stud assemblies. Wall configuration is summarized by the identifier at the top of each column, 1 or 2 denotes the number of layers of gypsum board, & denotes the framing, and R resilient channels.*

The regression expression for the structural steel stud walls was determined using a population of 27 walls. This population did not include any rebuild assemblies.

The accuracy of the regression expression for the steel stud assemblies can be gauged by comparing the residuals (measured STC minus the regression estimate). The sum of the residuals is zero, which indicates that on average there is no bias in the estimation. Inspection of the individual residuals indicates that there is no consistent over or underestimation associated with a particular variable. Thus the expression is a reasonable predictor for the walls in this study.

# ANALYSIS OF INDIVIDUAL VARIABLES

This section reports on the trends in the transmission loss observed for each type of stud where a structured a succession of small changes were introduced to one component while all others were held constant. These trends (exhibited by observable changes in pair-wise transmission loss comparisons) are used explain the presence or absence of physical parameters in the regression expressions for the single number STC rating derived for the set of walls in tis study.

For example, the effect due to different types of insulation was evaluated in a wood stud wall where the studs, shear membrane, and the type and attachment of the gypsum board were all held constant. A similar approach was used for the 20 gauge steel-framed assemblies, although the parametric variations were more limited. This provided a basis for evaluating the changes due to specific parameters.

The transmission loss of a double leaf construction (a wall or floor) is determined by the sum of two transmission paths; an airborne path through the cavity and a structure borne path via the framing. Walls and floors that have high sound insulation have, by design, elements that control both of these paths.

Table 5 relates the elements of the wall to the two transmission paths. The series of pair-wise comparisons of this section is used to explore the importance of these construction elements and details.

| Wall Element | Airborne Transmission | Structure Borne Transmission |
|---|---|---|
| **Cavity Absorption** | Very Important | No effect |
| Thickness | X | |
| Propagation constant | X | |
| **Resilient Channels** | Minimal Importance | Very Important |
| Dynamic stiffness | X | X |
| **Layer** | Very Important | Very Important |
| Surface density | X | X |
| Fastener spacing | X | X |
| Stiffness | X | X |
| Damping | X | X |
| **Stud** | Moderate Importance | Very Important |
| Type (wood, steel) | | X |
| Spacing | X | X |
| Depth | X | X |

*Table 5: The construction elements of the wall and their relation to the two transmission paths. The physical characteristics that determine the sound insulation are also identified.*

The construction of the assemblies in the pair-wise comparisons given in the following section are identified using a short hand description, the key to which is given below:

Surface Layers:

| | |
|---|---|
| **nGxx** | 'n' layers of Gypsum board with a nominal thickness of 'xx' mm. |
| **OSBxx** | Oriented strand board with a nominal thickness of 'xx' mm. |
| **PLYxx** | Plywood with a nominal thickness of 'xx' mm. |

Framing

| | |
|---|---|
| **WSxx(ss)** | Wood studs with a nominal depth of 'xx' mm spaced 'ss' mm apart. |
| **SSxx(ss)** | Steel studs with a nominal depth of 'xx' mm spaced 'ss' mm apart. |
| **RCxx(ss)** | Resilient channels with a thickness of 'xx' mm and spaced 'ss' mm apart. |

Contents of the Cavity

| | |
|---|---|
| **GFBxx** | Glass fibre batts with a nominal thickness of 'xx' mm. |
| **MFBxx** | Rock fibre batts with a nominal thickness of 'xx' mm. |
| **CFLxx** | Blown cellulose fibre with a nominal thickness of 'xx' mm. |
| **AIRxx** | Air space with a nominal depth of 'xx' mm. |

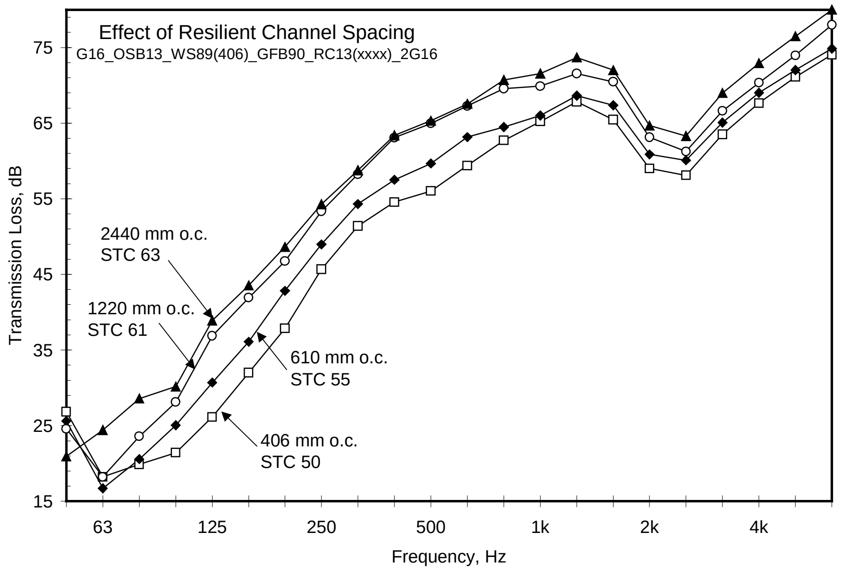
Note that for this key, all dimensions are rounded to the nearest millimetre. Thus, for example 12.7 mm gypsum board is listed as G13.

## Construction Details Affecting Structure Borne Transmission

Simple impedance-based theory suggests that the structural power flow between the stud and gypsum board is determined by the impedance of the gypsum board, the stud, and fasteners. The effective impedance of the fasteners is proportional to their number in the high frequencies where the wavelength (in either the stud or the gypsum board) is much smaller than the fastener spacing. This high-frequency approximation proves to be adequate to rank the effect of most construction changes involving resilient channels since their spacing is rather large compared to the wavelength for most frequencies of interest in this report.

Resilient channels are often used to isolate (create an impedance mismatch between) the stud and gypsum board thereby reducing the power flow. Increasing the spacing between the channels further reduces structure borne transmission and the transmission loss increases until the structural transmission path is no longer the most important path, as shown in Figure 7.

*Figure 7:*
*Change in transmission loss associated with increasing the spacing of the resilient channels on a wood stud shear wall. (Construction details are identified below the figure title).*




Increasing the channel spacing from 1200 to 2400 mm o.c. is of minimal benefit over a considerable frequency range (100-630 Hz) because airborne transmission through the cavity becomes dominant.

The improvement due to adding resilient channels, or increasing their spacing, is expected to differ for walls with different types of framing. The effect of resilient channels should be less for steel studs, because they are more compliant than wood studs of the same nominal depth. This is shown by the relative magnitude of the coefficients describing the resilient channels in each of the regression expressions. The coefficient for the 2x4 wood stud assemblies is twice that in the expression for the steel stud assemblies.

Figure 8 provides the comparison of sound insulation for the nominally identical wall with structural steel studs and with wood studs.

*Figure 8:*
*Change in transmission loss associated with changing the gauge of the structural steel studs from 16 to 20 gauge (Construction details are identified below the figure title).*

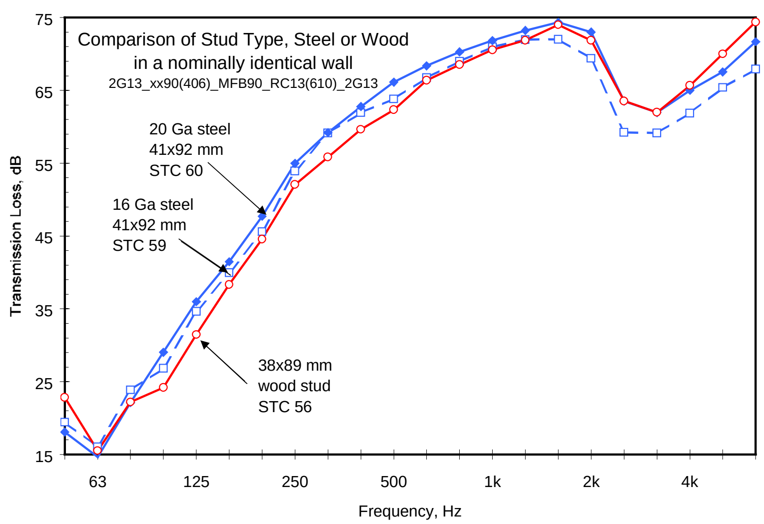


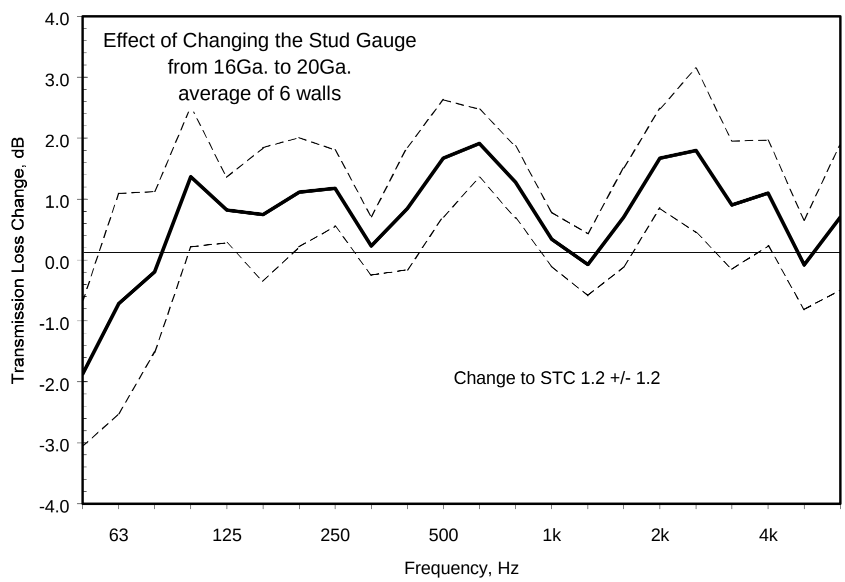

Figure 8 indicates that over a considerable portion of the low frequency range (100-500 Hz), the wall with steel studs of gauge of 16 or 20 offered greater transmission loss when compared to the nominally identical wall with wood studs. The STC rating for these walls is controlled by the transmission loss at

125 Hz, so the improvement in low frequency transmission loss is reflected in the improved STC rating. At frequencies above 1250 Hz, the wood stud and 20 gauge steel stud walls offer very similar sound transmission but the wall with the 16 gauge studs has considerably lower transmission loss. The reason for this was not established; it may be characteristic only of the single 16 gauge stud assembly tested in this project.

Comparing the results of the steel stud walls of the same figure, it appears that there is a slight improvement due to decreasing the thickness of the studs from 16 and 20 gauge when the gypsum board on one side of the wall is mounted on resilient channels. To examine this more reliably, data for several pairs of specimens were evaluated.

Figure 9 shows the mean improvement as a result of changing the stud gauge from 16 to 20 for six different pairs of gypsum board walls all having resilient channels and an STC of 49 or greater. The figure suggests that there may be some frequencies at which there is little or no improvement as a result of changing the gauge from 16 to 20 when the wall has resilient channels . (The effect of stud gauge is expected to be considerably more pronounced if there are no resilient channels. In this case, the gypsum board is direct-attached to both sides of the studs and the compliance of the studs determines the degree of structural coupling.) In terms of a single number rating, the STC increased, on average, by 1.2 with a standard deviation of 1.2. Thus, the STC for some walls may not change while for others there may be a small change.

*Figure 9: Mean improvement as a result of changing the stud gauge from 16 to 20 for six different gypsum board walls all having resilient channels and an STC of 49, or greater. The dashed lines indicate the range of one standard deviation about the mean.*




In the companion study of fire resistance, walls were made using both MSG 20 (0.912 mm) and MSG 20 *light* studs (0.840 mm). This represents a difference in the nominal thickness of approximately 9 percent. Given the characteristic change of 1.2 ± 1.2 in the STC as a result of reducing the actual thickness by 59% (16 to 20 gauge actual thickness as shown in Table A5), it is clear that a change of only 9% due to the *light* designation should be insignificant. Thus, for practical purposes the results of this report are equally applicable to walls with steel studs bearing the *light* designation. (This was not true for the companion fire resistance study).

Theory predicts that structural power flow between the direct attached layers will increase proportionally with the number of fasteners (screws and/or nails) when the spacing between the fasteners is large compared to the wavelength. (In this regime the layers are connected to the studs by a series of locally acting points). When the fastener spacing becomes smaller, the layer is effectively "line-connected" to the studs and increasing the number of fasteners does not increase power flow. However, the standard installation cases tested in this project do not illustrate this transition.

*Figure 10:*
*Effect associated with doubling the number of fasteners securing the shear membrane to the wood studs. (Construction details are identified below the figure title).*

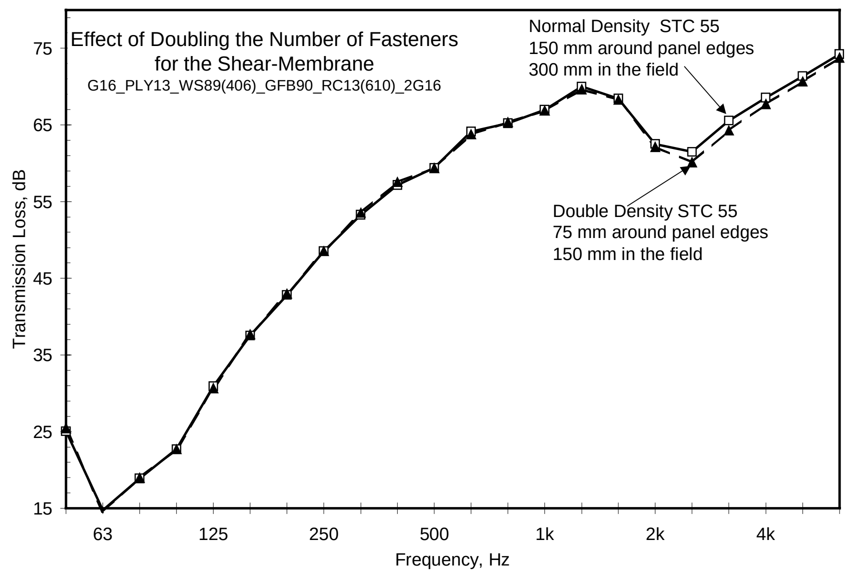
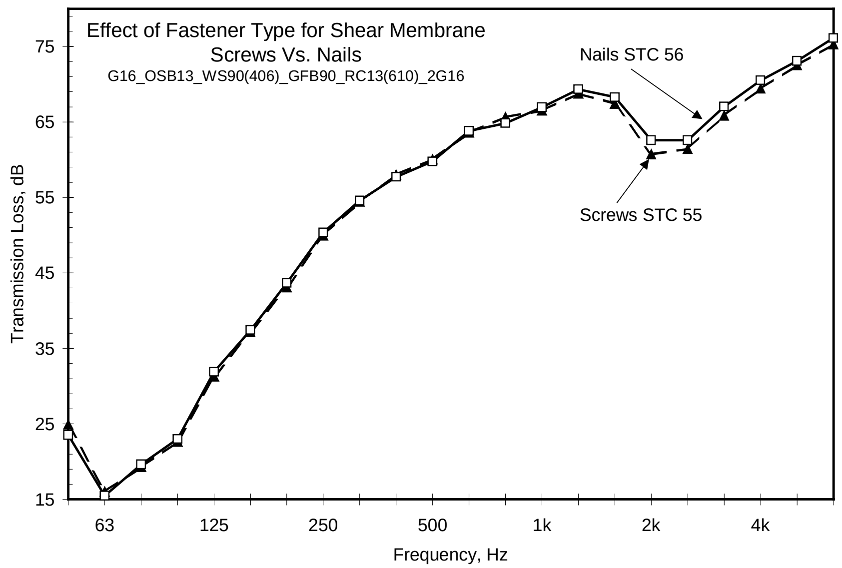



Figure 10 indicates that there is no appreciable effect associated with doubling the number of fasteners in the OSB shear membrane. This implies that with the normal density of fasteners in the shear membrane, plus those of the gypsum board layer on top of it, the layers were effectively line-connected to the wood studs.

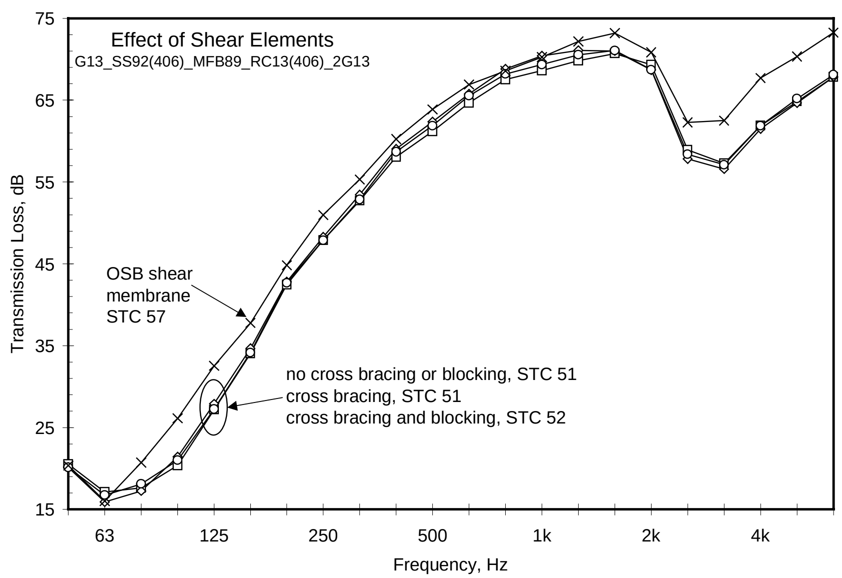
Similarly, no appreciable effect associated with changing the fastener type from nails to screws was observed, as shown in Figure 11.

*Figure 11:*
*Effect associated with changing the type of fasteners (nails or screws) used to secure the shear membrane to the studs. (Construction details are identified below the figure title).*




It might be expected that the cross bracing and blocking which are common elements in a shear resistant steel stud wall might have an effect on the transmission loss since these structural elements distribute forces across all the studs. Figure 12 indicates that cross bracing and blocking did not appreciably change the transmission loss. Thus, the steel stud walls presented in this report will likely exhibit a similar single number STC rating, with or without cross bracing and blocking. The figure also shows that if a shear membrane, in the form of an OSB panel, is used instead of the cross bracing and blocking, then a significant improvement can be realized because of the increased mass of the direct-attached layers. This additional mass has a significant effect because it reduces the structure borne component by increasing the impedance of the direct applied layers, and also the airborne component (as discussed in the next section).

*Figure 12:*
*Effect associated with introducing blocking, and/or shear resistant cross bracing in a 20 gauge (0.91 mm) structural steel stud wall. Also shown is the same wall with an OSB shear membrane to illustrate that the additional mass of the shear panels improves the transmission loss. (Construction details are identified below the figure title).*



**Summary, Structure Borne Transmission:**

An effective method of controlling structure borne transmission must break the structural connection between the gypsum board layers on the two faces of the wall. This is best done using double stud construction. However, if this is not possible and a single stud wall must be used, the layers on one side of the wall should be resiliently mounted.

Increasing the mass of the direct attached layers will improve the sound insulation but not as significantly as reducing the vibration transfer through the studs. This can be accomplished using resilient channels, which should be spaced as far apart as possible to minimize the number of connections to the studs. Similarly, the largest acceptable stud spacing should be used, because this also reduces the number of connections.

## Construction Details Affecting Airborne Transmission

Conceptually, airborne transmission through a cavity wall seems very simple - incident sound waves cause pressure fluctuations on the source side of the wall, which force the gypsum board layer(s) into motion. The motion of the gypsum board causes pressure fluctuations in the cavity, which in turn forces the gypsum board on the other side of the cavity into motion and sound is radiated into the receive space.

To discuss the functional dependence of the various elements that form the wall it is necessary to recognize that there will be two mechanisms of energy transport across the air cavity. They are resonant transmission and non-resonant transmission, respectively. Unfortunately these transmission mechanisms are not separable and can not be measured independently, so the measured transmission loss curves will most likely exhibit trends defined by the sum of the energies due to both mechanisms.

The various parameters used to generate the regression expressions are now investigated using pair-wise comparisons.

### *Cavity Absorption*

Experimental studies have shown that adding fibrous material to the cavity of a wall can significantly enhance the attenuation of airborne sound. The improvement in the airborne transmission loss is a complex function of many variables, several of which are interrelated and can not be fully separated. Unfortunately, there has not been a thorough systematic study of fibrous materials in gypsum board walls, however the following macroscopic properties of the material are known to be factors:

- Portion of the cavity filled (for walls this is usually determined by the thickness of the fibrous material);

- Airflow resistance (the product of the material thickness and airflow resistivity); and
- Bulk density (the bulk density and airflow resistivity are interrelated).

Although this section deals with airborne transmission it should be noted that the presence of fibrous material may introduce structural damping if the material comes in contact with the gypsum board or the studs. Structural damping of the installed gypsum board panels was not measured so this potential effect can not be quantified, but it is thought to relate to method of installation, mass, and material stiffness.

The change in the measured transmission loss will be examined for the limited range of physical properties provided by the series of walls presented in this report. The results are then used to help explain the presence or absence of the various physical properties found in the regression expressions for this set of single stud walls.

For the discussion that follows it is helpful to think of the fibrous material as introducing an excess attenuation, over that normally be experienced with an empty cavity, which is proportional to the distance traveled in the fibrous material. This attenuation with distance is described by the propagation constant for which there are simplistic non-linear empirical relationships defined in terms of the thickness and airflow resistivity of the material.

Since airflow resistance is the product of the thickness and the resistivity, it is tempting to use airflow resistance as the single descriptor for ranking the performance of fibrous materials in a cavity. However, it should be noted that there is a stronger dependence on thickness than on resistivity. It is for this reason that it may be beneficial to use a thicker batt having a lower airflow resistivity than to use a thinner batt with a higher resistivity. Thus, airflow resistance should not be used as the sole indicator of relative performance especially when the thickness of the materials is not the same.

Since the flow resistivity of a fibrous material is related to the bulk density, it should be possible to rank the resisitivity of materials based on their bulk density assuming that they have the same physical properties such as fibre diameter, tortuosity, and binder concentration. Of course, these properties vary appreciably between different types of fibrous absorbers.

In the following figures values are given for both the surface density (the product of the bulk density and the thickness) as well as representative airflow resistance (product of the typical airflow resistivity given in Table A2 and the nominal thickness).

*Figure 13:*
*Effect associated with adding fibrous absorption so that the cavity is completely filled. (Construction details are identified below the figure title).*

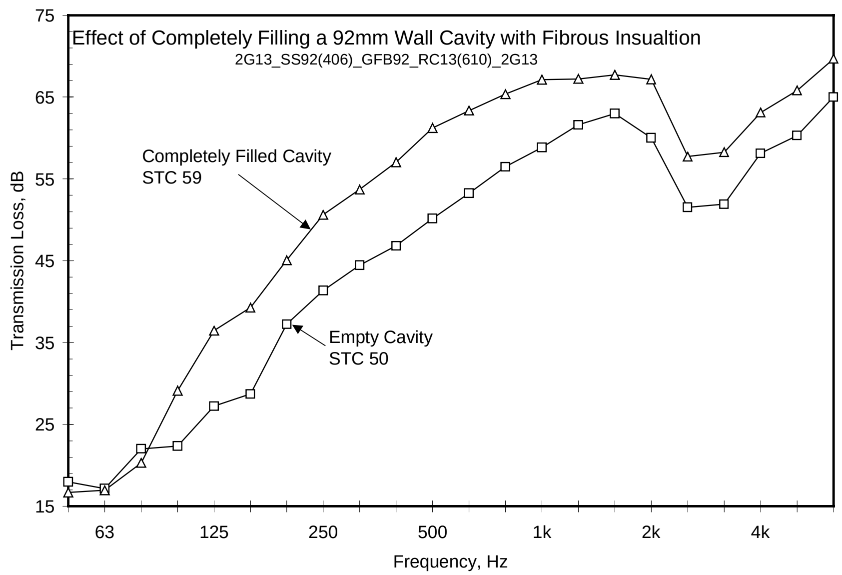



Figure 13 shows that adding cavity absorption will be very effective in improving the transmission loss at frequencies greater than about 80 Hz, although the effect is smaller at the low frequencies that tend to control STC for these constructions.

Figure 14 indicates that there is considerable benefit to increasing the thickness of the cavity absorption so that the cavity is almost completely filled. (For cavities filled with 90 mm batts, there will be a small air gap between the face of the batt and the gypsum board introduced by the resilient channels). Similar increases in sound transmission loss in the first phase of the project were shown in IRC report IR-693 for other types of absorptive material.

*Figure 14:*
*Effect associated with increasing the thickness of fibrous cavity absorption from 65 to 90 mm so that the cavity is almost completely filled. (Construction details are identified below the figure title).*

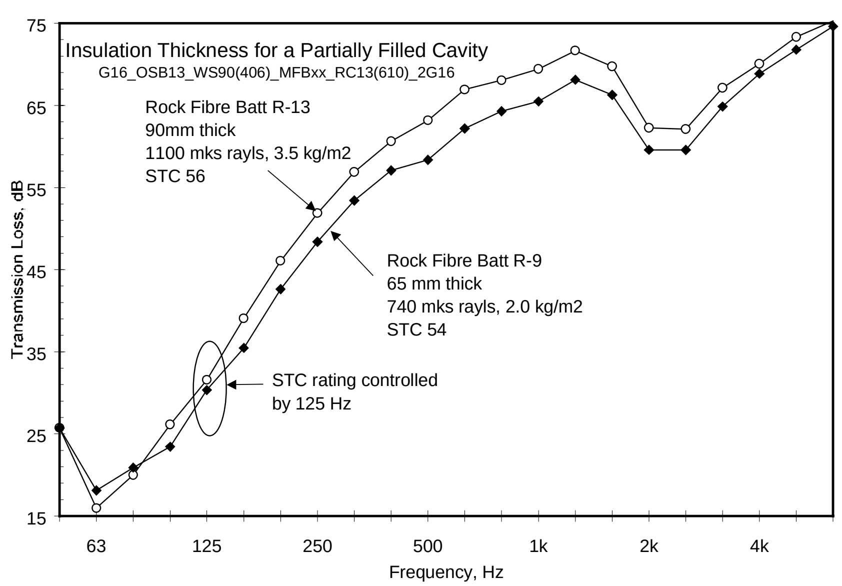


Figure 15 compares the cavity insulation type - rock or glass fibre - for 65 mm of insulation in an identical wall assembly. The figure suggests that there may be very little difference due to material type when the cavity is partially filled, but a more extensive comparison with several pairs of specimens would be needed to clearly establish this.

*Figure 15:*
*Effect associated with the type of cavity insulation in a partially filled cavity. Each batt material was nominally 65 mm thick and the cavity was nominally 90 mm deep. (Construction details are identified below the figure title).*

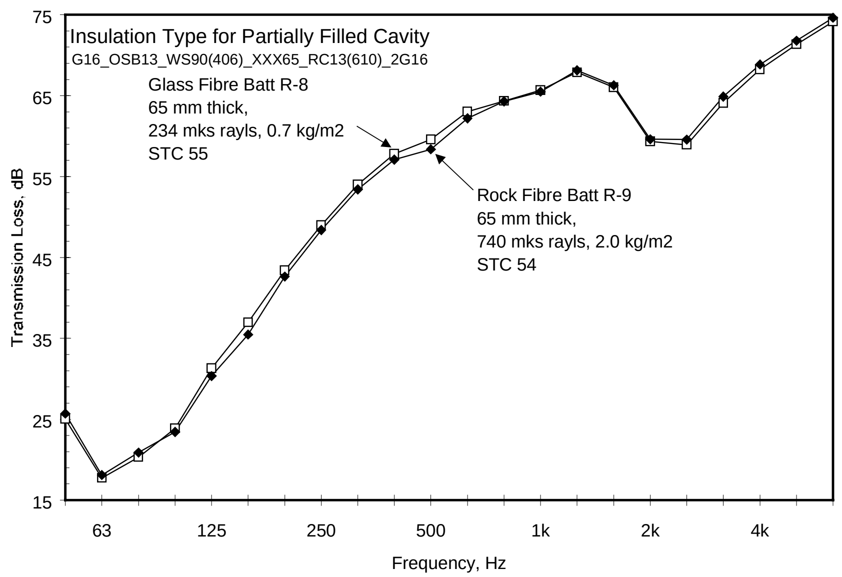
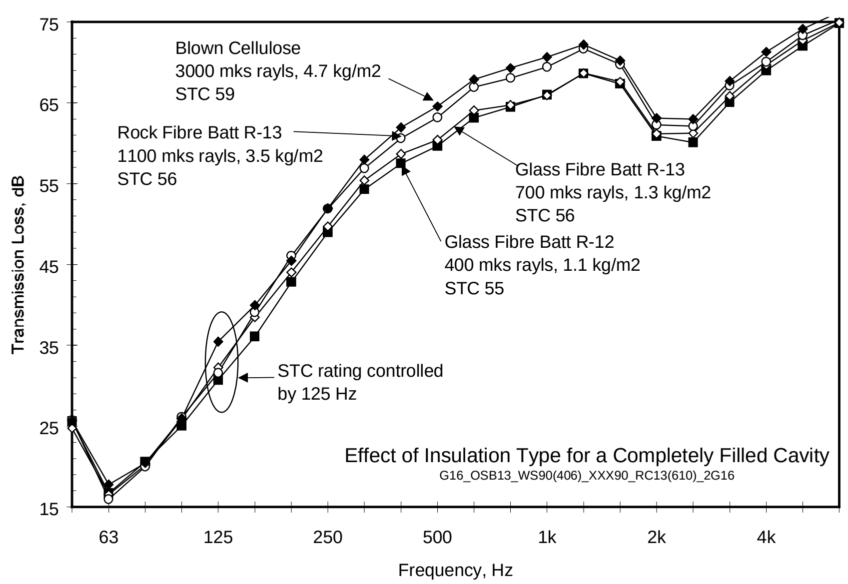



Figure 16 suggests that for frequencies greater than about 350 Hz the transmission loss of a 90 mm wall with a nearly completely filled cavity can be ranked by the airflow resistance of the fibrous material. It is thought that resonant transmission is dominating above this frequency and the additional mass and possible damping introduced by the heavier fibrous materials is having an effect. However, at the lower frequencies, where the STC is determined, the trend is much less clear.

*Figure 16:*
*Effect of type and density of fibrous cavity absorption that completely fills a wood stud shear wall. (Construction details are identified below the figure title).*



The results in Figure 15 suggest that airflow resistance (or bulk density in the case of like fibrous materials) is not very important for a partially filled cavity over the building acoustics range. However, the results of Figure 16 suggest that for frequencies above about 350 Hz airflow resistance is important when the cavity is almost completely filled.

In summary:

- Thickness of the fibrous material is a very important factor in determining the STC as well as broad-band transmission loss as shown by Figure 13 and Figure 14.
- Airflow resistance (or bulk density) will not be a good predictor of STC when the rating is determined by the low frequency transmission loss, namely that at 125 Hz, as shown by Figure 15 and Figure 16.
- The pair-wise comparisons agree with the multi-variate regression of STC which indicated that thickness was the strongest predictor for cavity absorption, and that airflow resistance and/or density were less-useful predictors. The uncertainty due to limited repeatability of the data prevents a strong conclusion, but these observations suggest limited applicability for simple linear models based on this set of data.

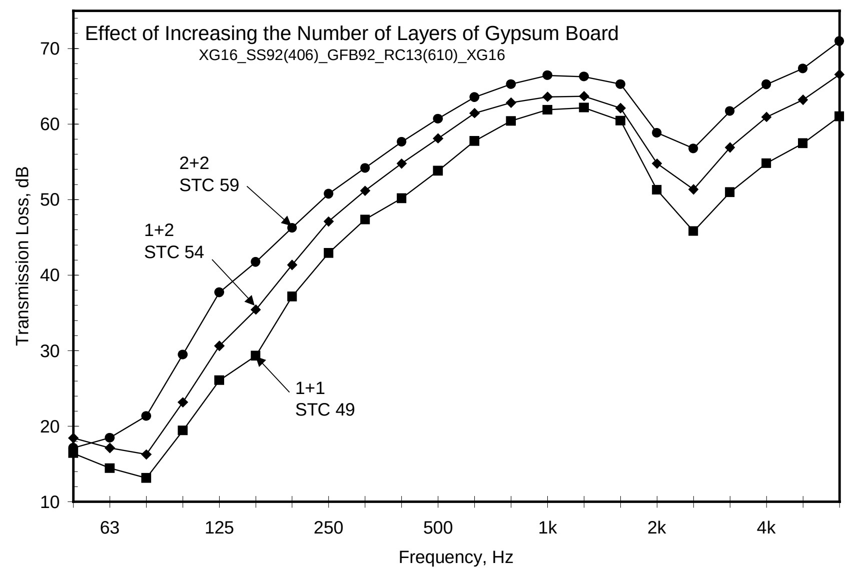
### *Layer Mass and Type*

Surface density of the layers is the single most important parameter since increasing the mass reduces the energy transmission into the cavity. According to simple theory, the transmission loss of a monolithic system increases 6 dB at all frequencies for a doubling of mass. Thus, doubling the mass of both sides of a cavity wall one might expect a 12 dB reduction of energy (a 6 dB plus 6 dB reduction) when the dimensions of the cavity are large compared to the wavelength. This would result in a 12 STC increase in the single number rating.

For the specimens in this project, the mass of a wall is increased by adding additional layers of gypsum board, and the improvement is consistently less than would be predicted by a theory which assumes the layer is monolithic.

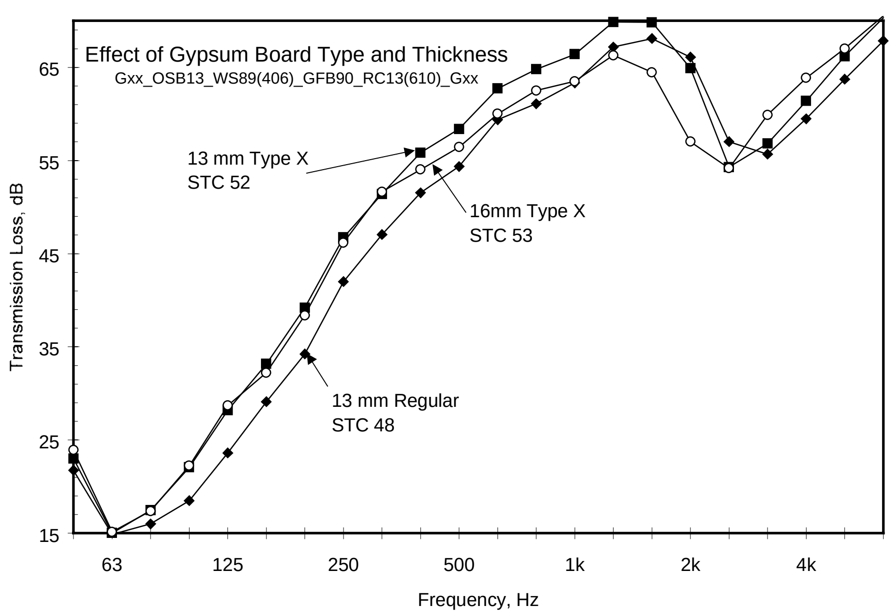
Figure 17 shows that typically there is an improvement in the transmission loss (and the STC) of about 4-5 dB when the number of layers is doubled on one side of the wall. (Compare 1+1 versus 1+2 layer assemblies). The same figure also shows an 8-10 dB improvement when the layers are doubled on both sides. (Compare 1+1 versus 2+2 layer assemblies). Note these trends and data are applicable only for three walls shown in Figure 17. The regression expression(s) provide a more general description for the walls of this report.

*Figure 17:*
*Effect of increasing the mass of the wall by adding additional layers of gypsum board to a structural steel stud wall. The captions indicate the number of layers of gypsum board on the wall. (For example 1 + 2 has one layer one side and two on the other). (Construction details are identified below the figure title).*




The measured improvement is slightly less than predicted by the simple theory that assumes that multiple layers on one side of the wall act as a monolithic element. In reality, the layers are not bonded; attachment to the studs allows the two layers to move independently. Impedance-based models suggest that with a small air space - less than 1 mm - the improvement will be closer to 5 dB for double the number of layers on one side of the wall and 10 dB when the layers are doubled on both sides. The trapped air between the layers will act like a spring, preventing the layers from behaving like a monolithic element. The reduced improvement observed around 1kHz is consistent with this prediction, as noted previously by Warnock in IR-766 and proceedings of InterNoise 2000[1].

*Figure 18:*
*Effect of changing the type and thickness of gypsum board. The surface density of the 16mm and 13mm fire-rated gypsum boards used in this study was very similar and there is not a great change in the single number rating. The 13mm regular gypsum board is considerably lighter and the sound insulation is lower below about 800 Hz where damping may not be a significant factor. (Construction details are identified below the figure title).*




[1] "Airborne and Impact Sound Insulation of Joist Floor Systems: A Collection of Data." Proc. INCE 2000 page 4-2417 to 4-2422

Figure 19 indicates that changing the type of shear membrane from plywood to OSB does not have an appreciable effect when the two have similar nominal thickness, presumably because the change in *overall* surface density is small.

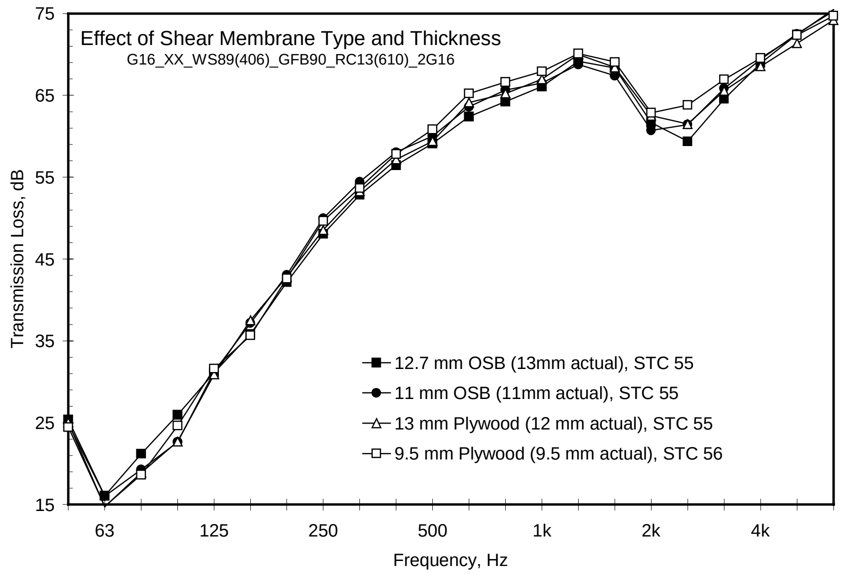



*Figure 19:*
*Effect of changing the type and thickness of the shear membrane in a wood stud wall. Changing the type of material from OSB to plywood of the same nominal thickness resulted in no appreciable change. The data suggest that reducing the thickness might improve the sound insulation. This probably related to the reduction in bending stiffness of the material. (Construction details are identified below the figure title).*

The effect on the transmission loss due to a change to the shear membrane type or thickness is expected to depend on the total surface density of the gypsum board layers. The greater the surface density of the gypsum board layers, the smaller the fractional change in the total surface density due to changing the shear membrane. Unfortunately, the study only permitted investigation of the shear membranes on one type of wall. However, for practical cases, any effect due to the type of shear membrane should be small.

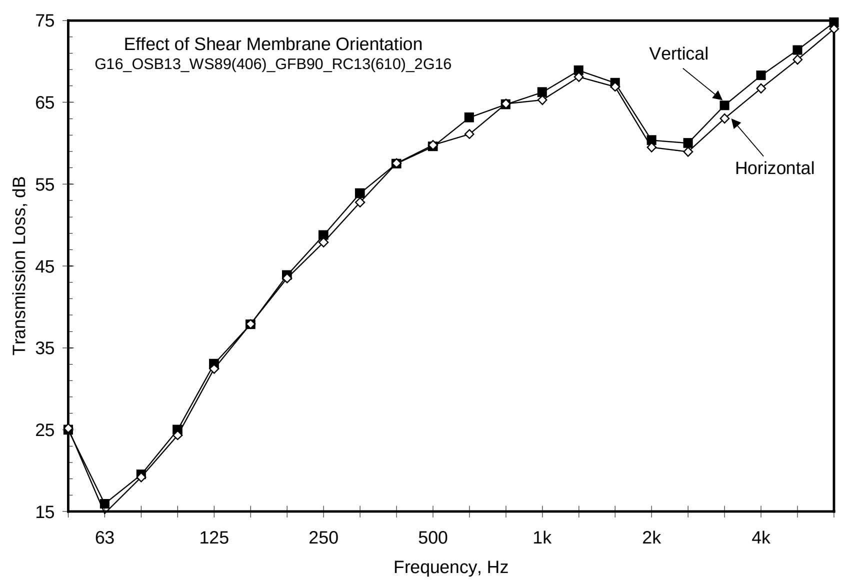



*Figure 20:*
*Effect of changing the orientation of the shear membrane. The captions in the figure indicate the orientation of the long axis of the shear panel with respect to the studs. In the frequency range where the STC is determined there was no measurable effect. (Construction details are identified below the figure title).*

It was thought that the orientation of the shear membrane might be an important factor since the panels are highly orthotropic (having a much higher bending stiffness parallel to the long axis of the panel). Figure 20 indicates that the transmission loss over most frequencies is insensitive to the orientation of the panel.

In this study the shear panels were positioned and fastened to the studs so that there was no gap at the butt joint between adjacent sheets. The effect of leaving a small gap at the butt joint between the panels was not investigated as part of this study. However, it is thought that the effect will be minimal.

### *Stud Spacing*

Studs effectively divide the wall into a series of smaller sub-areas and the spacing of the studs determines the dimensions of sub-panels, and hence the efficiency with which sound energy can be radiated into and out of the cavity. In general, the efficiency of energy radiation from a panel increases as the ratio of perimeter length to area increases. This implies that a fixed height wall with studs spaced 406 mm on center will have a lower sound insulation than one with studs 610 mm on center. All the walls selected by the Committee had a common stud spacing so the results of this study are not generally applicable to walls with a different stud spacing.

### *Fastener Spacing*

Figure 10 has already shown that doubling the number of fasteners in the shear membrane did not appreciably change the transmission loss. Dramatically reducing the fastener spacing would reduce the influence of the studs, and the effect of stud spacing would be expected to diminish. (The number of fasteners to achieve this is not known.)

Similarly, if the gypsum board is mounted on resilient channels then changing the spacing of connections of the gypsum board to the channels is not likely to significantly alter panel vibration and hence sound transmission.

**Summary, Airborne Transmission:**

Controlling airborne transmission requires that the gypsum board layers have sufficient mass and that the cavity contains fibrous absorptive material. The change in mass associated with the different types of shear membranes, and the range of thickness examined in this study (9.5 to 13 mm), did not have an appreciable affect on the transmission loss.

Changing stud spacing (typically 610 or 406 mm o.c.) is also expected be an important variable because it changes the modal response of directly attached panels, but this parameter was not varied in the present study.

Overall, it is important to recognize that energy transmission through the single stud walls considered in this study is determined by the sum of two transmission paths - airborne and structure borne. The effective transmission loss of a wall can not be any better than the dominant transmission path. This has two important implications:

1. First, for effective use of materials, the wall should be designed so that transmission is not limited by the structure borne path. An example would be a single stud wall with direct attached gypsum board on both sides and the cavity filled with fibrous material. The structure borne path is so strong that changing the airborne path has negligible effect - the cavity absorption could be removed without significant reduction of the STC.
2. Second, the expressions developed by regression analysis assume that there is a linear relationship between each variable and the resulting STC. This implies that, for example, increasing the thickness of the cavity absorption will increase the transmission loss regardless of the variables that control the structure borne path. Clearly, this is not true when structure borne transmission dominates transmission.

Both the trends discussed in this chapter and the linear regression expressions from the preceding chapter are simple first-order representations of a complex non-linear problem, and must be applied with care.

# APPENDIX: SPECIMEN DETAILS

This appendix presents information on the details of the specimens, including the materials from which they were fabricated. Most of the materials are essentially the same as those used in the preceding project on gypsum board walls (documented in IRC Internal Report IRC-IR-693, October 1995).

## Properties of Materials Used in Wall Specimens

The properties of the materials used in the specimens are given below in a series of tables. The limited set of material properties is not sufficiently detailed to completely characterize the acoustical performance of the various materials, but is thought to represent the most important parameters and allow product differentiation.

### *Fibrous Cavity Insulation*

| **Type of Insulation** | Thickness (mm) | Surface Density ($kg/m^2$) | | | Airflow Resistivity (mks rayls/m) | |
|---|---|---|---|---|---|---|
| | Nominal | Mean | Max. | Min. | Mean | Standard Deviation |
| Glass Fibre Batt | 65 mm * | 0.68 | 0.69 | 0.67 | 3600 | 200 |
| | 90 mm * | 1.00 | 1.21 | 0.80 | 4800 | 400 |
| Rock Fibre Batt | 65 mm * | 2.04 | 2.10 | 1.93 | 11400 | 1700 |
| | 90 mm * | 3.16 | 3.46 | 2.80 | 12700 | 2300 |
| Cellulose Blown | 90 mm * | 4.73 | 4.80 | 4.65 | 33000 | -- |

*Table A1: Material properties for the fibrous cavity absorption used in this study. The asterisk indicates that the actual value was not measured and the nominal value is given. The shading indicates previously measured data from an earlier IRC/NRCC study (IRC-IR-693).*

***Gypsum Board***

Note on classification of gypsum board: To help identify the type of gypsum board used in this study, the fire resistance designation “Type X” or “regular “ is used in addition to the nominal thickness. It must be noted that these designations (“Type X” or “regular “) refer to the fire resistance properties of the board and do not ensure that board products of the same nominal thickness within each designation will have very similar values for acoustically-important material properties. This may be particularly true of products bearing the “Type X” designation, since a board may be proprietary in nature. Boards whose mass differs significantly from those used in the measurements reported here would tend to give different sound insulation.

Thus measured data from this report should not be used to estimate performance of an assembly unless the material properties - especially surface density - of the gypsum board used in the proposed construction is similar to that used in this study (see Table A2 and its footnotes). Given the gypsum board surface density, the regression expressions presented on pages 18 and 21 should be used to estimate expected performance.

| **Gypsum Board** | Thickness (mm) | Surface Density ($kg/m^2$) | | | Bending Stiffness ($N*mm^2/mm$) | |
|---|---|---|---|---|---|---|
| | Nominal | Mean | Max. | Min. | Mean | Standard Deviation |
| 12.7 mm Regular[2] | 12.7 mm * | 7.38 | 7.41 | 7.30 | Short: 234900<br>Long: 312000 | 5800<br>24000 |
| 12.7 mm Type X[3] | 12.7 mm * | 10.24 | 10.70 | 10.0 | Short: 385000<br>Long: 434800 | 64700<br>13100 |
| 15.9 mm Type X[4] | 15.9 mm * | 11.29 | 11.56 | 10.61 | Short: 808700<br>Long: 708600 | 139800<br>116300 |

*Table A2: Material properties for the gypsum board used in this study. It should be noted that each type of gypsum board was supplied by a single manufacturer so the range in surface density given in this table should not be taken as typical of what might be expected if boards were selected from different manufacturers, as indicated by the footnotes. The asterisk indicates that the actual value was not measured and the nominal value is given. The shading indicates previously measured data from an earlier IRC/NRCC study (IRC-IR-693).*
*The panels are orthotropic, and the directions in which stiffness was measured are identified with the mean values. "Short" indicates the direction of measurement was parallel to the short dimension of the board, whereas "Long" indicates the direction of measurement was parallel to the long dimension of the board.*

[2] Material properties reported in IRC-IR-693 indicated a range of 7.3 to 8.2 $kg/m^2$ in surface density is likely for 12.7mm Regular products from different manufacturers. A larger range is possible.
[3] Material properties reported in IRC-IR-693 indicated a range of 8.7 to 10.0 $kg/m^2$ in surface density is likely for 12.7 mm Type X products from different manufacturers. A larger range is possible.
[4] Material properties reported in IRC-IR-693 indicated a range of 10.9 to 11.5 $kg/m^2$ in surface density is likely for 15.9 mm Type X products from different manufacturers. A larger range is possible.

### *Shear Panels and Framing*

| **Wood Shear Panels** | Thickness (mm) | | | Surface Density ($kg/m^2$) | | |
|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Mean | Max. | Min. |
| OSB 11 mm ** | 11.0 | --- | --- | 6.67 | --- | --- |
| OSB 13 mm | 12.6 | 13.0 | 12.0 | 7.77 | 8.19 | 7.56 |
| Plywood 9.5 mm ** | 9.5 | --- | --- | 4.66 | --- | --- |
| Plywood 12 mm | 12.3 | 13.0 | 12.0 | 5.70 | 5.77 | 5.63 |

*Table A3: Material properties for the wood-based shear panels used in this study. The double asterisk indicates that the material was used in only one specimen.*

| **Wood Studs** | Bulk Density ($kg/m^3$) | | |
|---|---|---|---|
| | Mean | Max. | Min. |
| 38 x 89 mm * | 524 | 536 | 492 |

*Table A4: Material properties for the wood studs used in this study.*

| **Steel Framing** | Nominal Thickness (mm) | Measured Thickness (mm) | | | Lineal Density (kg/m) | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Max. | Min. | Mean | Max. | Min. |
| 16 gauge** Stud | 1.52 | 1.49 | --- | --- | 2.00 | --- | --- |
| 18 gauge Stud | 1.21 | --- | --- | --- | --- | --- | --- |
| 20 gauge Stud | 0.91 | 0.94 | 0.98 | 0.87 | 1.27 | 1.30 | 1.20 |
| 26 gauge Resilient Channels | 0.45 | 0.45 | 0.50 | 0.40 | 0.25 | 0.30 | 0.20 |

*Table A5: Nominal thickness of Manufacturer's Standard Gauge system and the measured thickness for the steel framing used in this study. The double asterisk indicates that only one sample of the material was used. Data for the 18 Gauge studs were not recorded.*

## Framing Details and Fastener Patterns for Wall Specimens

The following drawings illustrate the framing details and the fastener patterns for attachment of surface layers for all the specimens in this study.

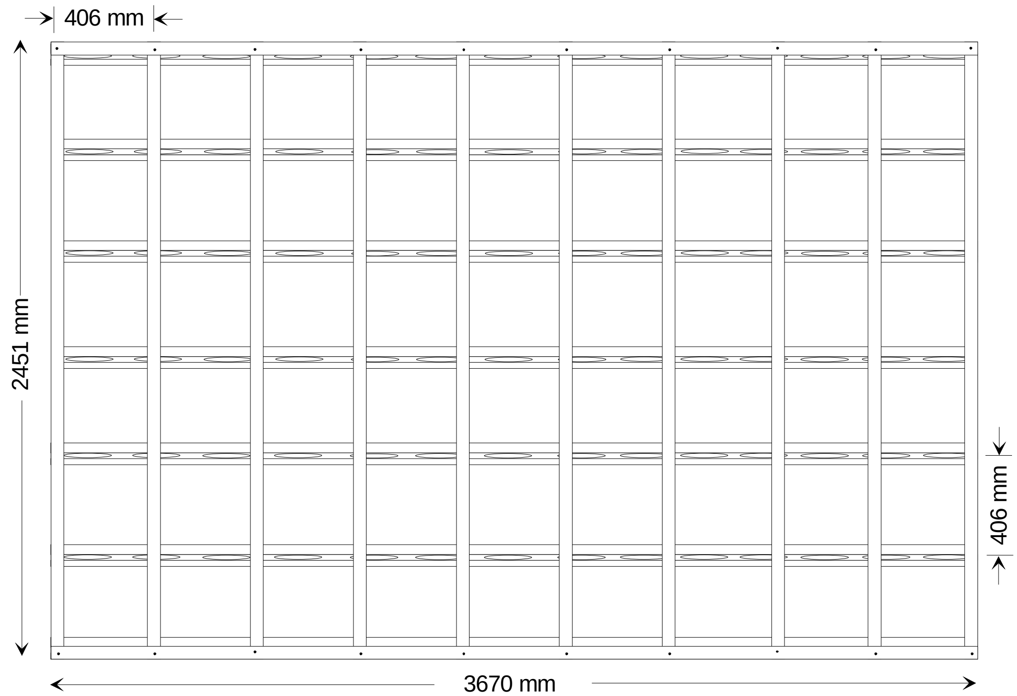



*Figure A-1.: Sketch of the steel stud and resilient channel location for most load-bearing steel-framed specimens constructed in this project, with the studs spaced 406 mm o.c. and resilient metal channels spaced 406 mm o.c. The fasteners securing the studs to the track and the resilient channels to the studs were 19 mm low-profile self-drilling # 10 screws.*

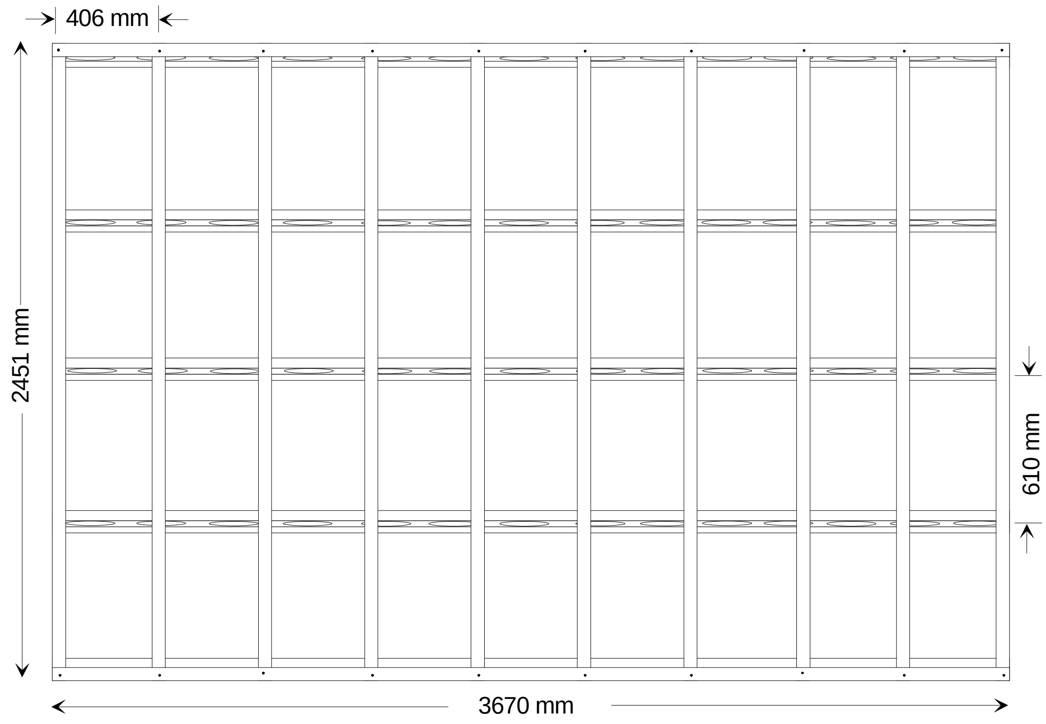



*Figure A-2.:* *Sketch showing the construction of the load-bearing steel framing assembly with studs spaced 406 mm o.c., and resilient channels spaced 610 mm o.c. Other construction elements are unchanged from Figure A-1.*

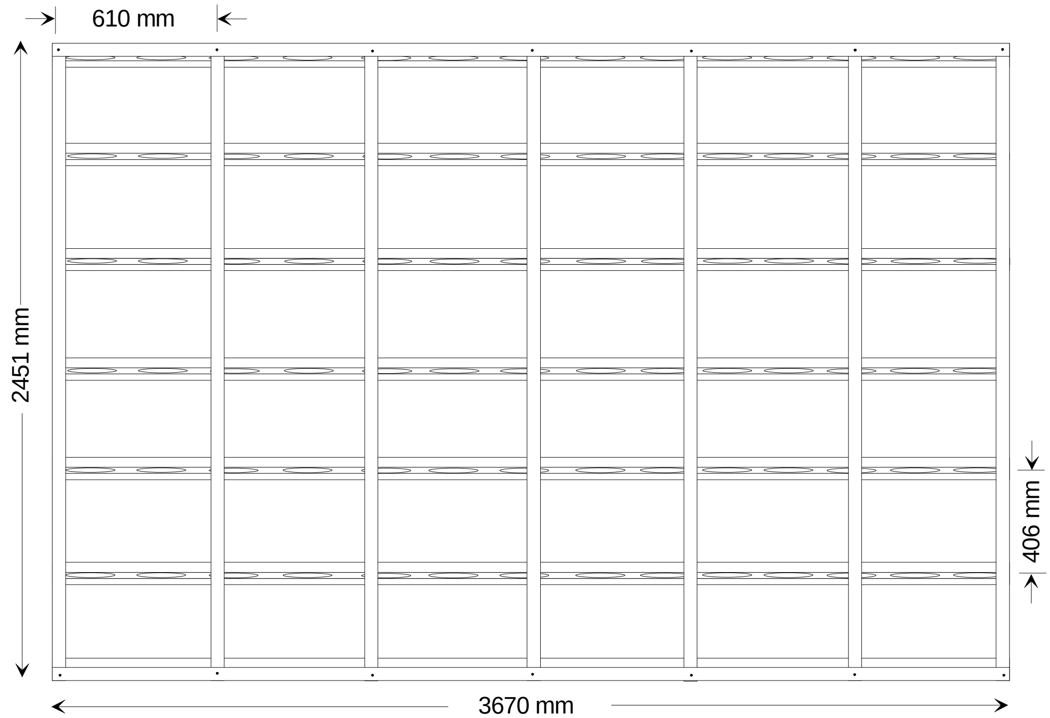



*Figure A-3.:* *Sketch showing the construction of the load-bearing steel framing assembly with studs spaced 610 mm o.c., and resilient channels spaced 406 mm o.c. Other construction elements are unchanged from Figure A-1.*

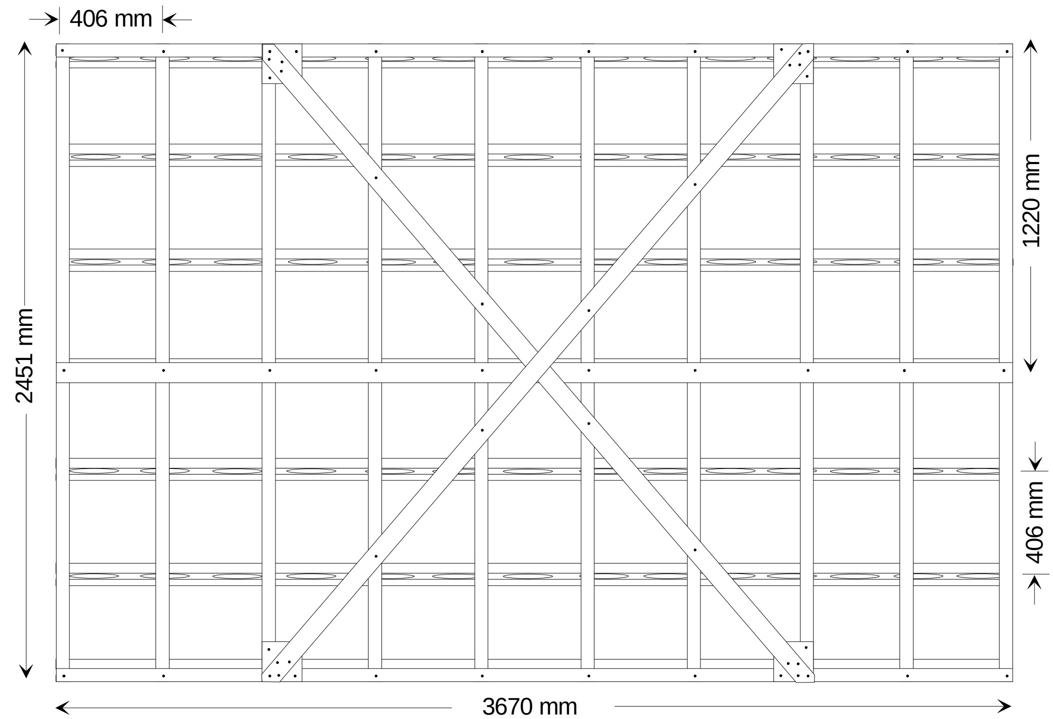



*Figure A-4.:* *Sketch showing the location of the bridging and cross bracing used in steel-framed specimens TLA-99-129 and TLA-99-131. The bridging and cross bracing were 75 x 0.84 mm flat strap and were secured using 19 mm #8 low-profile self drilling screws. The cross bracing and bridging were located on the side of the wall having the direct attached gypsum board.*
*Other construction elements are unchanged from the assembly shown in Figure A-1.*

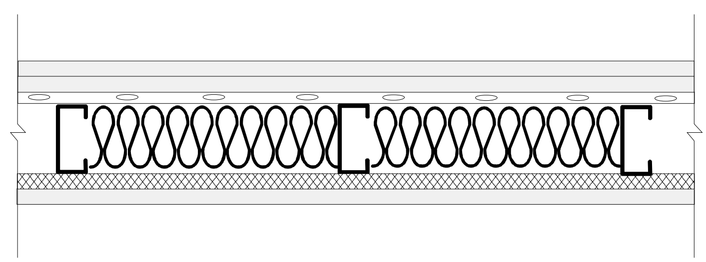


*Figure A-5.:* *Sketch showing the location of the 11.7 mm thick OSB structural panel used in steel-framed assembly TLA-99-135. The 1220x2440 mm structural panels were installed vertically and fastened to the studs using #8 wafer-head-square wood-to-metal self drilling screws spaced 152 mm along edges and 305 mm in the field. Other construction elements are unchanged from Figure A-1.*

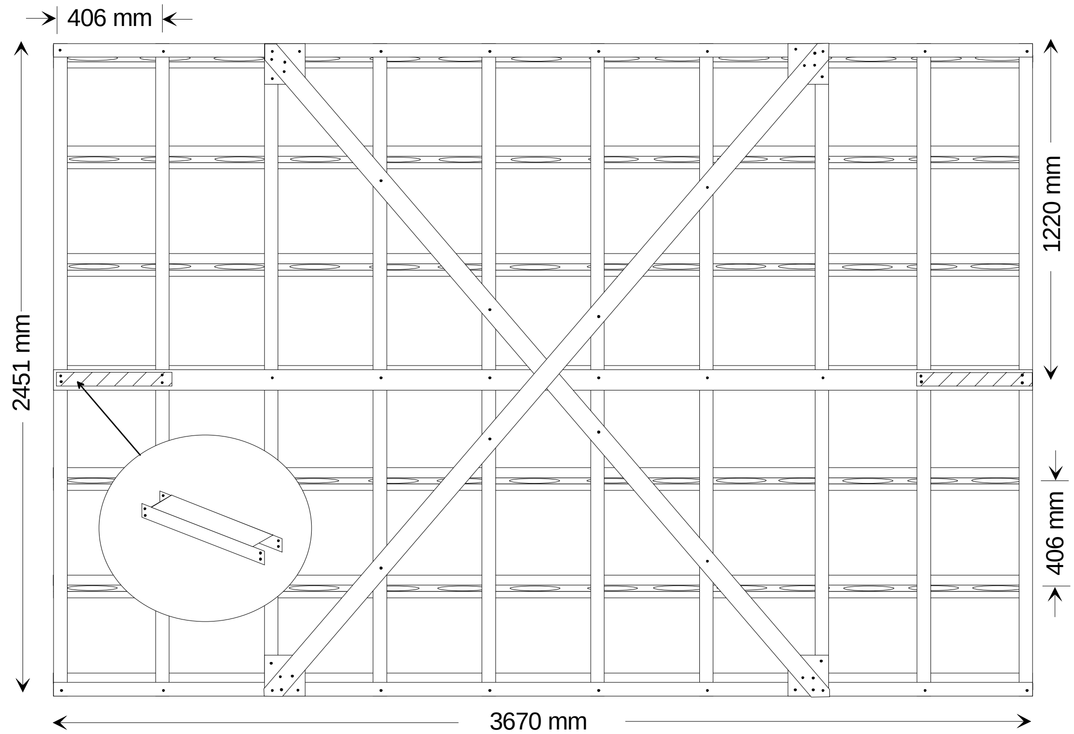



*Figure A-6.:* *Sketch showing the location of the solid blocking used in Assembly TLA-99-129. Other construction elements are unchanged from Figure A-2 and A-1.*

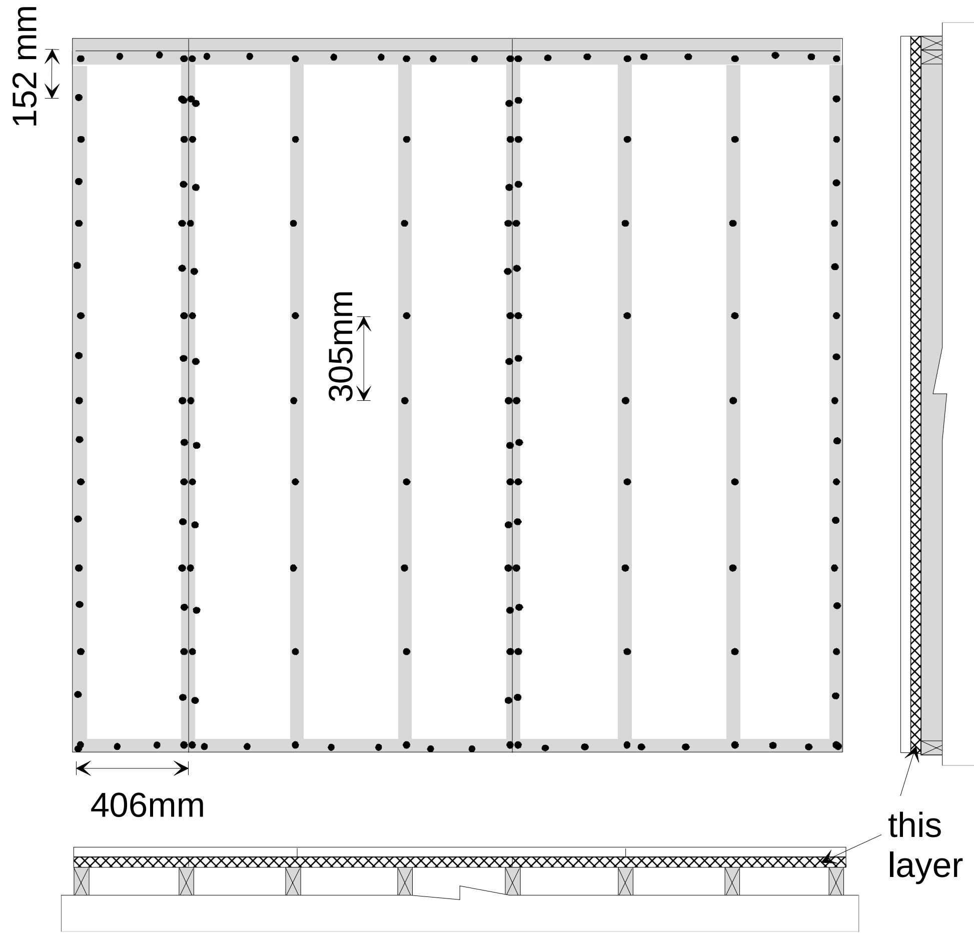



*Figure A-7.* *Wood shear resistant panel oriented vertically and attached to the studs with 76 mm (nominal) common nails 300 mm o.c. in the field and 150 mm o.c. at the edges, wood studs at 406 mm o.c., double plate at top, single plate at bottom. Meets requirements of CAN/CSA-A82.31-M91, Clause 7.3.4. Drawing not to scale.*

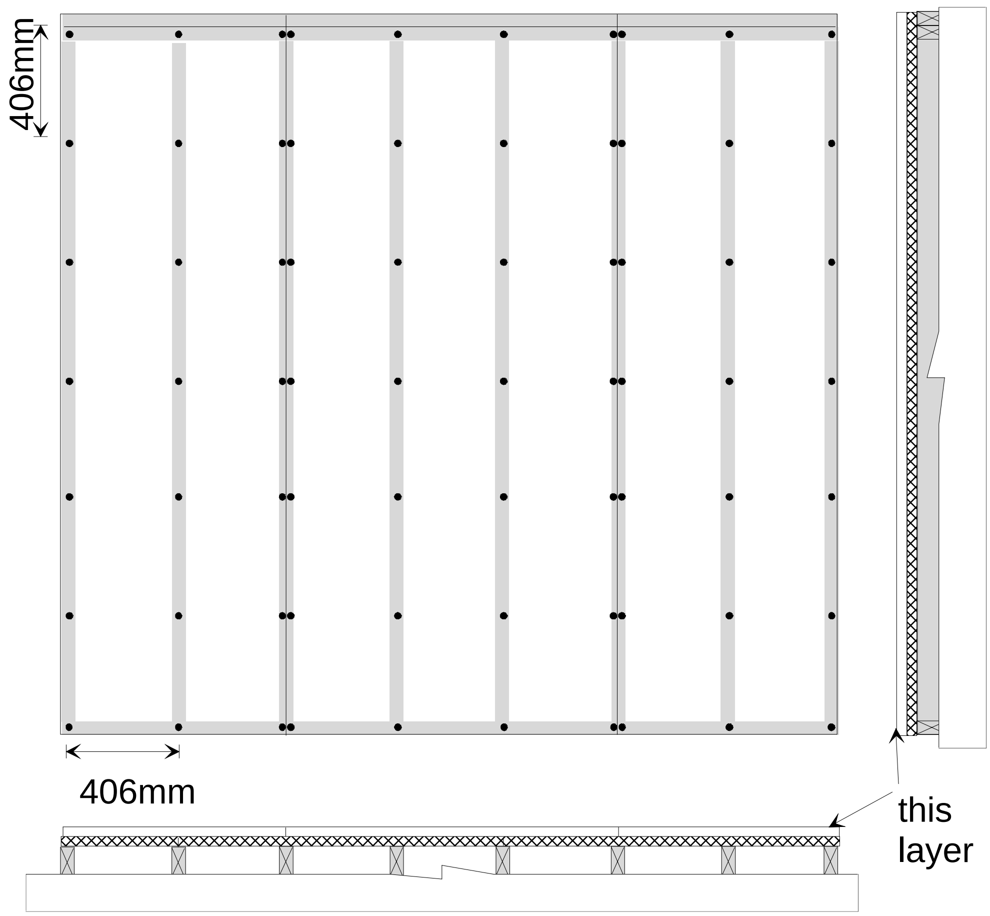



*Figure A-8.:* *Face-ply of gypsum board oriented vertically and placed over the wood shear resistant panel, wood studs at 406 mm o.c., double plate at top, single plate at bottom. Meets requirements of CAN/CSA-A82.31-M91, Clause 7.3.4. Drawing not to scale.*

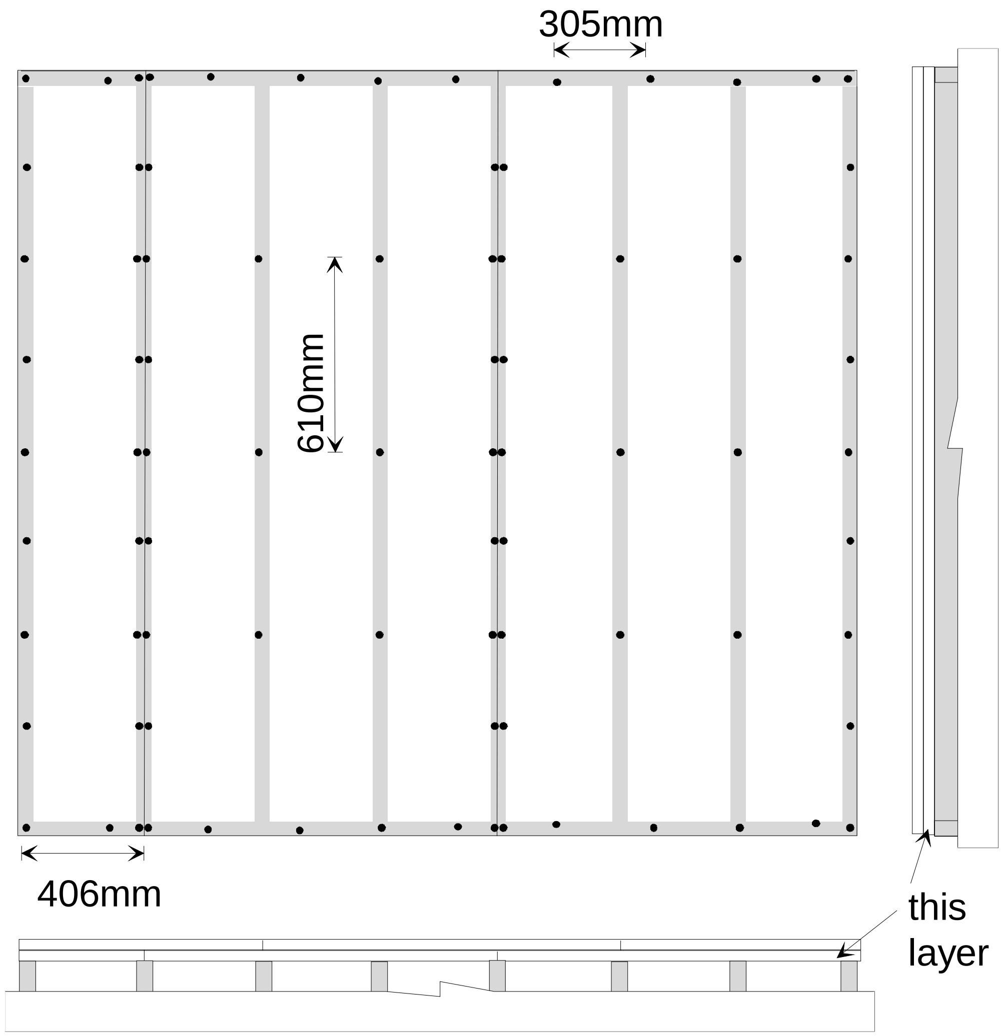



*Figure A-9.:* *Base-ply of two-ply gypsum board attached parallel to the load-bearing steel studs spaced 406 mm o.c., single track top and bottom. Screw pattern meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1, and National Building Code of Canada, Section 9.29.5.9. Drawing not to scale.*

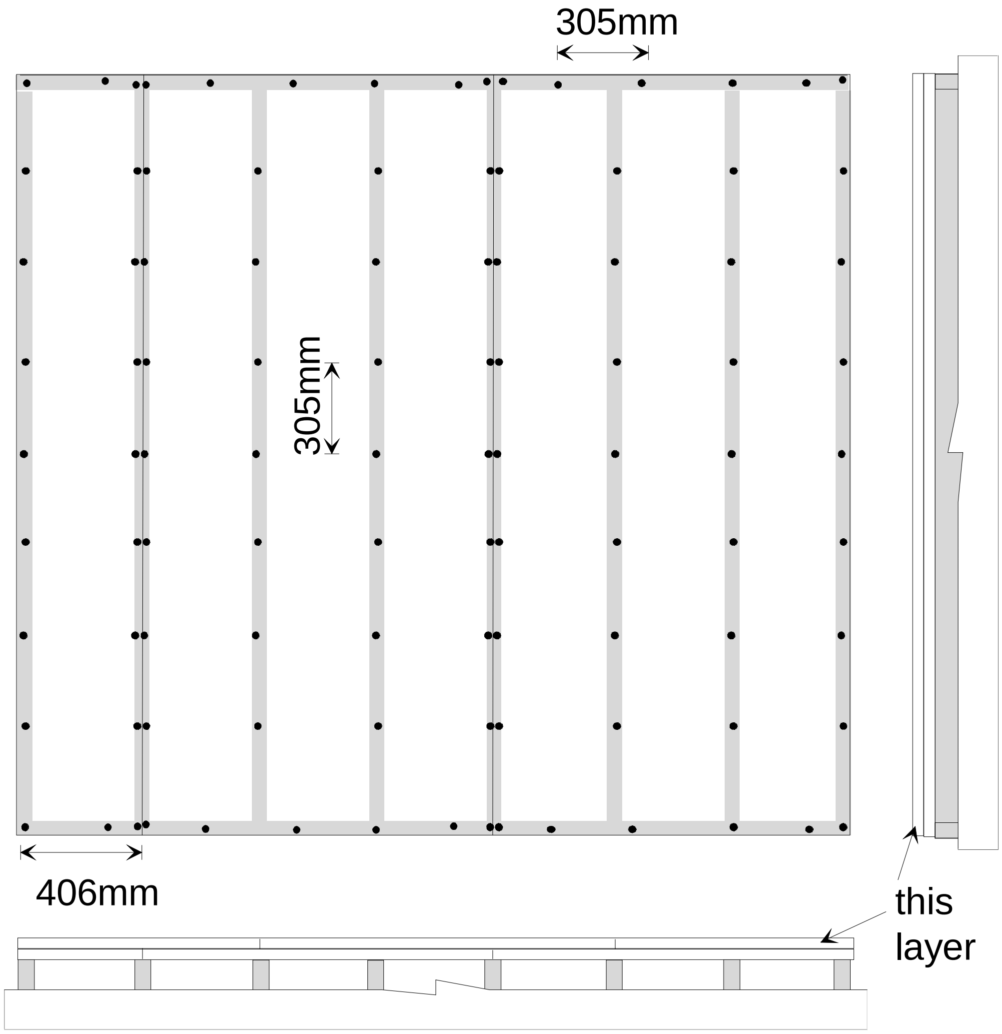



*Figure A-10.:* *Face-ply of two-ply gypsum board attached parallel to the load-bearing steel studs spaced 406 mm o.c., single track top and bottom. Screw pattern meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1, and National Building Code of Canada, Section 9.29.5.9. Drawing not to scale.*

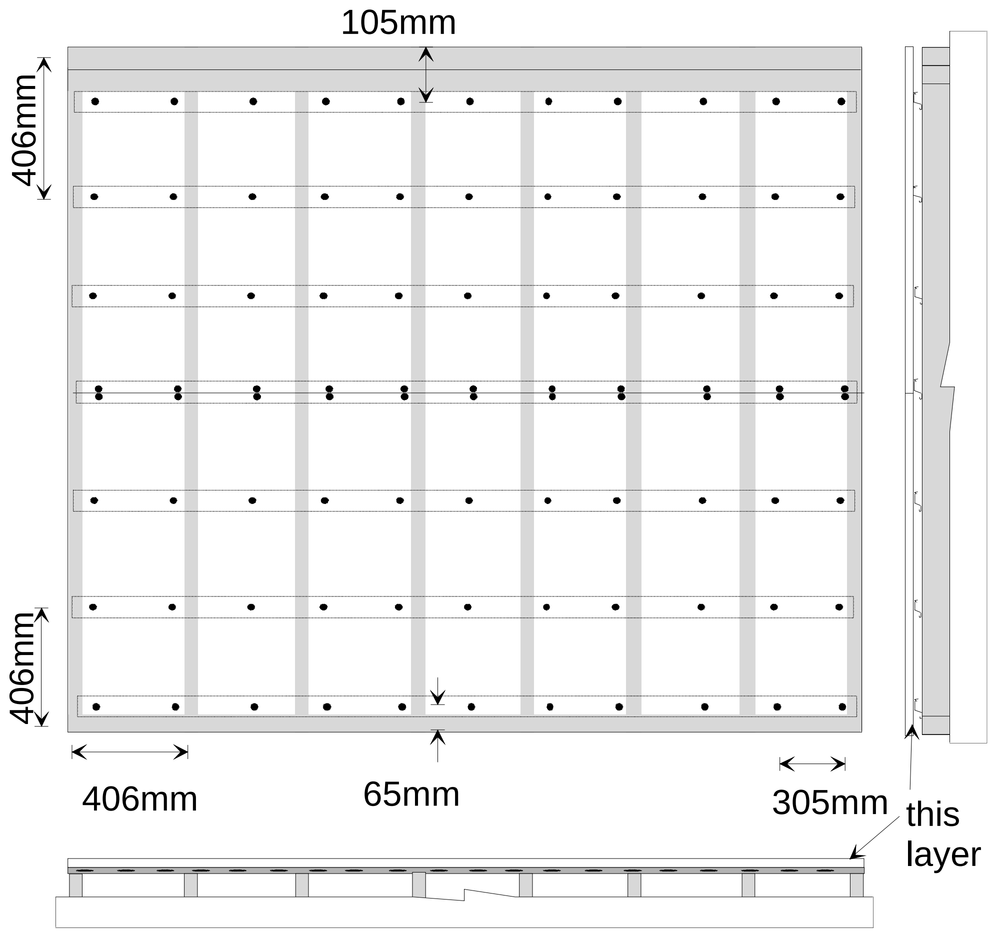



*Figure A-11.:* *Single-ply gypsum board attached parallel to resilient furring channels. Resilient channels attached perpendicular to studs at 406 mm o.c.. Studs at 406 mm o.c., double plate at top, single plate at bottom. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, single plate at bottom. Same location of resilient channels and screws was used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*

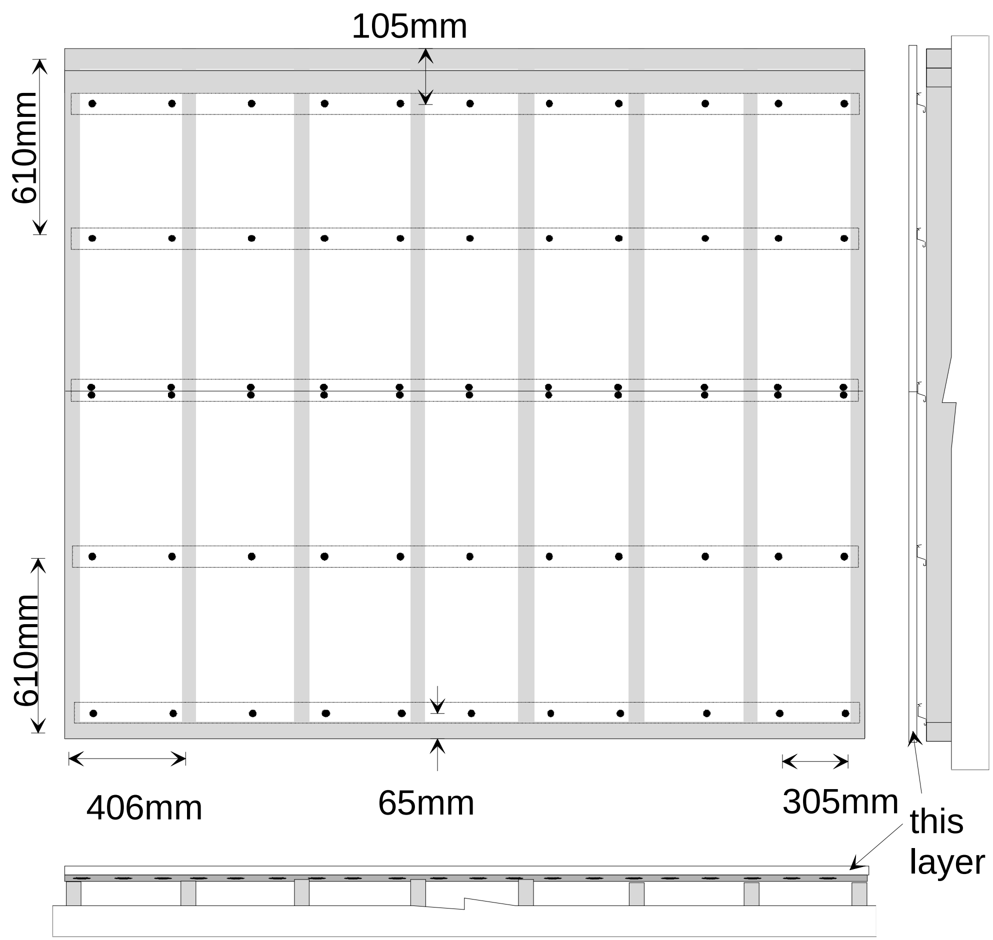



*Figure A-12.:* *Single-ply gypsum board attached parallel to resilient furring channels. Studs at 406 mm o.c. Resilient furring channels attached perpendicular to studs at 610 mm o.c.. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, single plate at bottom. Same location of resilient channels and screws was used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*

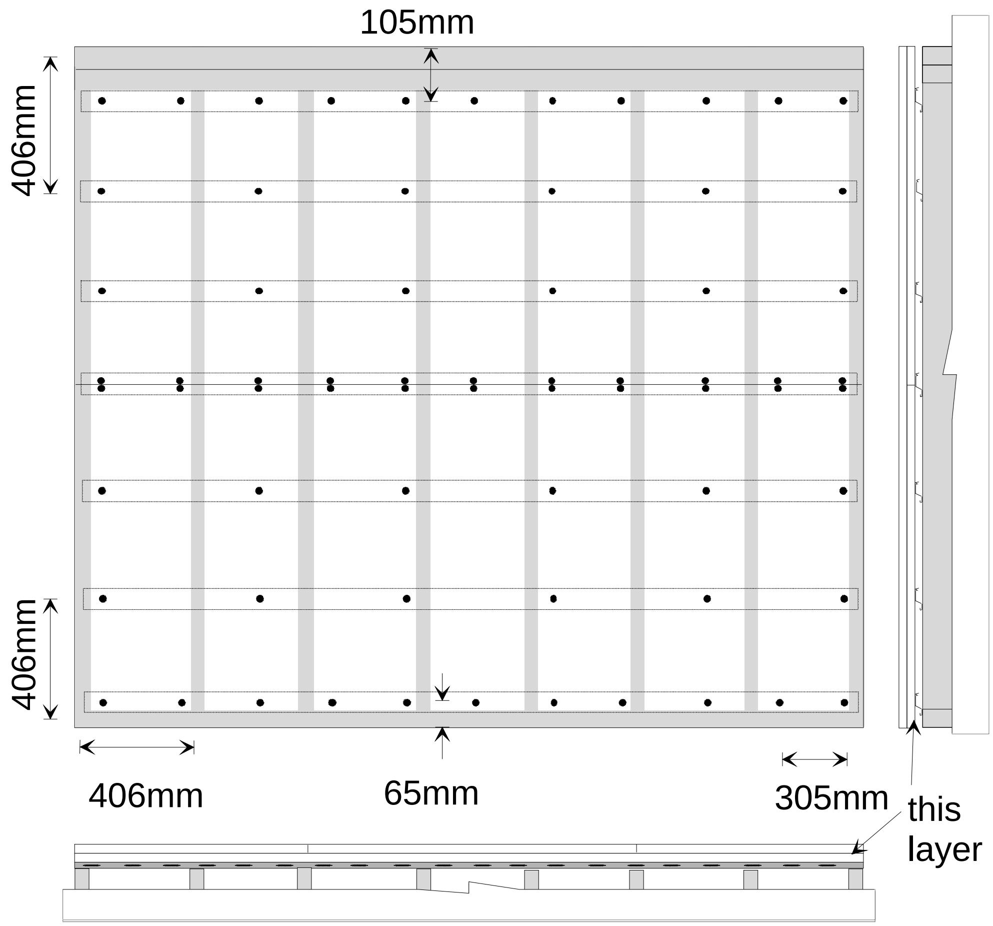



*Figure A-13.:* *Base-ply of two-ply gypsum board attached parallel to resilient furring channels. Resilient channels attached perpendicular to studs at 406 mm o.c.. Studs at 406 mm o.c., double plate at top, single plate at bottom. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.2. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, single plate at bottom. Same location of resilient channels and screws was used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*

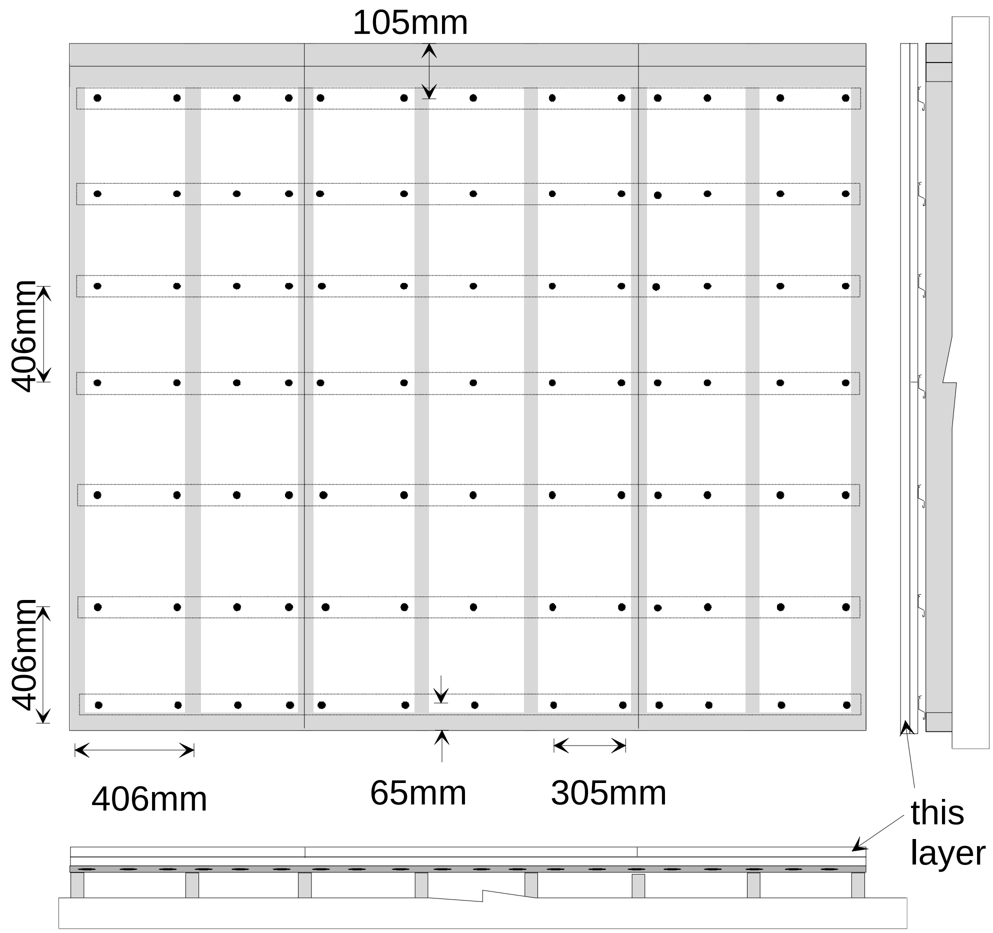



*Figure A-14.:* *Face-ply of two-ply gypsum board attached perpendicular to resilient furring channels. Resilient channels attached perpendicular to studs at 406 mm o.c.. Studs at 406 mm o.c., double plate at top, single plate at bottom. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, single plate at bottom. Same location of resilient channels and screws was used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*

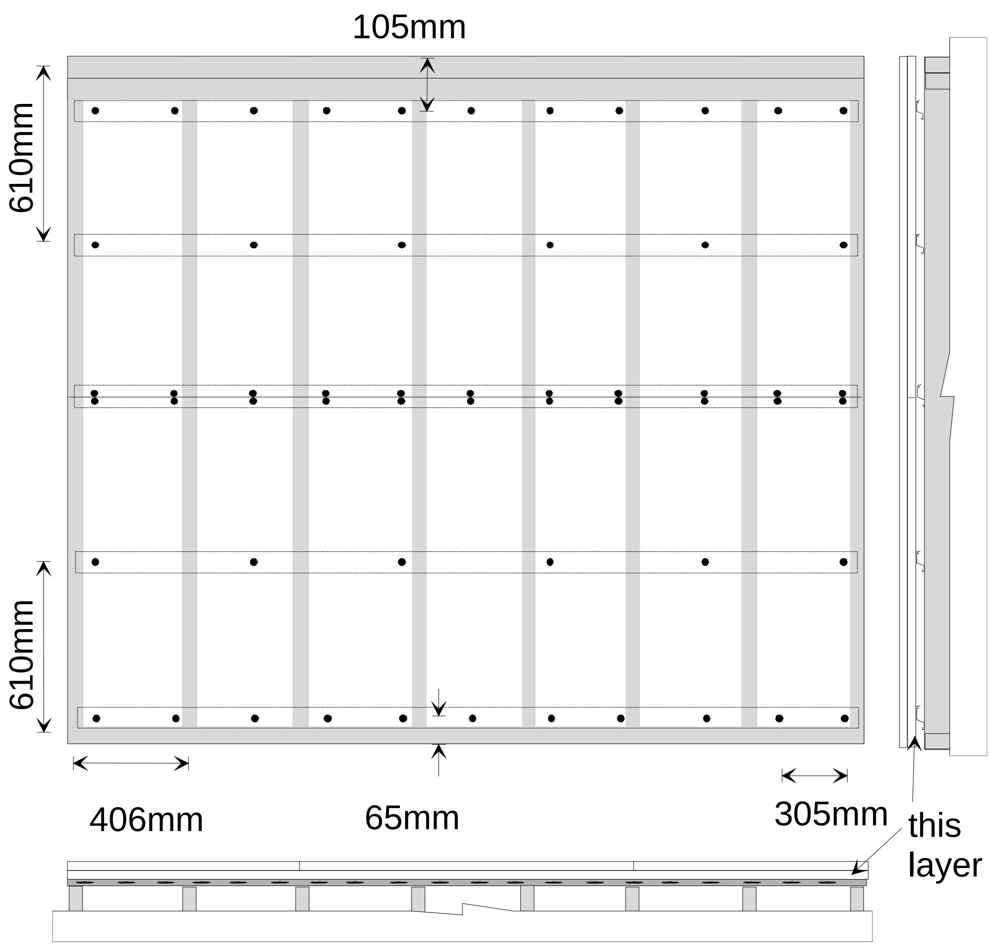



*Figure A-15.:* *Base-ply of two-ply gypsum board attached parallel to resilient furring channels. Resilient channels attached perpendicular to studs at 610 mm o.c.. Studs at 406 mm o.c. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.2. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, single plate at bottom. Same location of resilient furring channels and screws is used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*

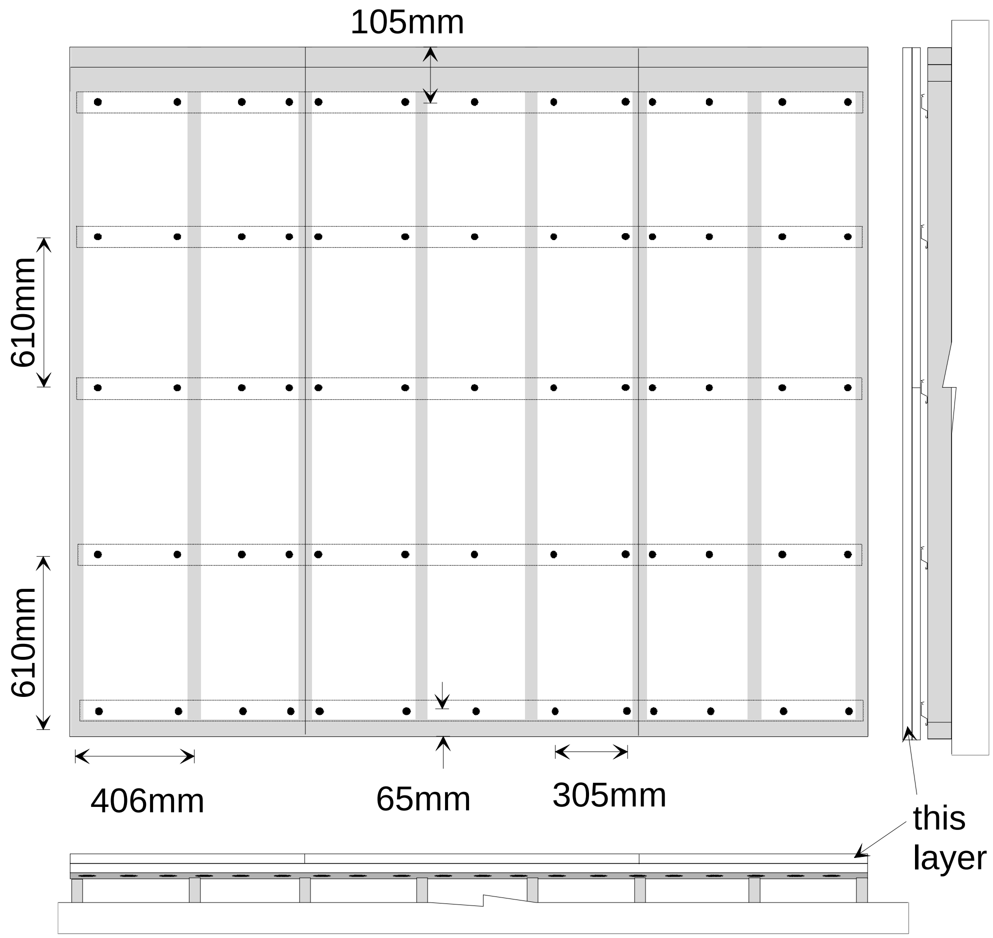



*Figure A-16.:* *Face-ply of two-ply gypsum board attached perpendicular to resilient furring channels. Resilient channels attached perpendicular to studs at 610 mm o.c.. Studs at 406 mm o.c.. Meets requirements of CAN/CSA-A82.31-M91, Clause 12.2.3.1. Note that screw spacing was shifted from ideal locations to avoid contact with studs. Drawing not to scale.*

*Drawing shows wood studs at 406 mm o.c., with double plate at top, and single plate at bottom. Same location of resilient furring channels and screws was used with load-bearing steel studs, except that single track was used at the top, and dimension from top to first row of screws was 70 mm.*