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Apparent Sound Insulation in Mass Timber Buildings

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Canada

Scope

This Report presents the results from experimental studies of the airborne sound transmission of mass timber assemblies, together with an explanation of the calculation procedures to predict the apparent sound transmission class (ASTC) rating between adjacent spaces in a building constructed of mass timber assemblies.

The experimental data which is the foundation for this Report includes the laboratory measured sound transmission loss of wall and floor assemblies constructed of Cross Laminated Timber (CLT), Nail-Laminated Timber (NLT) and Dowel-Laminated Timber (DLT), and the laboratory measured vibration reduction index between assemblies of junctions between CLT assemblies. The presentation of the measured data is combined with the presentation of the appropriate calculation procedures to determine the ASTC rating in buildings comprised of such assemblies along with numerous worked examples.

Several types of CLT constructions are commercially available in Canada, but this study focused on CLT assemblies with an adhesive applied between the faces of the timber elements in adjacent layers, but no adhesive bonding between the adjacent timber elements within a given layer. These CLT assemblies could be called "Face-Laminated CLT Assemblies" but are simply referred to as CLT assemblies in this Report. Another form of CLT assemblies does have adhesive applied between the faces of the timber elements in adjacent layers as well as adhesive to bond the adjacent timber elements within a given layer. These assemblies are referred to as "Fully-Bonded CLT Assemblies" in this Report. Because fully-bonded CLT assemblies have different properties than face-laminated CLT assemblies, the sound transmission data and predictions in this Report do not apply to fully-bonded CLT assemblies.

Disclaimer

Although it is not repeated at every step of this Report, it should be understood that some variation in sound insulation is to be expected in practice due to changes in the specific design details, workmanship, substitution of "generic equivalents", or simply rebuilding the construction. It would be prudent to allow a margin of error of several ASTC points to ensure that a design will satisfy a specific requirement.

Despite this caveat, the authors believe that methods and results shown here do provide a good estimate of the apparent sound insulation for the types of constructions presented.

Changes from the First Edition (2017) of Research Report RR-335:

1. The most significant change from the first edition of RR-335 is the addition of test data for direct sound transmission through Nail-Laminated Timber (NLT) and Dowel-Laminated Timber (DLT) assemblies including data for linings. Although there are appreciable differences among the acoustic results for the three variants of mass timber assemblies, they have strong similarities in their behaviour.
2. For consistency with nomenclature for other types of materials which include the thickness of the assembly as the primary identifier, the descriptors for CLT assemblies have been changed. For example, the descriptor for the 5-ply CLT assembly has been changed from CLT05 to CLT175(5) to identify it by the thickness (in mm) and the number of layers.
3. Despite the addition of data for NLT and DLT assemblies, the ASTC calculations in Chapter 4 are restricted to examples for CLT construction because data for the vibration transmission at junctions of DLT or NLT assemblies is currently not available. As more data becomes available, more calculation details and examples for these assemblies will be included in future editions of this Report.
4. The explanatory material in Chapter 1 and at the beginning of Chapter 4 has been revised to maintain consistency with the fifth edition of The Guide RR-331 which addresses the calculation of the ASTC rating for many common types of constructions.

Acknowledgments

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In addition, the contribution of several individuals who contributed to this report is acknowledged. Stefan Schoenwald, Berndt Zeitler and Ineke Van Zeeland contributed to the first edition of this Report. Jonathan Hamelin, Ivan Sabourin, Stefan Schoenwald, Julie McIntyre, Steven Kruithof, Ryan Moloughney, Vince Iacovitti, David Klein and Theresa Reif contributed to the collection of the measurement data included in this Report.

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1 Sound Transmission via Many Paths

The simplest approach to controlling sound transmission between adjacent rooms in buildings considers only the sound transmission through the separating wall or floor between the rooms. This approach has been entrenched in North American building codes which for many decades have only included requirements for the single number ratings for the common assembly between dwellings. The single number ratings used by this approach have been the sound transmission class (STC) rating for airborne sources and the impact insulation class (IIC) rating for footstep noise.

Implicit in this approach is the simplistic assumption that sound is only transmitted through the separating assembly between rooms – the separating wall assembly when the rooms are side-by-side as illustrated in Figure 1.1 or the floor/ceiling assembly when rooms are one-above-the-other. Under this approach, if there is a noise complaint, the problem is often incorrectly attributed to errors in either the design of the separating assembly or the workmanship of those who built it and remediation only focusses on that assembly.

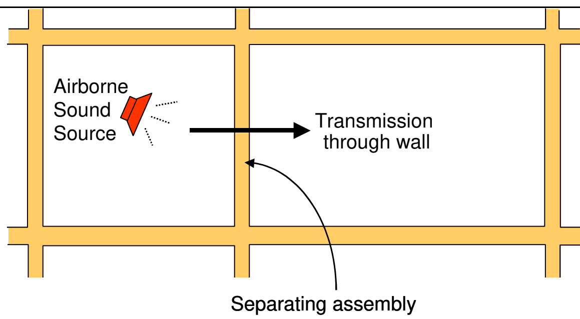

Figure 1.1: A cross-section through two side-by-side rooms of a building showing the historic perspective that sound from an airborne noise source (represented by the red loudspeaker in the drawings but could include anything from a home theatre to people talking loudly) is <u>only</u> transmitted directly through the separating assembly between the rooms (in this case the wall).

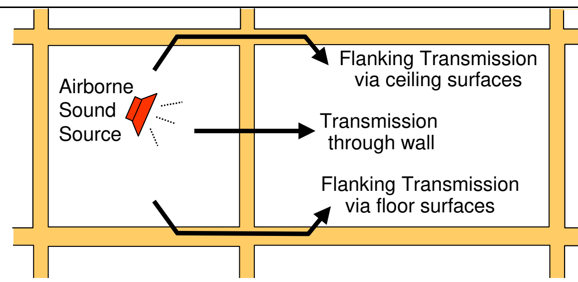

Figure 1.2: This figure shows that in reality, there are many paths for sound transmission between adjacent rooms including both direct transmission through the separating assembly and indirect flanking paths, a few of which are shown in the figure. The flanking paths usually significantly affect the overall sound transmission. See Section 1.4 for more details about the different paths.

In reality, the technical issue is more complex, as illustrated in Figure 1.2. There is direct transmission of sound through the separating assembly, but that is only part of the story of how sound is transmitted between the adjacent rooms. As shown in the figure, the airborne sound source excites all the surfaces in the source room and all of these surfaces vibrate in response. Some of this vibrational energy is transmitted as structure-borne sound across the surfaces abutting the separating assembly, through the junctions where these surfaces join the separating assembly, and into the surfaces of the adjoining room. The surfaces in the adjoining room then radiate part of the vibrational energy as airborne sound. The sound transmission by these paths is called flanking sound transmission.

The occupants of the adjacent room hear the combination of the radiated sound due to the direct transmission through the separating assembly plus the radiated sounds due to structure-borne flanking transmission involving all the other elements coupled to the separating assembly. There may also be the transmission of sound through leaks (openings) in the walls. Therefore, it follows that in reality, the sound insulation between adjacent rooms is always worse than just the sound insulation of the separating assembly. The importance of including all of the transmission paths has long been recognized in principle and the fundamental science was largely explained decades ago by Cremer et al. [8].

Whereas the STC rating is used as the single number rating for sound transmitted only through a wall or floor, there is a single number rating called the apparent sound transmission class (ASTC) rating which includes the contribution of the sound transmitted directly through the separating assembly plus the sound transmitted by all of the flanking paths. Although the measurement of the ASTC rating in a building according to the standard, ASTM E336 is quite straightforward, predicting the ASTC rating of a building is more complex. The challenge has been to reduce the complicated calculation of the sound transmission by multiple paths into manageable engineering that yields trustworthy quantitative estimates and to standardize that process to facilitate its inclusion in a regulatory framework.

For design or regulation, there are standardized frameworks for estimating the overall sound transmission which have been developed and have been in use to support performance-based European building codes. For example, in 2005, the International Organization for Standardization (ISO) published the standard, ISO 15712-1, “Building acoustics — Estimation of acoustic performance of buildings from the performance of elements — Part 1: Airborne sound insulation between rooms” [7]. This standard is one part of four dealing with sound transmission in buildings. In 2017, the four parts of ISO 15712 were replaced by the corresponding parts of ISO 12354. However, this Report continues to reference ISO 15712, for the reasons which will be discussed in Section 1.1.

The standard, ISO 15712-1 outlines a procedure for estimating the weighted apparent sound reduction index (R'_w) of building assemblies. The weighted apparent sound reduction index has a corresponding rating called the apparent sound transmission class (ASTC) rating as described in the standard, ASTM E336 [2]. It is the ASTC rating that is used in the 2015 edition of the National Building Code of Canada as explained in detail in the NRC Report RR-331 [15].

However, there were two significant impediments to applying the standard, ISO 15712-1 in a North American context. Although ISO 15712-1 provides reliable estimates for some types of building constructions such as buildings with concrete floors and concrete or masonry walls, the estimates are more difficult to make for the lightweight framed construction widely used for buildings in North America. Secondly, the ISO standards for building acoustics have many differences from the ASTM standards used by the construction industry in North America, both in terms of the terminology and in specific technical requirements for measurement procedures and ratings. The following sections of this chapter outline a strategy for dealing with these limitations, both explaining how to merge ASTM and ISO test data and procedures, and providing recommendations for adapting the calculation procedures for mass timber constructions.

1.1 Predicting Sound Transmission in a Building

The standard, ISO 15712-1 provides reliable estimates for buildings with concrete floors and walls of solid concrete or masonry, but it is less accurate for other common types of construction, especially for constructions with a stiffness that has a directional dependence, such as wood-frame and steel-frame constructions.

ISO 15712-1 has other limitations as well. For example, especially for light frame construction, the Standard identifies situations where the detailed calculation is not appropriate, but the Standard does not provide specific guidance on how to deal with such limitations. Many of these limitations can be overcome by using measurement data for various combinations of construction types and junctions measured according the four parts of the ISO 10848 standard [6]. The 2015 edition of the National Building Code of Canada (NBCC) addresses these limitations of ISO 15712-1 by specifying the suitable procedures and test data to calculate the ASTC rating for different types of construction, with direct references to ISO 15712-1 and the ISO 10848 series.

The type of attached wall and floor assemblies dictates both the required input data and the steps of the standardized procedures required to calculate the ASTC rating. This Report is restricted to the calculation of the ASTC rating for buildings where the walls have a structure of mass timber, and these walls are attached to other walls of mass timber or to floors of mass timber. The common cases are explained in Chapters 2 to 4 of this Report. This Report indicates which equations from ISO 15712-1 apply in each context and provides key adaptations of the ISO expressions needed to apply the concepts in an ASTM context.

It is important to note that in 2017, the 4 parts of ISO 15712 were replaced by the corresponding parts of ISO 12354. The procedures in ISO 12354-1 are equivalent to those of ISO 15712-1 and resolve most of the concerns identified in the preceding paragraphs. At the time of preparing this Report, the NBCC had not been updated to replace the references to ISO 15712-1 with the corresponding links to the new ISO 12354-1. For consistency with the NBCC, this Report outlines the steps of the standardized calculation procedures with references to ISO 15712-1. Referencing ISO 12354-1 would have negligible impact on the contents of this Report other than the different number of the referenced standard.

1.2 Applying the Concepts of ISO Standards in an ASTM Environment

In Canada, the direct sound transmission loss of building elements is normally tested according to the standard, ASTM E90 [1]. The acoustic requirements in the National Building Code of Canada are given in terms of the apparent sound transmission class (ASTC) rating which is determined from the apparent sound transmission loss (ATL) which includes contributions from both the direct sound transmission and the flanking transmission for the set of frequency bands from 125 Hz to 4000 Hz, following the procedure outlined in the standard, ASTM E413 [3].

Although the building acoustics standards developed by ASTM are very similar in concept to the corresponding ISO standards, there are differences in the terminology and the technical requirements which presents numerous barriers to using a mix of standards from the two domains. Although the ASTM standard, E336 recognizes the contribution of flanking sound transmission to the apparent sound transmission, there is neither an ASTM standard for measuring the structure-borne flanking sound transmission that often dominates sound transmission between rooms, nor an ASTM counterpart of ISO 15712-1 for predicting the combination of direct and flanking sound transmission. In the absence of suitable ASTM standards, this Report uses the procedures of ISO 15712-1 and data from the complementary ISO 10848 series for some constructions, but connects this ISO calculation framework to the ASTM terms and test data widely used by the North American construction industry. This methodology combines identifying which data from ASTM laboratory tests can reasonably be used in place of their ISO counterparts, and presenting the results using ASTM terminology (or new terminology for flanking sound transmission that is consistent with existing ASTM terms) to facilitate their use and understanding by a North American audience. Some obvious counterparts in the terminology are presented in Table 1.1.

ISO Designation	Description	ASTM Counterpart
ISO 10140 Parts 1 and 2 [5] (formerly ISO 140-3)	Laboratory measurement of the airborne sound transmission through a wall or floor	ASTM E90
sound reduction index, R (ISO 10140-2)	Fraction of sound power transmitted (in dB) at each frequency, in laboratory test	sound transmission loss, TL (ASTM E90)
weighted sound reduction index, R_w (ISO 717-1 [4])	Single-number rating determined from R or TL values in standard frequency bands	sound transmission class, STC (ASTM E413)
apparent sound reduction index, R' (ISO 16283-1)	Fraction of sound power transmitted (in dB) at each frequency, including all paths in a building	apparent sound transmission loss, ATL (ASTM E336)
weighted apparent sound reduction index, R'_w (ISO 717-1)	Single-number rating determined from R' or ATL values in standard frequency bands	apparent sound transmission class, ASTC (ASTM E413)

Table 1.1: Standards and terms used in ISO 15712-1 for which ASTM has close counterparts

It is important to note that the description “counterpart” does not imply that the ASTM and ISO standards or terms are exactly equivalent. For example, neither the descriptors R_W and STC nor R'_W and ASTC are interchangeable due to systematic differences in the calculation procedures. However, the laboratory tests used to measure the airborne sound transmission through wall or floor assemblies (ASTM E90 and its counterpart ISO 10140-2) are based on essentially the same procedure with minor variants in facility requirements. Therefore, the measured quantities “sound transmission loss” from the ASTM E90 test and “sound reduction index” from the ISO standard are sufficiently similar so that data from ASTM E90 tests can be used in place of data from ISO 10140-2 tests in the calculations of ISO 15712-1 to obtain a sensible answer. Similarly, the simplified calculation of ISO 15712-1 may be performed using STC ratings to predict the ASTC rating. The close parallel between “sound reduction index” and “sound transmission loss” also means that results from ISO 15712-1 calculations (normally expressed as R’ values) can confidently be treated as calculated apparent sound transmission loss (ATL) values and then used in the procedure of ASTM E413 to calculate the ASTC rating, which is the objective for designers or regulators in the North American context. To merge the ASTM terms with the ISO 15712-1 procedures in this Report, the terms “direct sound transmission loss” and “flanking sound transmission loss” have been introduced to provide consistency with ASTM terminology while matching the function of the direct and flanking sound reduction indices defined in ISO 15712-1.

For purposes of this Report, a glossary of new terms with counterparts in ISO 15712-1 and ISO 10848 and using terminology consistent with the measures used in ASTM standards is presented in Table 1.2. In addition, there are other scientific terms that are used at various stages of the calculation in ISO 15712-1 which are used without change in this Report. These terms include: radiation efficiency, velocity level difference, internal loss factor, total loss factor, equivalent absorption length, and transmission factor. These terms are described in the glossary found in Annex A of ISO 15712-1.

Table 1.2: Key terms used in this Report to deal with concepts from ISO 15712-1 and ISO 10848 for which current ASTM acoustics standards have no counterparts.

Terms used in this Report	Description
Structural reverberation time (T_S)	The structural reverberation time is a measure indicating the rate of decay of the vibration energy in an element and can apply either to a laboratory wall or floor assembly, or to a wall or floor assembly in-situ in a building.
Sound transmission loss in-situ (TL_{situ})	The sound transmission loss in-situ is the counterpart of sound reduction index in-situ (R_{situ}) described in ISO 15712-1 as "the sound reduction index of an element in the actual field situation".
Change in sound transmission loss (ΔTL)	The change in sound transmission loss is the difference in sound transmission loss due to the addition of a lining on one side of a wall or floor assembly when measured according to ASTM E90, compared with the sound transmission loss of the same assembly without a lining.
Change in sound transmission class (ΔSTC)	The change in sound transmission class is the difference in the single number rating due to a lining applied on one side of a wall or floor assembly. The calculation procedure for the ΔSTC rating is described in Appendix A2 of this Report.
Vibration reduction index (K_{ij})	The vibration reduction index (K_{ij}) is described in ISO 15712-1 as the "direction-averaged vibration level difference over a junction, normalised to the junction length and the equivalent sound absorption length to make it an invariant quantity". Depending on the type of building element, K_{ij} values may be determined using the equations of Annex E of ISO 15712-1 or the measurement procedures of ISO 10848.
Velocity level difference (VLD)	The velocity level difference (VLD) is described in ISO 15712-1 as the "junction velocity level difference in-situ between an excited element (wall or floor) and the receiving element (wall or floor)." It is calculated by correcting the K_{ij} value to allow for edge loss conditions (identified through structural reverberation times) of the assemblies in-situ.
Flanking sound transmission loss (Flanking TL_{ij})	The flanking sound transmission loss is the counterpart of flanking sound reduction index (R_{ij}) in ISO 15712-1. It is a measure of the sound transmission loss via the flanking path from element i in the source room to element j in the receiving room, normalised like the apparent sound transmission loss.
Flanking sound transmission class (Flanking STC_{ij})	The flanking STC rating is the single number rating calculated from the flanking sound transmission loss following the STC calculation procedure of ASTM E413.

1.3 Combining Sound Transmitted via Many Paths

The calculations of ISO 15712-1 combine the sound transmitted via the direct transmission path and via a set of flanking paths. To keep track of the sound transmission paths, it is useful to introduce the labeling convention for the paths used in ISO 15712-1 and as shown in Figure 1.3.

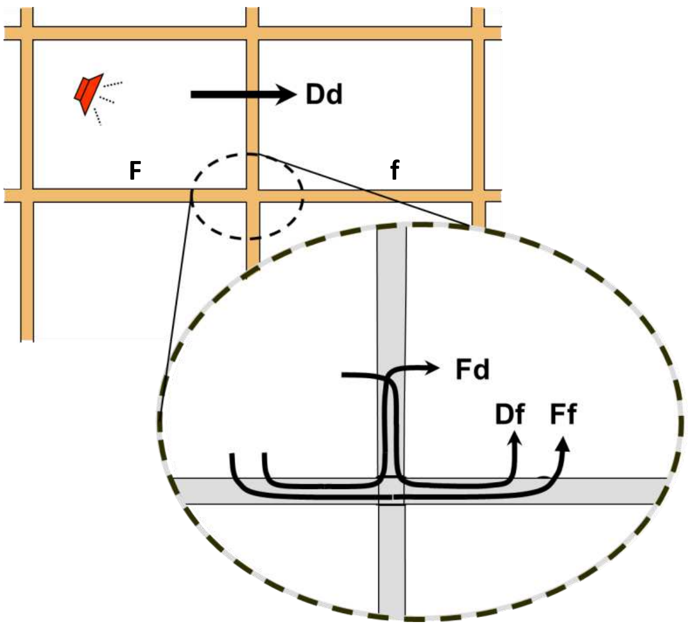

Figure 1.3: This figure shows the labelling convention used for the transmission paths in ISO 15712-1. Consider the transmission of airborne sound from a source room (left) to a receiving room (right). Each transmission path involves one surface in the source room (denoted by a capital letter) and one in the receiving room (denoted by a lower case letter). **D**irect transmission through the separating assembly is path **Dd**. For each edge of the separating assembly there are three flanking paths: **Ff** from flanking surface F to flanking surface f, **Df** from direct surface D to flanking surface f, and **Fd** from flanking surface F to direct surface d.

Note that the letter "F" or "f" denotes **f**lanking surface, and "D" or "d" denotes the surface for **d**irect transmission, i.e. the surface of the separating assembly. These surfaces may be either wall or floor/ceiling assemblies.

The apparent sound transmission loss (ATL) between two rooms (assuming the rectangular room geometry used for examples in Chapter 4, and neglecting sound that is by-passing the building structure, for example sound transmitted through leaks and ducts) is the resultant of the direct sound transmission loss (TL_{Dd}) through the separating wall or floor assembly and the set of flanking sound transmission loss contributions of the three flanking paths (TL_{Ff}, TL_{Fd}, and TL_{Df}) for each junction at the four edges of the separating assembly as shown in Fig. 1.3. This concept is presented in Equation 1.1.

$$ATL = -10 \cdot \log_{10}\left[10^{-0.1 \cdot TL_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1 \cdot TL_{Ff}} + 10^{-0.1 \cdot TL_{Fd}} + 10^{-0.1 \cdot TL_{Df}}\right)\right] \qquad \text{Eq. 1.1}$$

Note that this equation differs slightly from the calculation of the apparent sound transmission loss defined in Equation 14 of ISO 15712-1. Eq. 1.1 of this Report treats the set of paths at each edge of the separating assembly in turn to match the presentation for the examples in this Report. Eq. 1.1 is universally valid for all building systems, so the only remaining challenge is to find the right expressions to calculate the sound transmission via the different paths for the chosen building system and situation.

Each of the flanking sound transmission loss values for a specific path is normalized like the apparent sound transmission loss (ATL), and can be considered as the apparent sound transmission loss that would be observed if only this single path were contributing to the sound transmitted into the receiving room. Normalization of the direct and the flanking sound transmission loss input data so that the receiving room absorption is numerically equal to the area of the separating assembly (i.e. using apparent sound transmission loss and the ASTC rating as the measure of system performance) requires suitable corrections to data calculated according to ISO 15712-1, or values of flanking sound transmission loss from laboratory testing according to ISO 10848, so that the set of path sound transmission loss values can be properly combined or compared. This normalization process is described in the calculation procedures in Chapter 4 of this Report.

The standard ISO 15712-1 describes two methods of calculating the apparent sound insulation in a building: the Detailed Method and the Simplified Method. This Report describes both methods to calculate the apparent sound insulation in a building consisting of mass timber wall assemblies and mass timber floor assemblies.

The Simplified Method uses the single number ratings (STC or Flanking STC for each transmission path, as appropriate) instead of the frequency-dependent sound transmission loss values, and yields the ASTC rating directly:

$$ASTC = -10 \cdot \log_{10}\left[10^{-0.1 \cdot STC_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1 \cdot STC_{Ff}} + 10^{-0.1 \cdot STC_{Fd}} + 10^{-0.1 \cdot STC_{Df}}\right)\right] \quad \text{Eq. 1.2}$$

The Simplified Method has been widely used by designers in Europe for many years for calculations based on R_W data. Its primary advantage over the Detailed Method is the simplicity of the procedure which makes it usable by non-specialists as illustrated by the worked examples in Section 4.1 and Section 4.3. Although it is less rigorous than the Detailed Method presented in Section 4.2, the differences between the results using the two methods are typically small, and the calculations for the Simplified Method use approximations that should ensure the results are slightly conservative, especially so if the effect of linings is included in the calculations.

This Report provides both the single number ratings needed to calculate the ASTC rating using the Simplified Method and the corresponding sets of one-third octave band data needed for the Detailed Method for mass timber constructions.

Cautions and limitations to examples presented in this Report:

This Report was developed to support the transition to ASTC ratings for sound control objectives in the National Building Code of Canada. Simplifications were made to meet the specific needs of that application, where sound insulation is addressed only in the context of multi-unit residential buildings. The simplifications include that:

- Transmission around or through the separating assembly due to leaks at its perimeter or penetrations such as ventilation systems are assumed negligible.
- Indirect airborne sound transmission (for example airborne flanking via an unblocked attic or crawl space) is assumed to be suppressed by normal fire blocking requirements.

For adjacent units in a multi-family residential building, these two issues should be dealt with by using normal good practice for fire and sound control between adjoining dwellings.

If this Report is applied to situations other than the separation between adjacent units in multi-family residential buildings, some of these issues may have to be explicitly addressed in the calculation process. For example, for adjoining rooms within a single office or home, flanking paths such as ventilation ducts or open shared plenum spaces may be an issue. The flanking sound transmission loss associated with these additional paths should be determined and included in the calculated ASTC rating. ISO 15712-1 includes specific guidance for such issues and the examples in this Report allow for such a correction.

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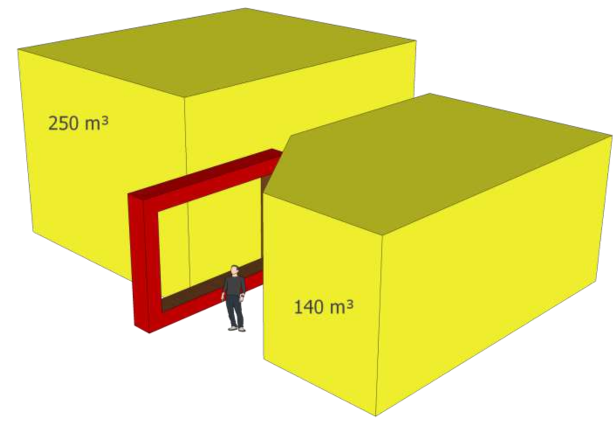
2 Sound Transmission through Laminated Timber Walls and Floors

The direct sound transmission loss tests of wall and floor assemblies were conducted in the NRC's Wall and Floor Sound Transmission Facilities according to the standard, ASTM E90. Concept drawings of the sound transmission facilities are presented in Figure 2.1.



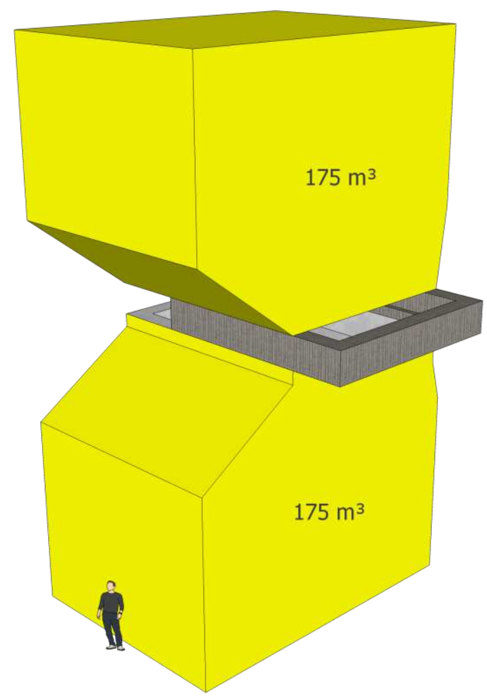


Figure 2.1: A concept drawing of the Wall Sound Transmission Facility at the NRC is presented in the upper drawing. The NRC Floor Sound Transmission Facility, shown in the lower drawing, is similar except that one room is above the other.

In both cases, full scale test assemblies are mounted in the massive, concrete, movable test frames between two reverberation rooms. The test openings are 3.66 m by 2.44 m for walls and 4.70 m by 3.78 m for floors.

For the wall facility, the reverberation rooms (designated "large chamber" and "small chamber") have approximate volumes of 250 m^3 and 140 m^3 respectively. In the floor facility, both chambers have volumes of approximately 175 m^3. All the facility rooms are hard-walled reverberation chambers that are vibration-isolated from each other and from the specimen frame. The rooms have fixed diffusor panels to increase the diffusivity of the sound fields.

The facilities, including instrumentation and the test procedures satisfy or exceed all requirements of ASTM E90.

The measurements of the direct airborne sound transmission loss (TL) were conducted in accordance with the requirements of ASTM E90-09, “Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions”. The sound transmission loss tests were performed in both transmission directions – from the large chamber to the small chamber and vice-versa for walls, and from the upper chamber to the lower chamber and vice-versa for floors. The results presented in this Report are given as the averages of the two transmission directions to reduce measurement uncertainty due to factors such as calibration errors and local variations in the sound fields.

For every measurement, the direct sound transmission loss values were calculated from the average sound pressure levels in the source room and the receiving room and the average reverberation times of the receiving room. One-third octave band sound pressure levels were measured for 32 seconds at nine microphone positions in each room and then averaged to get the average sound pressure level in each room. Five sound decays were averaged to get the reverberation time at each microphone position in the receiving room and these times were averaged to determine the average reverberation times for each room.

The frequency-dependent direct sound transmission loss was measured in one-third octave bands in the frequency range from 50 Hz to 5000 Hz. However, only the frequency range between 125 Hz and 4000 Hz is considered in the calculation of the sound transmission class (STC) single-number rating in accordance with ASTM E413 [3].

The direct airborne sound transmission loss data is presented as follows in this Report:

- The sets of one-third octave band direct sound transmission loss results from 50 Hz to 5000 Hz are presented in Appendix A1.
- This chapter presents a more compact summary of results in terms of STC ratings.

In addition to the sound transmission loss measurements, the loss factors, the radiation efficiencies and the wave numbers of the assemblies were measured. The structural reverberation times and wave numbers are presented in Appendix A1. For the mass timber assemblies evaluated as part of this study, it was established that the loss factors are high enough to justify ignoring corrections for edge losses in the detailed calculations in accordance with Section 4.3 of ISO 15712-1, which greatly simplifies those calculations.

2.1 Sound Transmission through CLT Wall and Floor Assemblies

The calculation of the ASTC rating of a building where cross-laminated timber wall and floor assemblies are used requires the sound transmission loss data for the assemblies. For the Simplified Method of ISO 15712-1, the required sound transmission loss data is the STC rating for the floor and wall assemblies while the Detailed Method of ISO 15712-1 requires both the one-third octave sound transmission loss values and the corresponding values for the structural reverberation time of the tested floor and wall assemblies.

This section focuses on the transmission loss of Cross-Laminated Timber (CLT[1]) assemblies. Several types of CLT assemblies are commercially available in Canada, but this study included only CLT assemblies that use adhesive bonding between the faces of the timber elements in adjacent layers, but no adhesive bonding the adjacent timber elements within a given layer. There can be noticeable gaps between some of the timber elements comprising each layer of the CLT assembly. These CLT assemblies could be called "Face-Laminated CLT Assemblies" but are simply referred to as CLT assemblies in this Report.

Another form of CLT assemblies has adhesive between the faces of the timber elements in adjacent layers as well as adhesive to bond the adjacent timber elements within a given layer. These are referred to as "Fully-Bonded CLT Assemblies" in this Report. Because fully-bonded CLT assemblies have different properties than face-laminated CLT assemblies, the sound transmission loss data and predictions in this Report do not apply to fully-bonded CLT assemblies.

This study included tests on five CLT assemblies as shown in Table 2.1.1. The tests included assemblies tested in the wall or floor testing facilities and may be single panels or panels connected with a single surface spline. Although the table includes a 9-ply assembly, only a limited amount of data was available for the CLT292(9) assembly at the time this Report was published. **None of the data for linings presented in this Report is applicable to CLT292(9).**

Table 2.1.1: CLT assemblies included in this evaluation

Code	Description	Thickness (mm)	Mass per unit area (kg/m^2)
CLT78(3)	3-ply single-leaf	78	42.4
CLT175(5)	5-ply single-leaf	175	91.4
CLT245(7)	7-ply single-leaf	245	130
CLT292(9)	9-ply single-leaf	292	158
CLT78(3)_GFB25_ CLT78(3)	Double-leaf 3-ply comprised of two leafs of CLT78(3) separated by a 25 mm cavity filled with sound absorbing material	181	89.6

While the transmission loss data provided in this Report is based on measurements conducted with CLT assemblies with the parameters listed above, the data may also be used as a conservative estimate for face-laminated CLT assemblies with the same number of plies but with greater thickness or higher mass. For example, a 5-ply single-leaf wall which is more than 175 mm thick or has a mass per area of more than 91.4 kg/m^2 can in general be expected to have an STC rating at least as high as the value reported here for CLT175(5) . **The data in this Report may not be used for fully-bonded CLT assemblies or for CLT assemblies with lower thickness or mass per area than the CLT assemblies in this Report.**

The remainder of Section 2.1 is arranged as follows:

- **Section 2.1.1** focuses on the sound transmission loss of CLT assemblies without linings.
- **Section 2.1.2** discusses changes in the sound transmission loss due to adding various linings on one side or both sides of the single-leaf CLT assemblies.
- **Section 2.1.3** discusses linings added on two-leaf CLT assemblies
- **Section 2.1.4** presents results for structural loss factors of the CLT assemblies
- **Section 2.1.5** presents the bending wavenumbers of the CLT assemblies

2.1.1 CLT Walls and Floors without Linings

Each of the CLT assemblies evaluated was tested both bare and with linings attached to one or both of the faces of the CLT assembly. Figure 2.1.1.1 compares the direct sound transmission loss of the bare CLT assemblies with no linings.

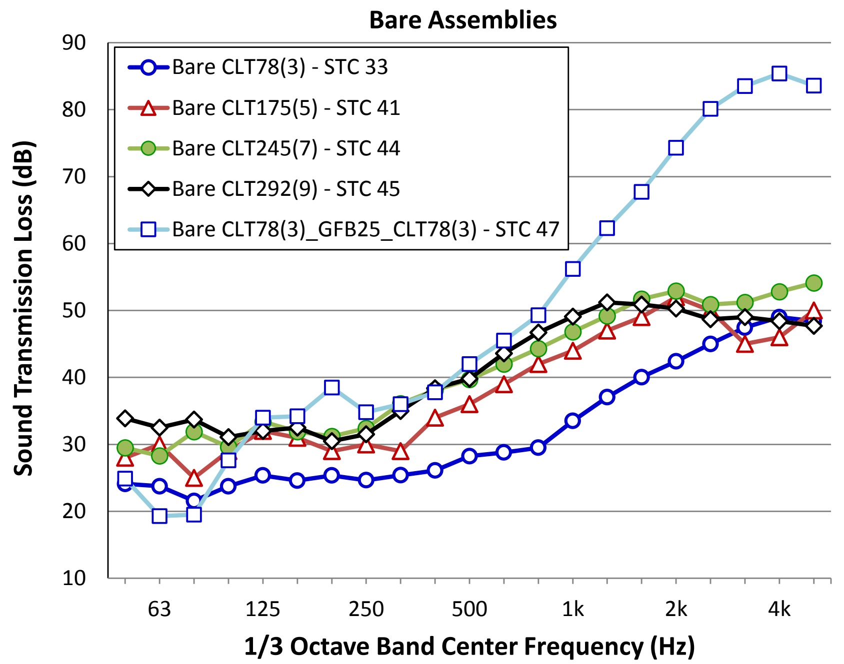


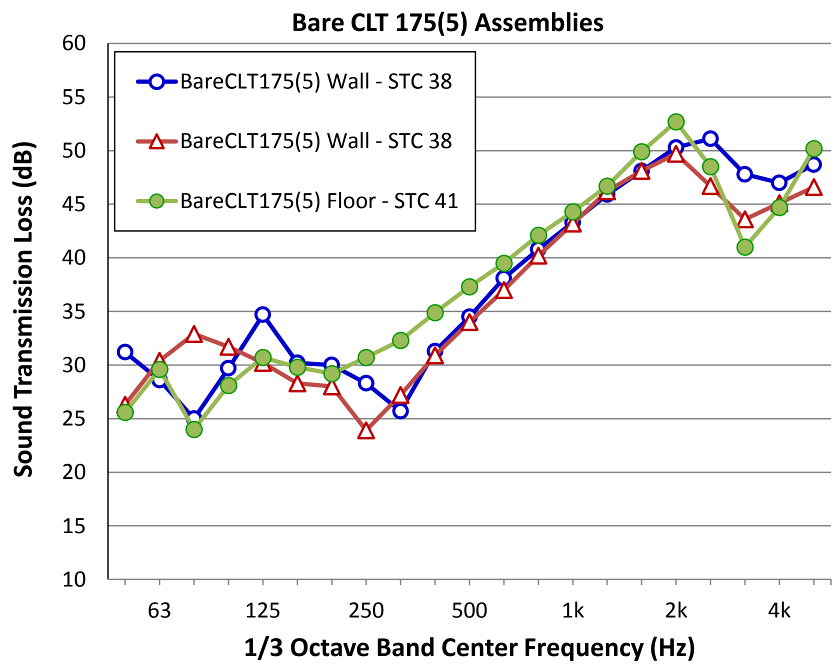
Figure 2.1.1.1
Comparison of sound transmission loss for the bare CLT assemblies.

The figure shows that the double-leaf CLT78(3)_GFB25_CLT78(3) assembly exhibits a frequency dependence that is quite different from that for the single-leaf CLT assemblies. Further discussion of the double-leaf assembly is therefore postponed to Section 2.1.3.

The measured direct sound transmission loss curves for the bare single-leaf CLT assemblies differ appreciably from the behaviour expected for homogeneous walls or floors. The most obvious peculiarity is the difference between the results measured for three different CLT175(5) assemblies as shown in Figure 2.1.1.2. The assemblies were measured in either 2012 or 2018 and so some differences due to changes in manufacturing processes is to be expected. However, significant differences are evident between the sound transmission loss curves, especially the sharp dips at the low frequencies and around 3000 Hz.

Figure 2.1.1.2
Comparison of sound transmission loss for the bare CLT175(5) assemblies.

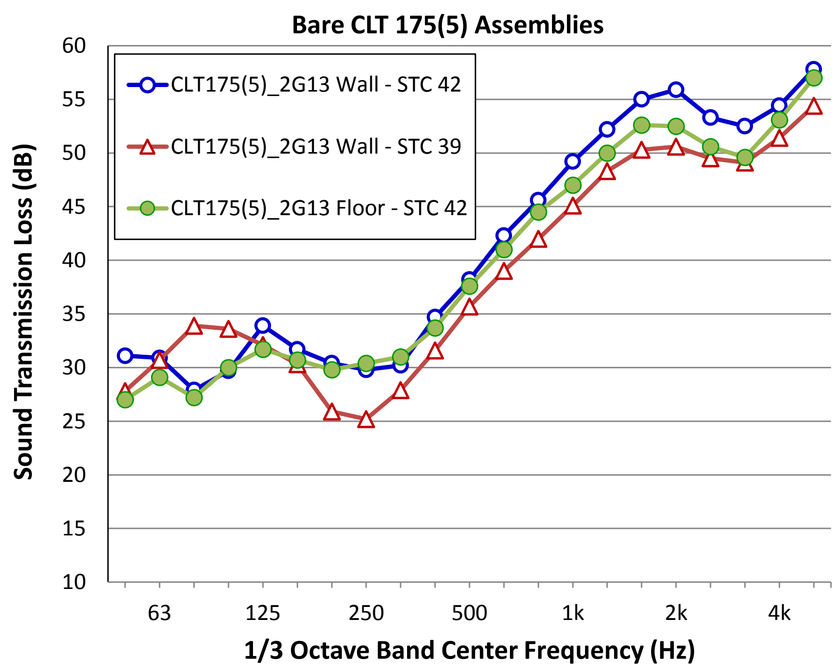
Although these assemblies were nominally identical, there were differences in the direct sound transmission loss curves with the wall exhibiting a dip around 300 Hz and the floor exhibiting a more pronounced dip around 3 kHz.



The transmission loss values for the same CLT175(5) assemblies with two layers of gypsum board applied to one face are compared in Figure 2.1.1.3. A comparison between Figure 2.1.1.2 and Figure 2.1.1.3 indicates that the differences between the curves was primarily due to the leakage of sound through the CLT assemblies.

Figure 2.1.1.3
Comparison of sound transmission loss for the CLT175(5) assemblies with a layer of gypsum board directly fixed to one side.

With the addition of the lining, the assemblies show similar trends at frequencies above the 250 Hz one-third octave band.



When a lining of 2 layers of gypsum board was fastened directly to each surface of the CLT175(5) assemblies, the sharp dips in the direct sound transmission loss curves exhibited by the bare assemblies were reduced. It was concluded that the effect was primarily due to the linings blocking any leaks through gaps in the assemblies, eliminating the sound transmission due to leakage.

The term **"Base CLT"** is used throughout the remainder of this Report to denote a CLT assembly without a lining but without any reduction of the direct sound transmission loss due to leakage. The term "**Bare CLT**" will be used to denote a CLT assembly which does include a reduction of the direct sound transmission loss due to leakage. The Base CLT assemblies are more appropriate for the determination of the effect of linings (presented in Section 2.1.2) and for the calculation of the ASTC ratings (presented in Chapter 4) than the measured values for Bare CLT assemblies given in Figure 2.1.1.1.

Several differences between the Base CLT estimates and the Bare CLT results should be noted:

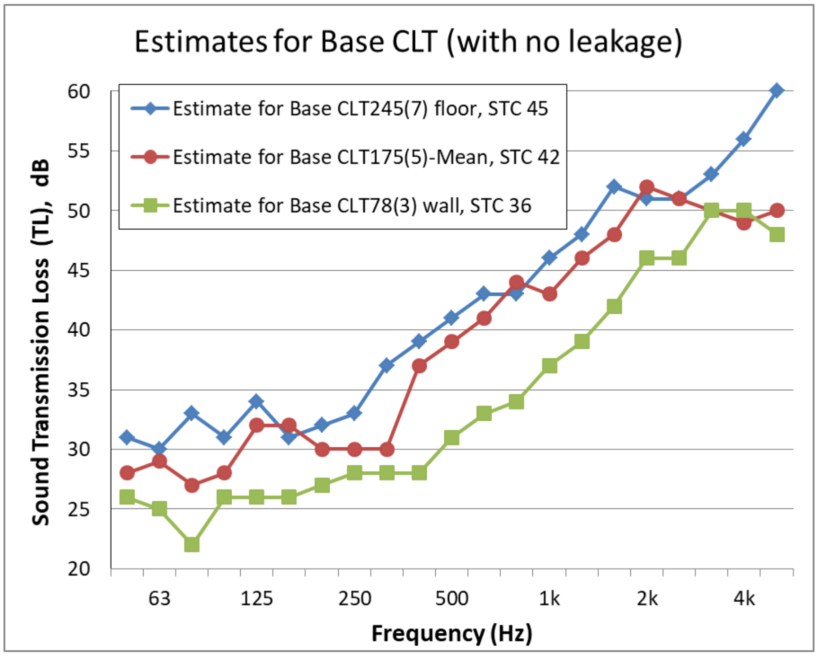
- In all cases, the STC rating for the Base CLT assembly without leakage is higher than the STC rating for the corresponding Bare CLT assembly. As a result, the STC ratings for Base CLT assemblies should not be used to quantify the direct sound transmission loss of CLT assemblies without linings.
- The changes in the direct sound transmission loss curves and in the STC ratings are largest for the thinner assemblies, and smallest for the thicker assemblies. This is consistent with the expectation that there will be less sound leakage as the number of interior plies in a CLT assembly increases, and that the application of a lining will have a smaller effect on the damping and structural properties of the heavier CLT assemblies.

The direct sound transmission loss curves for the Base CLT assemblies in Figure 2.1.1.4 exhibit behavior which is broadly consistent with the theory for thick homogeneous panels:

- The coincidence dips are not obvious due to high damping and orthotropic stiffness of the CLT assemblies. Below the coincidence frequency (approximately 200 Hz, 300 Hz and 400 Hz for CLT245(7), CLT175(5), and CLT78(3), respectively), the sound transmission loss curves exhibit little dependence on frequency other than minor dips and peaks due to resonances controlled by assembly dimensions and edge constraints.
- At frequencies below the coincidence frequency, the average sound transmission loss for the three curves differ by about 6 dB, which is close to the variation due to assembly mass expected from the theoretical "mass law."
- Above the coincidence frequency, each curve rises at a rate of approximately 3 dB per one-third octave band.
- At higher frequencies, a dip due to a thickness resonance is expected and shown at approximately 2 kHz, 4 kHz and 6 kHz for CLT245(7), CLT175(5), and CLT78(3), respectively.

Figure 2.1.1.4:
Direct sound transmission loss for the Base CLT assemblies without linings.

These values are used both for calculation of ΔTL values in Section 2.1.2 and in the calculation of ASTC ratings in Chapter 4.



The STC ratings and one-third octave band direct sound transmission loss values for the CLT assemblies without linings (both directly measured values for the bare assemblies, and derived values for the Base CLT assemblies) are presented in the tables in Appendix A1.1.

For the first edition of this Report, a systematic methodology of calculating the Base case without sound leakage by comparing the transmission loss values of the assemblies with different linings attached was developed. This method is presented below and is used for all of the CLT elements presented in this second edition of this Report. Since the first edition of this Report was published, the NRC developed a new testing protocol for mass timber elements so that the effect of sound leakage could be measured directly for the calculation of the change in the transmission loss of linings installed on the mass timber elements. The new protocol was used to determine the Base case for the NLT and DLT elements presented in this second edition of this Report.

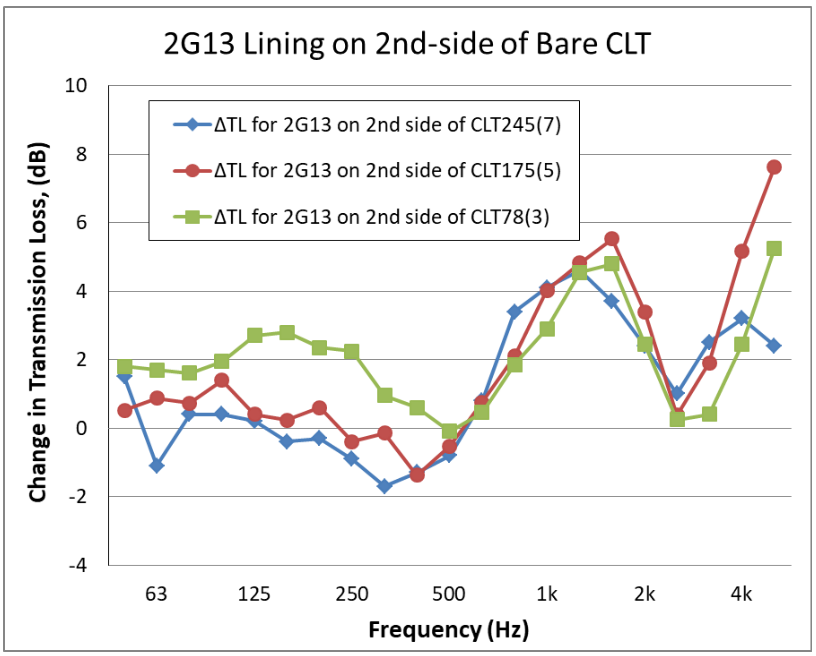
Calculations of the Base Case Using Lining Data

For test series which did not include a systematic sealing and re-testing of the bare CLT assemblies, a good estimate of the sound transmission loss for CLT assemblies without sound leaks can be extracted by using the finding (as illustrated in Figures 2.1.1.2 and 2.1.1.3) that adding a lining reduces the sound transmission due to leakage to insignificance. This is important information since the calculations of the flanking sound transmission loss in Chapter 4 must be based on the sound transmission of the bare assemblies without leakage.

The first step in the process of estimating the direct sound transmission loss of CLT assemblies without sound leaks was to establish the effect of attaching two layers of 12.7 mm gypsum board directly to the CLT assemblies when a lining on the other side already suppressed the sound transmission due to leakage and introduced additional damping and structural connections, as shown in Figure 2.1.1.5.

Figure 2.1.1.5:
Change in the direct sound transmission loss, ΔTL due to adding a lining of two layers of 12.7 mm gypsum board to the CLT assemblies where a lining on the opposite side has already reduced the effects of leakage which compromised the measured sound transmission loss for the bare CLT assemblies.

The features of these curves are discussed in Section 2.1.2, as part of the discussion of linings on single-leaf CLT assemblies.



Subtracting the changes in the direct sound transmission loss curves due to the addition of the lining on the second side from the corresponding measured direct sound transmission loss for the CLT78(3), CLT175(5), and CLT245(7) assemblies with the lining applied to one side, yields estimates for the direct sound transmission loss for the "**Base CLT"** assemblies. These derived direct sound transmission loss results for the Base CLT assemblies are shown in Figure 2.1.1.4.

Measurement of the Base Case by Parging

The base case of cross-laminated timber assemblies can be determined through a testing protocol that includes a final test where one side of the assembly is sealed with a thin layer of cementitious material (parge) that seals the openings of the seams between the timber elements comprising the assembly. The layer of cementitious material was used because it effectively stopped the sound leakage without significantly changing the mass or stiffness of the element. The changes in the transmission loss of the cementitious material itself could be determined by applying the cementitious material to the other side of the element and subtracting the measured transmission loss of the element with cementitious material on both sides from the transmission loss of the same element with cementitious material on one side. This is discussed further in Section 2.2.1 of this Report which shows measurements of the transmission loss of a nail-laminated timber assembly with cementitious material on one side and with cementitious material on both sides of the assembly. Figure 2.2.1.1 shows that the cementitious material had a negligible transmission loss itself and therefore was a good means of sealing air leaks without otherwise affecting the transmission loss of the bare element.

2.1.2 Adding Linings on Single-Leaf CLT Wall or Floor Assemblies

It is common practice, especially in residential buildings, to add finishing surfaces to the basic structural floor or wall assemblies to conceal both the bare surfaces as well as the building services such as electrical wiring, water pipes and ventilation ducts. The finishing on walls or ceilings is commonly comprised of gypsum board panels, framing used to support the gypsum board panels and sound absorptive material in the inter-framing cavities between the gypsum board and the face of the basic structural floor or wall assemblies. On floors, the finish may include toppings such as concrete or a floating floor as well as flooring such as hardwood or tiles. These elements are described in ISO 15712-1 as “linings” or “liners” or “layers” or “coverings”. The term “linings” is used in this Report.

Two methods of characterizing the change in the direct sound transmission loss of the CLT assemblies by adding a lining are used in this Report. The first method is the change in the transmission loss (ΔTL) which is calculated from the difference between the transmission loss values measured with the lining installed on the Base CLT assembly and the transmission loss values of the Base CLT assembly without a lining. The ΔTL is used for the calculation of the ASTC rating using the Detailed Method.

The second method of characterizing the change in the direct sound transmission loss of the CLT assemblies by adding a lining is a single-number rating called the ΔSTC. The ASTM standards do not define a rating like ΔSTC, but there is a counterpart in the ISO standards called ΔR_W. The calculation of the ΔSTC rating is adopted from the ISO standard with modification as explained in Appendix A2 of this Report. The ΔSTC rating is used for the calculation of the ASTC rating using the Simplified Method.

The linings evaluated on CLT assemblies for this study are described in Tables 2.1.2.1 to 2.1.2.3. The corresponding ΔSTC ratings for the measured linings are listed in Table 2.1.2.4. The ΔTL values for the measured linings are provided in Appendix A1.1.

Each Lining Code shown in Table 2.1.2.1 to 2.1.2.3 begins with “ΔTL-CLT” to indicate that the lining applied to a CLT assembly has an effect on the direct sound transmission loss through the lined assembly. For the first three linings in Table 2.1.2.1 (W01, W02, and W03), the initial part of the code also indicates the thickness (for example CLT175(5)) of the Base CLT assembly to which the lining is applied. For the three other linings in Table 2.1.2.1 (W04, W05, and W06), the code does not indicate the thickness of the Base CLT assembly because the thickness of the Base CLT assembly did not have a significant effect on the change in direct sound transmission loss provided by the lining. The final part of the lining code is a letter (such as “W” to indicate a wall lining or “F” for a floor lining) followed by a unique number used to identify the lining in the table of ΔSTC ratings and in the worked examples in Chapter 4.

The Descriptive Short Code provides a compact physical description of each lining and is used in the figure captions and in the examples throughout this Report. This code identifies the elements of the lining beginning at the exposed side and proceeding to the face of the supporting CLT wall or floor assembly. As detailed in the descriptions in Tables 2.1.2.1 to 2.2.2.3, each component of the lining is described by the short code. For example: G13 is gypsum board that is 12.7 mm thick, 2G13 is two connected G13 layers, and WFUR38 is a 38 mm x 38 mm wood furring. The distance between components such as adjacent studs is indicated by a number in parentheses which is the distance (on center) between the components in millimetres.

The spacing and type of fasteners are not stated in the tables, but they are expected to conform to standard industry practice as specified in the endnotes. Where sound absorbing material was included in a tested assembly, the code indicates the specific material that was tested, but applicability to other sound absorbing materials is expected as explained in the endnotes of this Report.

Table 2.1.2.1: Linings tested on the CLT Wall Assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-CLT(n-ply)-W01	2G13	Two layers of 12.7 mm thick fire-rated gypsum board[2] screwed to the face of the CLT assembly
ΔTL-CLT(n-ply)-W02	2G13_WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 400 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[6] filling the spaces between the gypsum board and the CLT
ΔTL-CLT(n-ply)-W03	2G13_WFUR38(600)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT
ΔTL-CLT-W04	2G13_RC13(600)_ WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 13 mm resilient metal channels[3] (spaced 600 mm o.c.) that are screwed to 38 x 38 mm wood furring (spaced 400 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT
ΔTL-CLT-W05	2G13_WFUR64(600)_GFB65	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT
ΔTL-CLT-W06	2G13_WS64(600)_GFB65_AIR13	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood studs (spaced 600 mm o.c. and spaced 13 mm from the face of the CLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT

NOTES:
a. For the notes in this table please see corresponding endnotes
b. Linings listed here for wall assemblies may also be used on ceilings.
c. For linings W01, W02, and W03, the CLT thickness is indicated because it has an effect on the change in sound transmission loss provided by the lining; for the other linings, one short code applies for any of the CLT thicknesses considered in this Report.

Table 2.1.2.2: Linings tested on the Base CLT Floor Assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-CLT-F01	CON38(no bond)	38 mm thick concrete with no bond to the supporting CLT
ΔTL-CLT-F02	CON38_FOAM09	38 mm thick concrete on 9 mm thick closed-cell foam, covering the supporting CLT
ΔTL-CLT-F03	CON38_WFB13	38 mm thick concrete on 13 mm thick wood fiber board, covering the supporting CLT
ΔTL-CLT-F04	CON38_FELT19	38 mm thick concrete on 19 mm thick felt of recycled fiber, covering the supporting CLT
ΔTL-CLT-F05	CON38_RESL13	38 mm thick concrete on mat of 13 mm rubber nuggets, covering the supporting CLT
ΔTL-CLT-F06	CON38_RESL08	38 mm thick concrete on 8 mm thick shredded rubber mat, covering the supporting CLT
ΔTL-CLT-F07	CON38_RESL17	38 mm thick concrete on 17 mm thick shredded rubber mat covering the supporting CLT
ΔTL-CLT-F08	2CEMBRD12_WFB13	Two layers of 12 mm thick fiber-reinforced cement board on 13 mm thick wood fiber board, covering the supporting CLT
ΔTL-CLT-F09	GCON38_FOAM09	38 mm thick gypsum concrete on 9 mm thick closed-cell foam, covering the supporting CLT

NOTES:
a. For the notes in this table please see the corresponding endnotes
b. For all the floor linings listed, one short code applies for any of the CLT thicknesses considered in this Report.

Table 2.1.2.3: Linings tested on Base CLT Ceiling Assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-CLT-C01	2G13_WFUR38(600)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board[2] screwed to 38 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[6] filling the spaces between the gypsum board and the CLT
ΔTL-CLT-C02	2G13_UC22(600)_CC38(1200)_ GFB140	Two layers of 12.7 mm thick fire-rated gypsum board screwed to metal grillage (U-channels spaced 600 mm o.c. supported by orthogonal 38 mm C-channels spaced 1200 mm o.c. that are supported on wires 140 mm below the bottom face of the CLT) with 140 mm thick glass fiber batts filling the space between the furring and the CLT
ΔTL-CLT-C03	G16_UC22(600)_CC38(1200)_ GFB140_2G13	One layer of 15.9 mm thick fire-rated gypsum board screwed to metal grillage (U-channels spaced 600 mm o.c. supported by orthogonal 38 mm C-channels spaced 1200 mm o.c. that are supported on wires 140 mm below the bottom face of 2 layers of 12.7 mm thick fire-rated gypsum board screwed to the CLT) with 140 mm thick glass fiber batts filling the spaces between the furring and the bottom of the gypsum board screwed to the CLT

NOTES:

a. For the notes in this table please see the corresponding endnotes
b. The linings listed for wall assemblies may also be used on ceilings.
c. For all the ceiling linings listed, one short code applies for any of the CLT thicknesses considered in this Report.

Change in the Transmission Loss ΔTL due to Linings on Single-Leaf CLT Assemblies

The trends in the change in the sound transmission loss when linings are added to single-leaf CLT assemblies are presented and discussed in this Section.

The changes in the transmission loss are presented as follows:

- The averaged one-third octave band changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the CLT assemblies are given in Table A1.1.2 of Appendix A1.1. The ΔTL data is needed for the calculation of the ASTC rating using the Detailed Method as presented in Report RR-331 and Chapter 4 of this Report.
- The corresponding single-number ΔSTC ratings for each lining are given in Table 2.1.2.4. The ΔSTC ratings are needed for the calculation of the ASTC rating using the Simplified Method as presented in Report RR-331 and in Chapter 4 of this Report.

For the assemblies evaluated in this study, each type of lining was tested in the first situation listed below with the lining applied only on one side of the CLT assembly (sometimes there were several tests), and many were tested in one or both of the other situations.

Situation 1: the lining was tested on one side: The transmission loss of the Base CLT assembly was subtracted from the transmission loss with the added lining on one side to obtain the ΔTL values.

Situation 2: the lining was tested on both sides: The transmission loss of the Base CLT assembly was subtracted from the transmission loss with the added lining on both sides, and the result was divided by 2 to obtain the ΔTL.

Situation 3: different linings were tested on each side: The transmission loss of a CLT assembly with the other lining on one side was subtracted from the transmission loss for the wall with two different linings to obtain the ΔTL.

Because the test results for assemblies with linings on both sides were likely to be compromised by the facility flanking limit, several precautions were included when lining data was averaged to determine the ΔTL values to be used in the calculations:

- A weighted average of the different situations was used with a 50% weighting for data from situation 1 and a 50% weighting for the mean of situations 2 and 3.
- Where the measured direct sound transmission loss was above the facility flanking limit (10 dB below the maximum sound transmission loss recorded for that frequency band in the facility) the potentially compromised results were excluded from the average values.

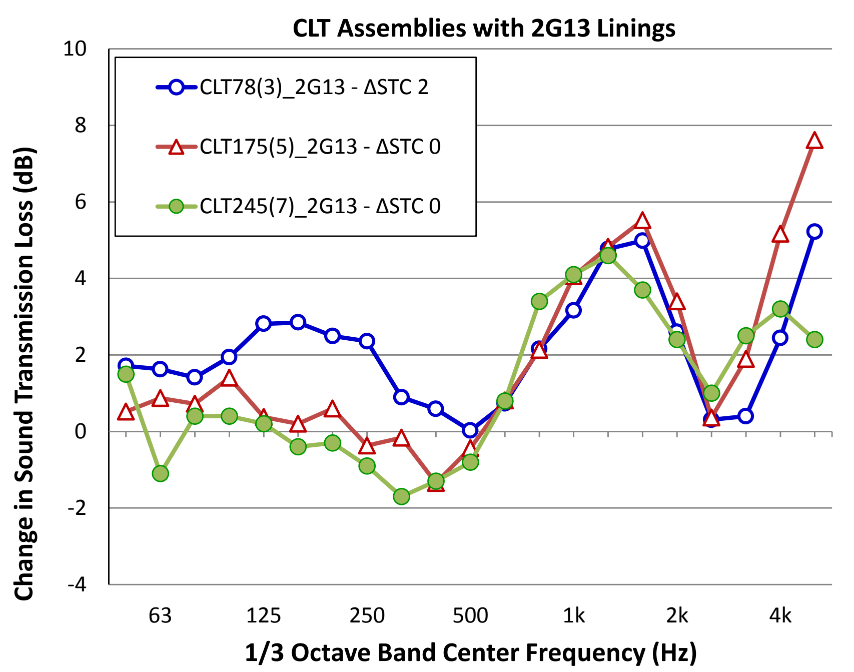
The lining that was tested most often was the 2G13 lining of two layers of 12.7 mm gypsum board screwed directly to the surface of the CLT assembly. This lining was tested when applied on one side of all of the thicknesses of the CLT assemblies and for many of the thicknesses of the CLT assemblies, the lining was applied to the second side as well. Subsets of these test results were shown previously in Section 2.1.1 to explain the calculation of estimates of the direct sound transmission loss for Base CLT assemblies.

The results from averaging the full set of ΔTL data for all the test assemblies with the 2G13 lining are given in Figure 2.1.2.1.

Figure 2.1.2.1

Change in direct sound transmission loss (ΔTL) due to the addition of the 2G13 lining on the CLT assemblies.

Note the close similarity among the results for all CLT thicknesses above the mass-air-mass resonances. Also note the higher ΔTL for the lighter CLT base assemblies below the mass-air-mass resonances.



The results in Figure 2.1.2.1 illustrate the key features typical of all of the linings discussed in this Report:

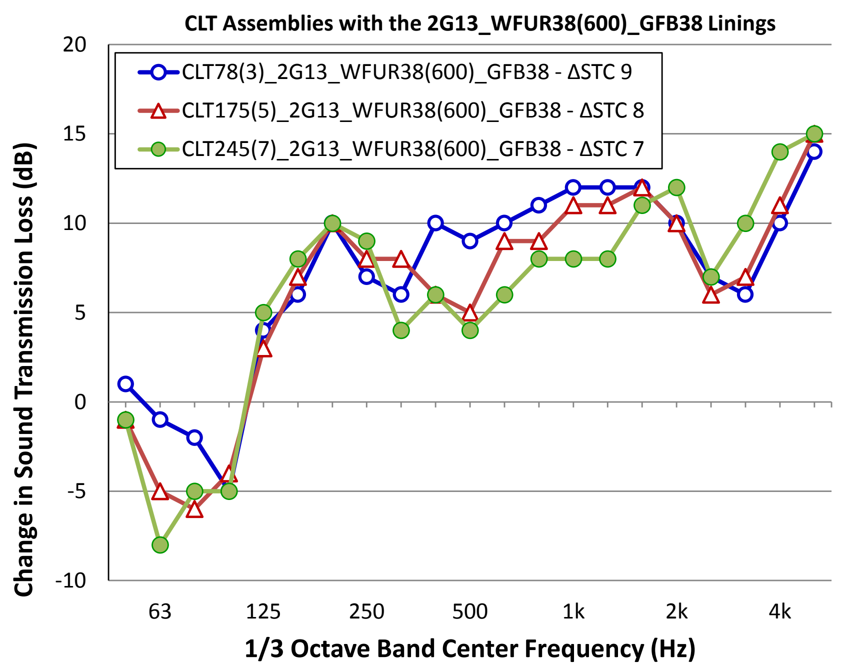
- A dip can be observed in each of the ΔTL curves at the mid-frequencies, varying from about 315 Hz for CLT245(7) to 500 Hz for CLT78(3). The dips are due to the mass-air-mass resonance caused by air which is trapped between the gypsum board and the CLT assembly which acts like a spring.
- The dip in the ΔTL curves around 2500 Hz is due to the critical frequency of the gypsum board panels. The critical frequency in the 2500 Hz one-third octave band is typical for 12.7 mm fire-rated gypsum board.
- Increasing the width of the CLT assembly shifts the mass-air-mass resonance to lower frequencies, resulting in higher ΔTL above the resonance frequency and generally higher ΔSTC ratings. Improvements are also possible by increasing the mass of the gypsum board layer, increasing the gap between the gypsum board and the surface of the CLT and filling the gap with sound absorbing material.

- Below the mass-air-mass resonance, the values of the ΔTL curves tend to increase as the mass of the CLT assembly is decreased. The mean increase of about 2 dB in ΔTL due to adding the 2G13 lining to CLT78(3) versus the smaller ΔTL for adding the lining to CLT245(7) reflects the changing ratio of the lining's mass relative to that of the CLT.
- Above the mass-air-mass resonance, there is little dependence on the mass of the supporting CLT assembly.

As noted in the legend in Figure 2.1.2.1, the ΔSTC rating is slightly higher for this lining on CLT78(3) than on the CLT175(5) or CLT245(7). Similar effects are observed for other linings with a rather small cavity (under 40 mm) between the gypsum board and the CLT.

The averaged ΔTL data for all the test assemblies with the 2G13_WFUR38(600)_GFB38 lining are shown in Figure 2.1.2.2.

Figure 2.1.2.2
Change in direct sound transmission loss (ΔTL) due to the addition of the lining W03 on the Base CLT assemblies.

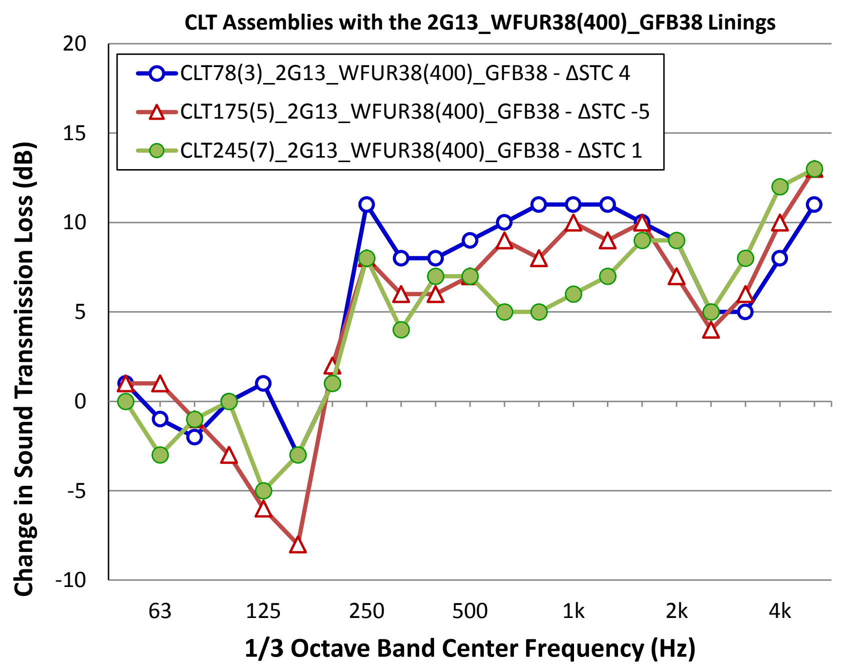


The ΔTL curves for this lining show quite similar trends for the CLT78(3) and CLT175(5) assemblies with a mass-air-mass resonance below 125 Hz. This is just below the frequency range that determines the STC rating, so the resonance has little influence on the single-number ΔSTC rating. Between 125 Hz and 2 kHz, most of the ΔTL values for the lining on the CLT78(3) assembly are higher than those for the CLT175(5) assembly, resulting in a slightly higher ΔSTC rating for the former.

The full ΔSTC ratings are listed in Table 2.1.2.4.

Figure 2.1.2.3 shows the corresponding ΔTL data for the assemblies with the 2G13_WFUR38(400)_GFB38 lining. The only change from the assemblies in the preceding figure is the reduction of the spacing between the furring strips from 600 mm to 400 mm, but this is shown to cause a large change in the ΔTL values at the low frequencies and thereby a change in the ΔSTC ratings.

Figure 2.1.2.3
Change in direct sound transmission loss (ΔTL) due to the addition of the lining W02 on the Base CLT assemblies.



Some features of the changes in the direct sound transmission loss in Figure 2.1.2.3 should be noted:

- The change in the sound transmission loss due to the addition of a lining is not always an improvement. In this case, the ΔTL values are negative at frequencies below about 200 Hz. That is, the sound transmission loss of the CLT with the added lining is below that for the Base CLT assembly. **This finding emphasizes the point that linings for the CLT assemblies must be chosen with care to avoid reducing the transmission loss of the assembly.**
- The addition of a matching lining on both sides of the wall approximately doubles the ΔTL values at each frequency relative to the change observed for adding a lining to one side of the Base CLT so that the negative dips become even more negative when both sides have this lining.
- Note that the change in the STC rating does NOT usually double due to addition of the lining on the second side. Unfortunately, the negative low frequency dips in the ΔTL value like those due to adding this lining have a strong influence on the STC rating. It is this sort of behaviour that forces the conservative process for calculating the ΔSTC rating as presented in Appendix A2.

Reducing the spacing of the wood furring strips from 600 mm to 400 mm reduces the transmission loss of the CLT assembly. Similar effects are observed for wood-framed walls with gypsum board attached directly to the studs.

The practical solution is to avoid supporting the gypsum board on rigid furring spaced less than 600 mm on centre. Spacing the furring at 400 mm on centre rather than at 600 mm on centre increases material and labor costs for the construction, and provides much worse sound insulation.

HENCE, THE USE OF LINING 2G13_WFUR38(400)_GFB38 IS NOT RECOMMENDED.

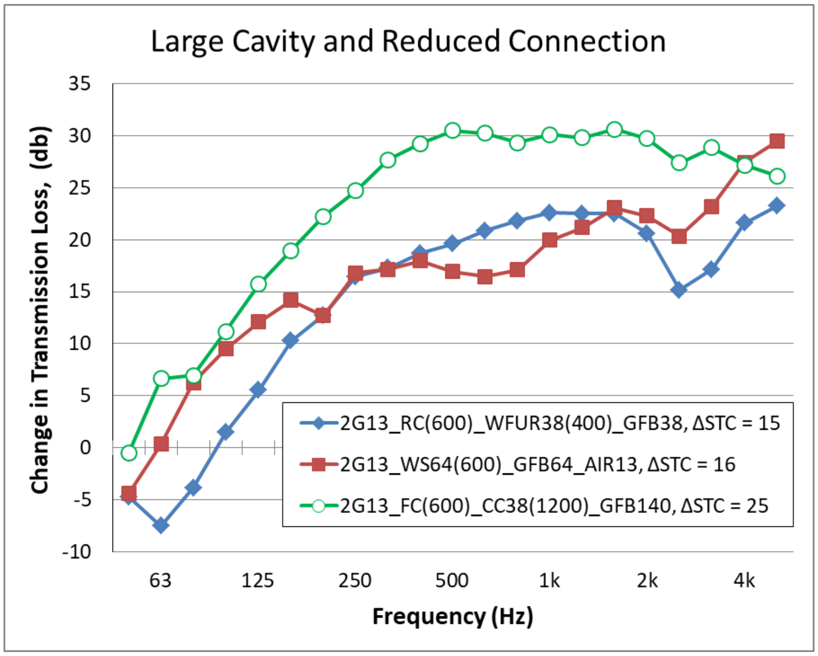
Fortunately, this was the only CLT lining considered in this study that exhibited such a strong and variable reduction in the ΔSTC rating. For all linings with cavity depth less than about 60 mm, however, the STC ratings were noticeably reduced by the resulting low frequency resonance effect, especially when the cavities were not filled with sound absorptive material.

Figure 2.1.2.4 presents the ΔTL data for test assemblies with a variety of linings that rely on an increased distance between the gypsum board and the surface of the CLT assembly as well as reduced structural connections between those surfaces.

The larger cavity depth shifts the mass-air-mass resonance to lower frequencies with the shift being most obvious for the suspended ceiling with a cavity over 150 mm in depth. Even for the wall lining with resilient metal channels with a cavity depth that is only 30% greater than the cases with 38 x 38 mm wood furring presented in Figures 2.1.2.2 and 2.1.2.3, the increase in the cavity depth is enough to shift the resonance down in frequency well below 100 Hz, and therefore out of the frequency range which controls the STC rating.

Figure 2.1.2.4:
Change in the direct sound transmission loss (ΔTL) due to the addition of a set of linings to the CLT175(5) assembly.

For these linings, the supporting framing reduced the structural connection between the gypsum board surface and the CLT, and the cavity depth ranged from 50 mm to over 150 mm. The result of these detail differences is a large increase in the ΔTL values above 100 Hz and therefore, higher ΔSTC ratings.



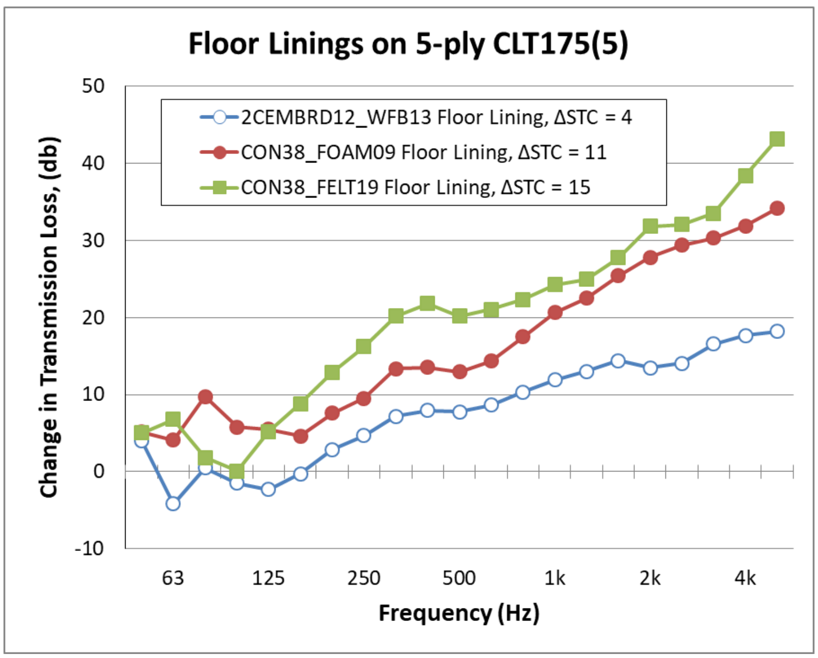
The significantly larger ΔTL values exhibited in Figure 2.1.2.4 as opposed to those shown in earlier figures are only partly due to the increased cavity depth. These linings also provide fewer structural connections between the gypsum board and the surface of the CLT assembly.

- The suspended gypsum board ceiling (green circles in the figure) is supported from a grid of metal furring channels hung on wires which supress transmission of the bending waves that commonly dominate sound transmission.
- The independent studs supporting the gypsum board for lining 2G13_WS64(600)_GFB64_AIR13 (red squares in the figure) approximately double the cavity depth (from 38 mm to about 76 mm) and provide structural connections to the surface of the CLT assembly only at the perimeter.
- The resilient metal channels of lining 2G13_RC(600)_WFUR38(400)_GFB38 (blue diamonds in the figure) increase the cavity depth by only 30%, but the channels also limit the vibration transmission between the surfaces and provide much less rigid attachment points where the gypsum board is supported. These construction details suppress the strong resonance evident in Figure 2.1.2.3 at around 160 Hz.

A variety of floor linings were installed on top of the CLT175(5) floor assembly. Figure 2.1.2.5 presents the ΔTL data for a subset of these test assemblies. The findings show:

- Lighter floor toppings (such as the cement board on wood fiber board) provide appreciable ΔTL values in the mid- and high frequencies, but almost no improvement in the transmission loss at the low frequencies.
- Higher values of ΔTL were observed for the heavier linings such as concrete and gypsum concrete. The choice of the resilient underlayment used altered the shape of the ΔTL curve as well as the overall ΔSTC rating. A mass-spring-mass resonance is expected at fairly low frequencies, but did not cause a significant negative dip in the ΔTL values for the floating floor toppings tested in this series.
- The resonance frequency depends on both the mass of the floating layer and the stiffness of the supporting resilient layer and is higher than would be observed for the same lining on a structural concrete floor because the CLT assembly is lighter and less rigid.
- Adding typical flooring materials on top of the floating concrete or gypsum concrete topping is predicted to have little effect on the ΔTL values or the ΔSTC ratings.

Figure 2.1.2.5:
Change in direct sound transmission loss (ΔTL) due to addition of various floor linings to the Base CLT175(5) assembly.



ΔSTC Ratings for Linings on Single-Leaf CLT Assemblies

To characterize the change in the direct sound transmission loss due to adding a specific lining to a CLT assembly, a single-number rating called the ΔSTC is introduced. ASTM does not define a rating like the ΔSTC rating, but it has a counterpart (ΔR_W) in the ISO standards. The procedure described here is adapted from its ISO counterpart, as explained in Appendix A2.

Section 2.1.2 presented and discussed the trends in results of the sound transmission loss values for a series of assemblies comprising a single-leaf CLT wall or floor assembly with an added lining covering one side or both sides. This section presents the corresponding single-number ΔSTC ratings.

- The ΔSTC ratings for the linings are given in Table 2.1.2.4.
- The changes in the transmission loss ΔTL values for each lining are listed in Appendix A1.1.

Key points regarding the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed and used in the worked examples in Section 4.1.
- The ΔSTC ratings were calculated from the experimental data in this Report using the procedure described in Appendix A2, and are presented in Table 2.1.2.4.
- The tabulated ΔSTC ratings from Table 2.1.2.4 can be used for the calculation of the ASTC rating of a building construction of CLT assemblies, like those in the examples of Chapter 4, without the need to perform the calculations detailed in the Appendix.

Table 2.1.2.4: ΔSTC ratings for linings on single-leaf CLT wall, ceiling or floor surfaces.

Lining Code	Lining Descriptive Code	Base CLT	ΔSTC
Wall Linings:			
ΔTL-CLT-W01	2G13	CLT78(3)	**2**
		CLT175(5) or CLT245(7)	**0**
ΔTL-CLT-W02	2G13_WFUR38(400)_GFB38	CLT78(3)	**4**
		CLT175(5) or CLT245(7)	**-5**
ΔTL-CLT-W03	2G13_WFUR38(600)_GFB38	CLT78(3)	**9**
		CLT175(5) or CLT245(7)	**8**
ΔTL-CLT-W04	2G13_RC13(600)_WFUR38(400)_GFB38	Any	**15**
ΔTL-CLT-W05	2G13_WFUR64(600)_GFB65	Any	**6**
ΔTL-CLT-W06	2G13_WS64(600)_GFB65_AIR	Any	**16**
Ceiling Linings:			
ΔTL-CLT-C01	2G13_WFUR38(600)_GFB38	Any	**7**
ΔTL-CLT-C02	G16_UC22(600)_CC38(1200)_GFB140_2G13	Any	**25**
ΔTL-CLT-C03	2G13_UC22(600)_CC38(1200)_GFB140	Any	**25**
Floor Linings:			
ΔTL-CLT-F01	CON38(no bond)	Any	**7**
ΔTL-CLT-F02	CON38_FOAM09	Any	**11**
ΔTL-CLT-F03	CON38_WFB13	Any	**10**
ΔTL-CLT-F04	CON38_FELT19	Any	**15**
ΔTL-CLT-F05	CON38_RESL13	Any	**9**
ΔTL-CLT-F06	CON38_RESL08	Any	**9**
ΔTL-CLT-F07	CON38_RESL17	Any	**11**
ΔTL-CLT-F08	2CEMBRD12_WFB13	Any	**4**
ΔTL-CLT-F09	GCON38_FOAM09	Any	**7**

NOTES:
a. The ΔTL values were determined using the Base CLT as the reference case without lining(s), and these values were combined with a reference curve as described in Appendix A2.
b. The ΔSTC ratings should be appropriate for all walls or floor/ceilings with a core of single-leaf CLT of 3-ply to 7-ply; for W01, W02, and W03, each listed value applies for a specific Base CLT.

2.1.3 Adding Linings on Double-Leaf CLT Wall Assemblies

For the double-leaf CLT wall assemblies, the change in the sound transmission loss due to adding linings is significantly different from the change for the single-leaf CLT assemblies as presented in the earlier section. Therefore, the ΔTL and the ΔSTC ratings for single-leaf and double-leaf CLT assemblies are not interchangeable.

This study included a double-leaf CLT wall which was constructed from two single-leafs of the CLT78(3) assembly (each leaf was 78 mm thick and had a mass per area of 42.4 kg/m^2) with a 25 mm thick layer of glass fiber filling the cavity between the two leafs. This assembly is denoted in this Report as CLT78(3)_GFB25_ CLT78(3).

In addition measurements of the transmission loss for the bare double-leaf CLT wall assembly, the measurements also included cases where gypsum board linings were applied to the double-leaf CLT assembly. The linings that were tested on the double-leaf walls are described in Table 2.1.3.1, and the corresponding ΔSTC ratings are listed in Table 2.1.3.2.

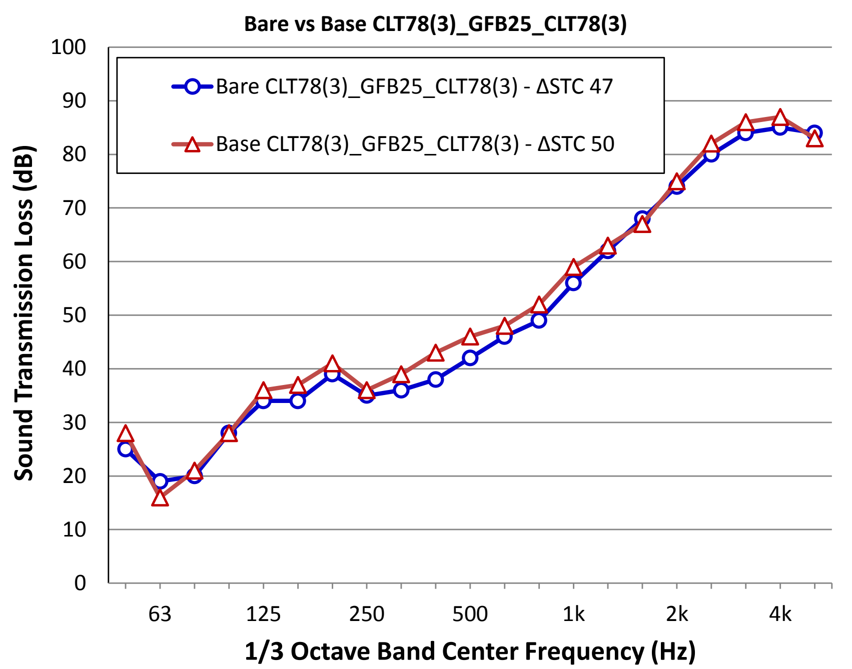
Table 2.1.3.1: Linings tested on a double-leaf CLT wall (two leafs of CLT78(3) with a 25 mm thick layer of glass fiber filling the space between the two leafs).

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-2xCLT-W01	2G13	Two layers of 12.7 mm thick fire-rated gypsum board[2] screwed to the face of the CLT assembly
ΔTL-2xCLT-W03	2G13_WFUR38(600)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm on center and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[6] filling the spaces between the gypsum board and the CLT assembly

NOTES: a. The descriptive codes for linings are explained in Section 2.1.2.

The evaluation of the double-leaf CLT assembly followed the same procedure to establish the Base CLT direct sound transmission loss that was used for single-leaf assemblies in Section 2.1.1. The linings tested with the double-leaf CLT assembly included two layers of 12.7 mm gypsum directly attached to one side of the bare double-leaf CLT and then again on both sides of the assembly. As shown in Figure 2.1.3.1, the difference between the sound transmission loss of the Base CLT assembly compared with the sound transmission loss of the Bare CLT assembly was a small but consistent increase between 125 Hz and 1600 Hz, which increased the STC rating from 47 to 50.

Figure 2.1.3.1
Comparison between the Bare and the Base sound transmission loss for the double-leaf assembly CLT78(3)_GFB25_CLT78(3).



The direct sound transmission loss curve for the Bare CLT78(3)_GFB25_CLT78(3) assembly exhibits a marked dip at 63 Hz, which is consistent with the expected mass-air-mass resonance due to the absorption-filled cavity between the two leafs of the wall assembly. The decreasing sound transmission loss above 3000 Hz is consistent with the expected panel thickness resonance at around 6000 Hz (as discussed for single-leaf assemblies in Section 2.1.1), but the results at the higher frequencies may also be affected by perimeter leakage as well as the flanking limit of the direct sound transmission facility.

In Figure 2.1.3.2, the measured ΔTL values for linings W01 and W03 on the double-leaf wall assemblies are compared with the changes due to the same linings applied to the single-leaf CLT78(3) assembly. The data for the linings are only shown for frequencies up to 1600 Hz, because at higher frequencies, the measured results converged to the curve for the Bare CLT78(3)_GFB25_CLT78(3) assembly, a result which was interpreted as an indication that those test data were limited by the facility flanking limit or leakage at the assembly perimeter. From a practical perspective, this limitation does not compromise the useful data.

For lining W01, the ΔTL values measured on the CLT78(3)_GFB25_CLT78(3) assembly were slightly higher than those measured on the single-leaf CLT wall. For lining W03, the ΔTL values measured on the CLT78(3)_GFB25_CLT78(3) assembly were very similar to those measured on the CLT78(3) assembly at the mid-frequencies and the frequency dependence at low frequencies shows the sharp drop below 125 Hz in both cases. These results suggest that linings provide similar changes on both the single-leaf and double-leaf CLT assemblies.

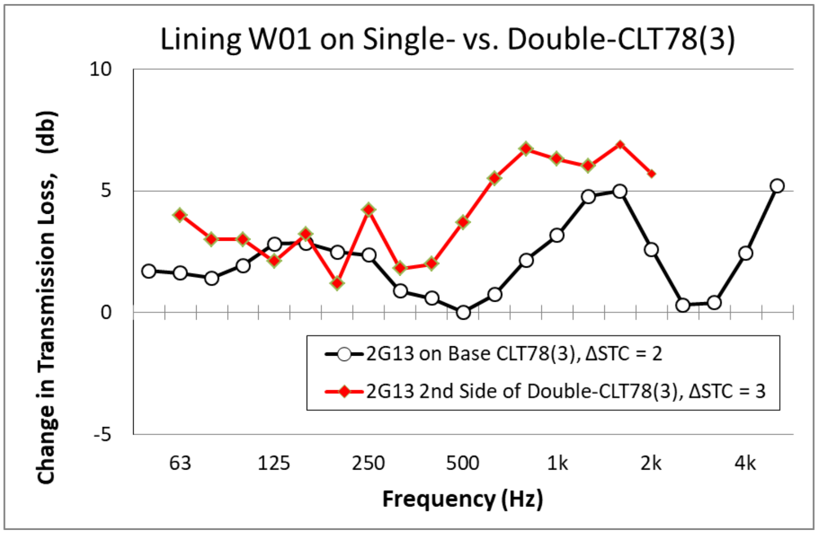
The results of the ΔSTC calculations are shown in Table 2.1.3.2. To provide estimates for some additional linings, the ΔTL values determined when other linings were added to single-leaf walls were processed to determine what improvement in the STC ratings these would provide when the sound transmission loss of the double-leaf assembly is used as the reference curve.

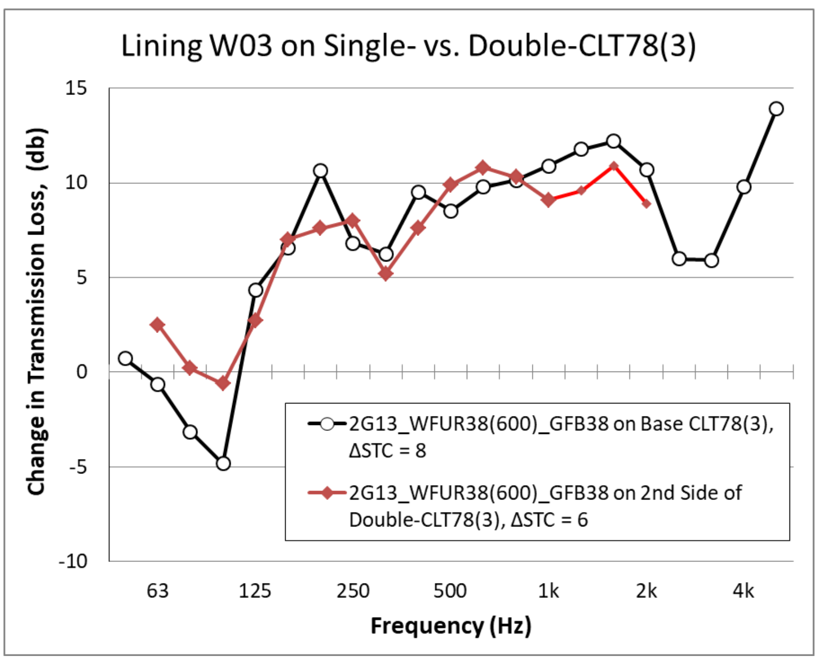
Figure 2.1.3.2:
Change in direct sound transmission loss (ΔTL) for linings W01 and W03 added to the CLT assemblies.

The upper graph shows the ΔTL results for lining W01 (descriptive code 2G13) applied to the single-leaf and the double-leaf assemblies.

The lower graph shows corresponding ΔTL results for lining W03 (descriptive code 2G13_WFUR38(600)_GFB38) measured with the lining applied to the single-leaf and the double-leaf assemblies.

In both cases the calculated ΔSTC rating approximately matched (within experimental uncertainty) when the linings were installed on the single or the double-leaf assembly.





ΔSTC Ratings for Linings on Double-Leaf CLT Assemblies

The averaged one-third octave band values of the changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the CLT78(3)_GFB25_CLT78(3) assembly were calculated following a similar procedure to those described in Appendix A2 for linings on single-leaf CLT assemblies. Because the direct sound transmission loss curve for the unlined double-leaf wall differed appreciably from the single-leaf curves, the estimate of the direct sound transmission loss for the Base CLT78(3)_GFB25_CLT78(3) assembly was used as the reference curve in place of the single-leaf CLT reference curve defined in Appendix A2. In practice, this change had little effect on the calculated ΔSTC rating.

The calculated ΔSTC ratings for linings attached to the CLT78(3)_GFB25_CLT78(3) assembly are presented in Table 2.1.3.2.

Table 2.1.3.2: ΔSTC ratings for linings on the CLT78(3)_GFB25_CLT78(3) assembly

Lining Code	Lining Descriptive Code	Base CLT Assembly	ΔSTC
Wall Linings:			
ΔTL-2xCLT-W01	2G13	CLT78(3)_GFB25_CLT78(3)	**3**
ΔTL-2xCLT-W03	2G13_WFUR38(600)_GFB38	CLT78(3)_GFB25_CLT78(3)	**6**
ΔTL-2XCLT-W04	2G13_RC13(600)_WFUR38(400)_GFB38	CLT78(3)_GFB25_CLT78(3)	**14**
ΔTL-2XCLT-W05	2G13_WFUR64(600)_GFB65	CLT78(3)_GFB25_CLT78(3)	**6**
ΔTL-2XCLT-W06	2G13_WS64(600)_GFB65_AIR	CLT78(3)_GFB25_CLT78(3)	**16**

NOTES:
a. For linings W01 and W03, the ΔTL values were calculated from measurement results with those linings on double-leaf CLT wall assemblies. For other linings, the values of ΔTL obtained for these linings on single-leaf assemblies (see Section 2.1.2) were used, as discussed above.
b. The calculation of the ΔSTC ratings followed the process described in Appendix A2, except that the sound transmission loss curve for the Base double-leaf assembly was substituted for the Reference curve of Figure A2.2, which introduces some small changes from the corresponding ΔSTC ratings for single-leaf assemblies that are presented in Table 2.1.2.4.

2.1.4 Structural Loss Factors for CLT Wall or Floor Assemblies

The structural reverberation times of each of the bare CLT wall and floor assemblies were measured according to ISO 10848 to determine the structural loss factors. The structural loss factors are required for the calculations of the ASTC rating using the Detailed Method.

The measured structural reverberation times are shown in Table A1.1.3 of Appendix A1.1. Following ISO 10848, the structural loss factor η_{total} was calculated from the data using Equation 2.4.1:

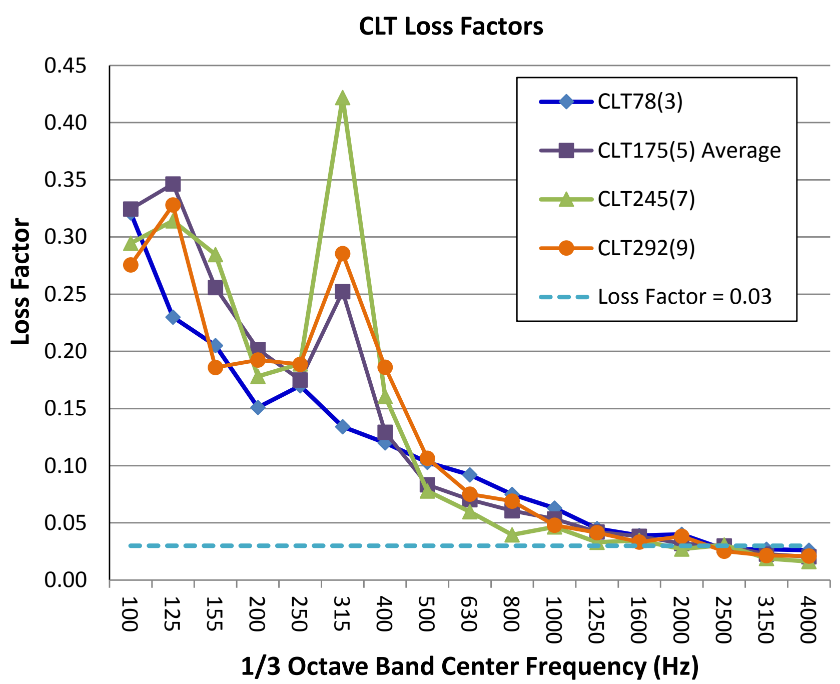
$$\eta_{total} = \frac{2.2}{fT_s} \qquad \text{Eq. 2.4.1}$$

where f is the one-third octave band frequency in Hz and T_s is the structural reverberation time per one-third octave band in seconds. The resulting loss factors are shown in Figure 2.1.4.1.

Figure 2.1.4.1

Structural loss factors, η_{total} for the CLT assemblies presented in this Report.
These loss factors were calculated from the structural reverberation times which are tabulated in Appendix A1.1.

The average values indicate that over most of the frequency range the loss factors tend to be above 0.03, which is the threshold for ignoring edge corrections when using the Detailed Method to calculate the ASTC rating.



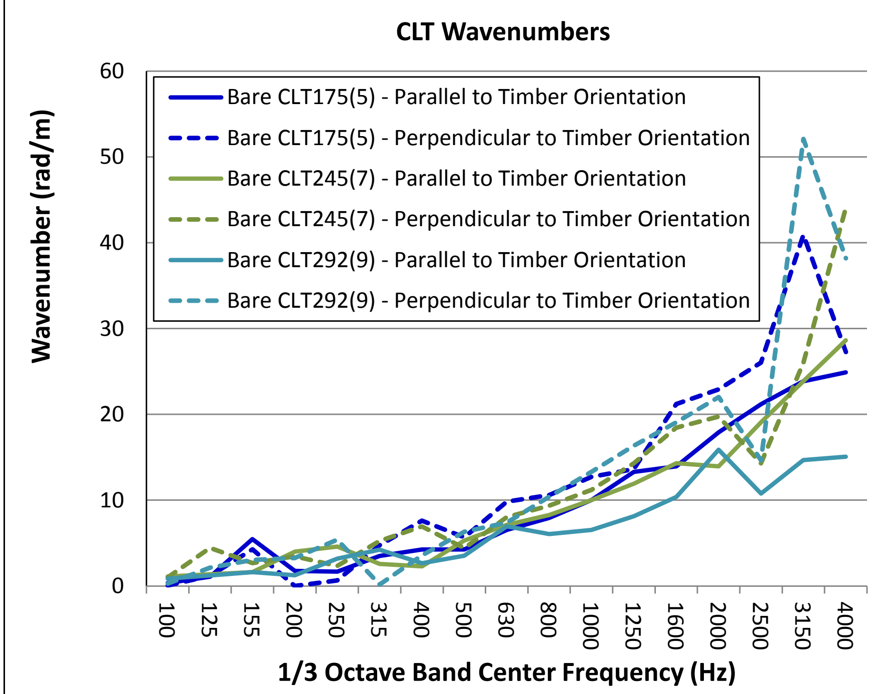
What is important for this study is that the loss factors are mostly above 0.03. Averaged over the frequency range used for the STC rating (125 Hz to 4000 Hz), the structural loss factors are over 0.04, and it is only at frequencies above 2000 Hz that the curves in Figure 2.1.4.1 fall below 0.03. For constructions whose structural loss factors exceed the threshold value of 0.03, the effect of edge conditions may be ignored when calculating the ASTC rating using the Detailed Method, which greatly simplifies the calculations.

2.1.5 Bending Wavenumbers for the CLT Assemblies

The horizontal and vertical wavenumbers for bending waves travelling in the CLT assemblies were measured as a function of frequency following the procedure detailed in [12]. A Scanning Laser-Doppler Vibrometer (SLDV) was used to measure the surface velocity at 21 equally spaced points, each for the horizontal and vertical direction. In the context of the measurements on the CLT elements, the horizontal direction was parallel to the timber of the top layer on the measured side and the vertical direction was perpendicular to the timber of the top layer on the measured side. The wavenumbers were measured only for the Bare CLT175(5), CLT175(5) and CLT292(9) assemblies.

The measured wavenumbers for the Bare CLT175(5), Bare CLT175(5) and Bare CLT292(9) assemblies are shown in Figure 2.1.5.1 and the numerical results are listed in Table A1.1.6 of Appendix A1.1. The data shows that the CLT assemblies can be regarded as homogeneous in terms of the wave propagation inside the elements, as the data is very similar for both the horizontal and vertical direction. This means that the material can be regarded as isotropic. The wavenumbers are also very similar for all elements, showing that there is no dependence on the element thickness.

Figure 2.1.5.1
Comparison between the measured wavenumbers for the Bare CLT175(5), Bare CLT245(7) and Bare CLT292(9) assemblies.



2.2 Sound Transmission through NLT Wall and Floor Assemblies

In this section, the focus is on the basic Nail-Laminated Timber (NLT[4]) assemblies (wall or floor) without an added lining such as a gypsum board finish supported on some form of framing.

Each of the NLT assemblies was fabricated by nailing together individual pieces of lumber as illustrated conceptually in Figure 2.2.1. This report includes test results for five thicknesses of NLT wall or floor assemblies which are listed in Table 2.2.1.

Figure 2.2.1:
A bare NLT assembly with no shear membrane or other lining on either side.

Table 2.2.1: Physical details of the five NLT assemblies evaluated in this report

NLT Designation	Common Timber Name	Mass / unit area (kg/m^2)	Fabrication
NLT89	2x4	39.5	Fabricated from 2x4 lumber of nominal cross-section 38 mm x 89 mm
NLT140	2x6	65.8	Fabricated from 2x6 lumber of nominal cross-section 38 mm x 140 mm
NLT184	2x8	81.6	Fabricated from 2x8 lumber of nominal cross-section 38 mm x 184 mm
NLT235	2x10	89.5	Fabricated from 2x10 lumber of nominal cross-section 38 mm x 235 mm
NLT286	2x12	136.8	Fabricated from 2x12 lumber of nominal cross-section 38 mm x 286 mm

While the transmission loss data provided in this Report is based on measurements conducted with NLT assemblies with the specific parameters listed in Table 2.2.1, the data may also be used as a conservative estimate for NLT assemblies of similar construction but greater thickness or higher mass. For example, an NLT wall which is more than 286 mm thick or has a mass per area of more than 137 kg/m^2 can in general be expected to have an STC rating at least as high as the value reported in this Report for NLT286.

The remainder of Section 2.2 is arranged as follows:

- **Section 2.2.1** focuses on the sound transmission loss of NLT assemblies without linings.
- **Section 2.2.2** discusses the changes in the sound transmission loss due to adding a series of linings on the single-leaf NLT assemblies.
- **Section 2.2.3** presents results for structural loss factors of the unlined NLT assemblies
- **Section 2.2.4** presents the bending wavenumbers of the NLT assemblies

2.2.1 NLT Walls and Floors without Linings

For the calculation of the ASTC rating of buildings comprised of NLT assemblies, it is important to determine the sound transmission loss of the sealed NLT assemblies without leakage. The transmission loss of the sealed NLT assemblies is also used as a conservative reference case for determining the change in the transmission loss due to adding linings to the NLT assemblies.

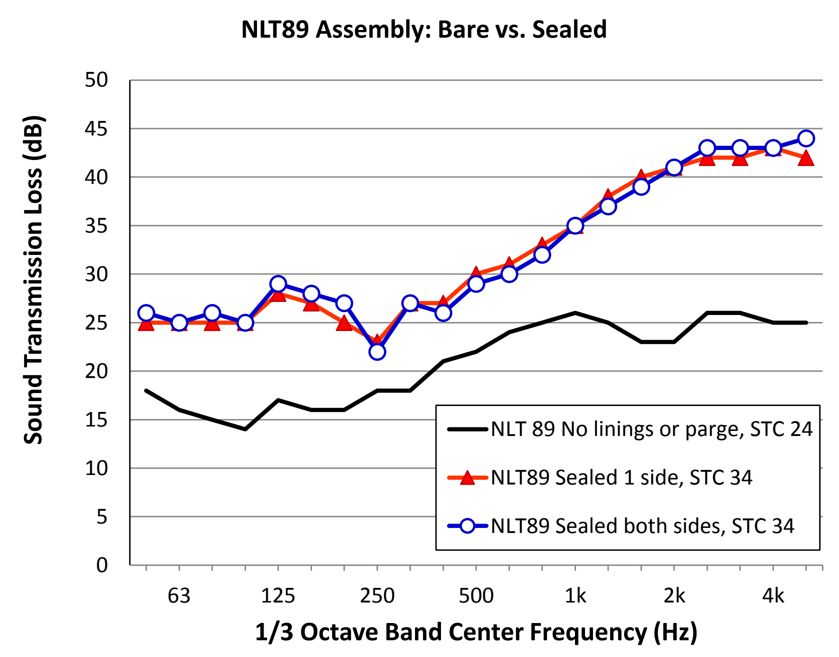
For the NLT assemblies considered for this study, the appropriate Bare (with leakage) and the Base (no leakage) assemblies needed to be determined. Based on the investigation discussed in detail below, it was concluded that the Bare NLT assembly would include a plywood shear element on one side since this is how the NLTs are commonly used in practice.

Note that:

- The third-octave-band transmission loss data for the unsealed NLT assemblies with a plywood shear membrane on one side, referred to as the **Bare** assembly is shown in Appendix A1.2.
- The third-octave-band transmission loss data for the sealed NLT assemblies with a plywood shear membrane on one side, referred to as the **Base** assembly is shown in Appendix A1.2.

Each of the Bare NLT assemblies listed in Table 2.2.1 was first tested with both surfaces of the assembly bare and then tested again with one or both of the surfaces sealed with a thin layer of cementitious material that seals the openings of the cracks between the timber elements comprising the NLT. The purpose of sealing of the cracks was to stop the leakage of sound through the cracks. Figure 2.2.1.1 presents the direct sound transmission loss measured for NLT89 without a shear membrane or other linings.

Figure 2.2.1.1
Comparison of the sound transmission loss of the basic NLT89 assembly with no lining on either side (bare) and with cementitious material on one and on both sides of the assembly (sealed).



There are two main takeaways from the data in the figure:

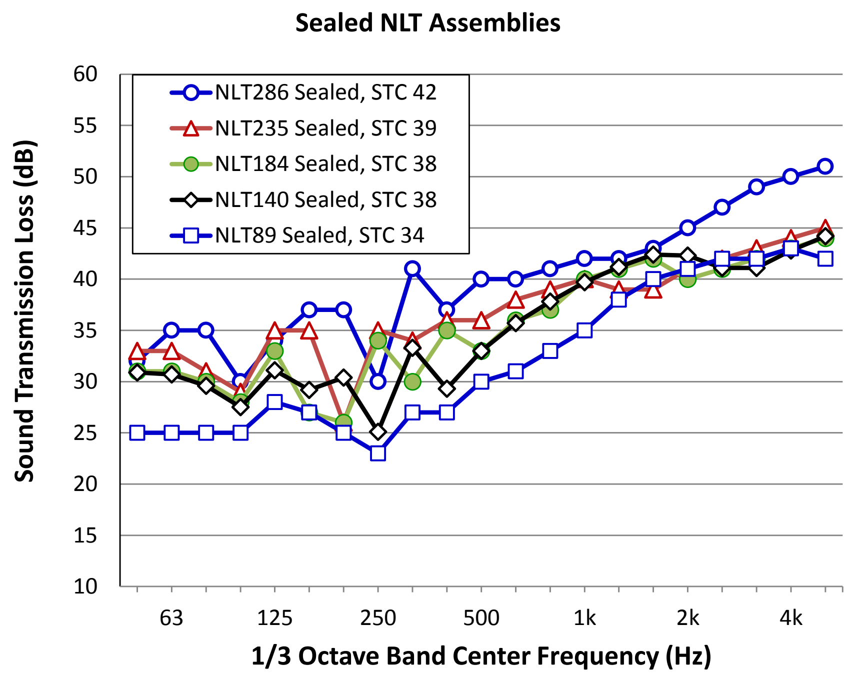
- The transmission loss curve for the bare NLT89 assembly is far below the transmission loss curve observed when the assembly was sealed with cementitious material. The difference indicates that for this sample, there was significant sound leakage through the thin slits between the individual pieces of lumber that comprised the NLT assembly.
- The result when both sides of the NLT assembly are sealed has the same STC rating as when only one side is sealed. The mean difference between the curves was 0.2 dB and the differences in any one-third octave band are smaller than the nominal measurement uncertainty. It was concluded that sealing the second side makes a negligible difference compared to sealing one side of the NLT assembly and therefore subsequent assemblies were evaluated with cementitious material on only one side.

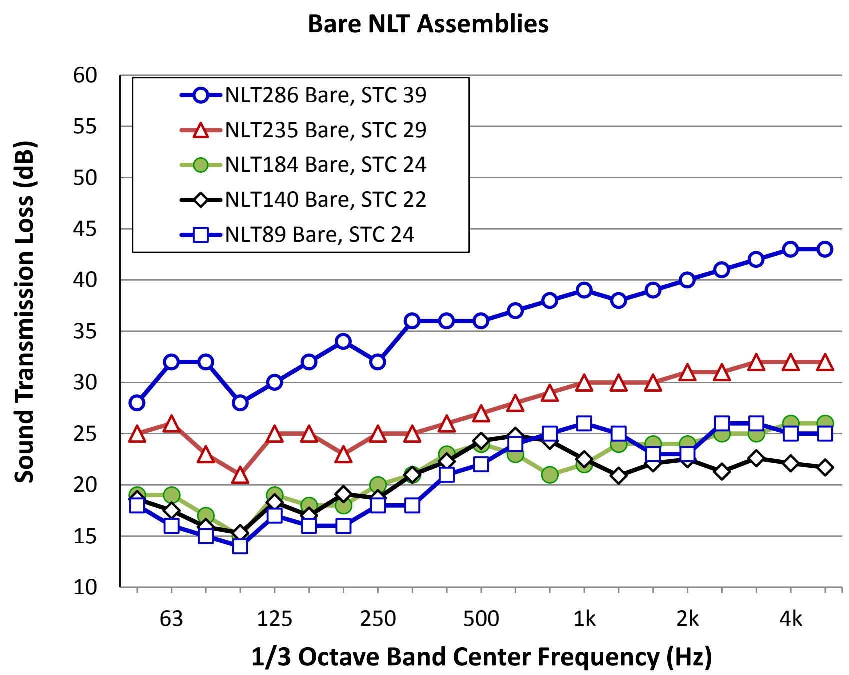
The change in the transmission loss due to sealing the NLT89 assembly was found to be typical for the other NLT assemblies, as shown in Figure 2.2.1.2.

Figure 2.2.1.2
Comparison between the direct sound transmission loss for the bare and sealed NLT assemblies

The upper graph shows transmission loss data for the sealed NLT assemblies.

The lower graph shows transmission loss data for the bare NLT assemblies.

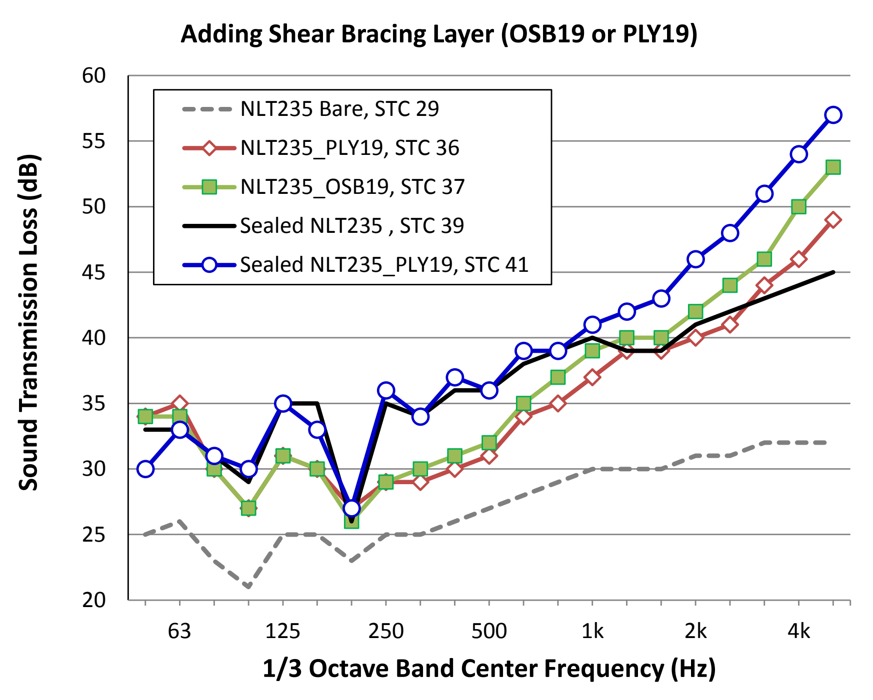




In every case, the bare NLT assembly had an appreciably lower transmission loss across the frequency range of interest than the comparable sealed NLT assembly although there was less of an effect due to sealing observed for the thickest NLT assemblies as compared to the thinner assemblies. Because the sealing process should have a negligible effect on the parameters that are significant for sound transmission such as the stiffness or weight of the assembly, the results are a clear indication that air leakage through the slits between the timber elements of the NLT assemblies dominated the sound transmission loss of the bare assembly. This result is not surprising since the slits between the individual pieces of lumber of the NLT assemblies were a millimetre wide in some instances.

In practice, membranes of plywood or oriented strand board (OSB) are often mechanically fastened with nails or screws to one face of the NLT assembly to resist shear forces that could otherwise distort the assembly. Figure 2.2.1.3 illustrates how the addition of a shear membrane alters the sound transmission loss of a bare or sealed 235 mm thick NLT assembly.

Figure 2.2.1.3
Comparison of the sound transmission loss curves of NLT235 due to sealing the assembly and/or adding a shear membrane of 19 mm thick plywood (Ply19) or OSB (OSB19).



The trends evident for the NLT235 assemblies are typical for all of the thicknesses of the NLT assemblies:

- Across all of the frequency range, adding a shear membrane or sealing the NLT assembly increases the transmission loss.
- Up to the 1000 Hz third-octave band, sealing the NLT assembly increases the transmission loss more than simply adding a shear membrane of plywood or OSB to the unsealed NLT. This indicates that the addition of a shear membrane to one face is not sufficient to stop the leakage of sound through the slits between the timber elements of the NLT assembly.

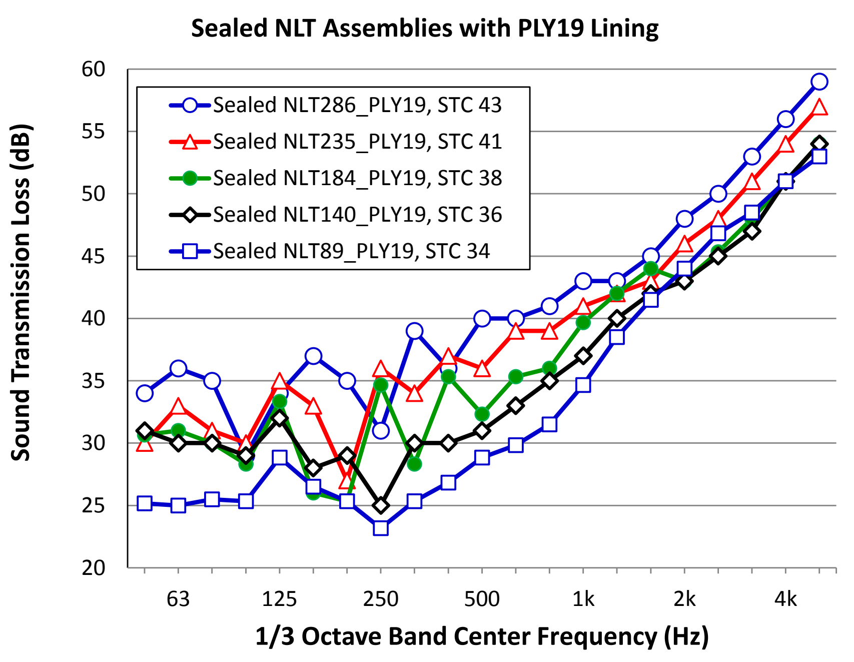
- Above 1 kHz, adding the plywood shear membrane to a sealed NLT235 assembly results in an increase in the transmission loss, but below about 1 kHz, the transmission loss is not significantly changed.
- ***When OSB is substituted for plywood*** as the shear membrane, the transmission loss increases consistently for all frequencies above about 250 Hz and the STC rating increased by one point. This behaviour was observed for all thicknesses of NLT assemblies and provides good confidence that substituting OSB in place of plywood will result in at least as good a sound transmission loss as the cases tested with plywood.

The magnitude and frequency of the peaks and dips shown in the figures below 500Hz are not consistent from one thickness of NLT to another. This is most evident in Figure 2.2.1.4 which shows the transmission loss curves for all five thicknesses of NLT assemblies with an attached shear membrane of 19 mm thick plywood. The dips are more pronounced than the corresponding peaks evident in the low frequency "plateau region" of the transmission loss curves presented for CLT assemblies in Figure 2.1.1.4. The peaks and dips reflect the effect of the very different stiffness of the NLT assemblies in the directions parallel and perpendicular to the long axis of the timbers elements of the NLT assembly.

Despite the peaks and dips at the lower frequencies, one can still discern the division of the transmission loss curves into two regions: a region below 500 Hz where the curves show no consistent trend and a region above about 500 Hz where the curve steadily increases with increasing frequency.

Figure 2.2.1.4

Comparison of the direct sound transmission loss curves for NLT assemblies with an added shear membrane of 19 mm thick plywood (Ply19).



NLT assemblies used as a wall or floor in a building will typically have an attached layer of plywood or oriented strandboard on at least one side to provide adequate shear bracing. Hence, the sound transmission loss data in Figure 2.2.1.4 for the NLT assemblies with the shear element attached are an appropriate starting point for the evaluation of the expected sound transmission in a building with a structure of NLT wall and/or floor assemblies. These values are used in Section 2.2.2 as the reference for determining the effect of linings and would also be considered as the base structure for calculation of the ASTC rating as discussed in Chapter 4.

As noted previously, the results of the tests of the NLT assemblies with a plywood shear membrane should provide a conservative estimate for the transmission loss when OSB is substituted for the plywood.

The STC ratings and one-third octave band direct sound transmission loss values for all the tested NLT assemblies (for bare assemblies and for the corresponding assemblies with an added shear-membrane and or other linings) are presented in the tables in Appendix A1.2.

2.2.2 Adding Linings on NLT Wall or Floor Assemblies

It is common practice, especially in residential buildings, to add finishing surfaces to the basic structural floor or wall assemblies to conceal both the bare structure surfaces as well as the building services such as electrical wiring, water pipes and ventilation ducts. The finishing on walls or ceilings is commonly comprised of gypsum board panels, framing used to support the gypsum board panels and sound absorptive material in the inter-framing cavities between the gypsum board and the face of the basic structural floor or wall assemblies. On floors, the finish may include toppings such as concrete or a floating floor as well as flooring such as hardwood or tiles. These elements are described in ISO 15712-1 as "linings" or "liners" or "layers" or "coverings". The term "linings" is used in this Report.

Two methods of characterizing the change in the direct sound transmission loss of the NLT assemblies by adding a lining are used in this Report. The first method is the change in the transmission loss (ΔTL) which is calculated from the difference between the transmission loss values measured with the lining installed on the Base NLT assembly and the transmission loss values of the Base NLT assembly without a lining. The Base NLT assembly is the NLT with the shear membrane attached to one side without leakage. The ΔTL is used for the calculation of the ASTC rating using the Detailed Method.

The second method of characterizing the change in the direct sound transmission loss of the NLT assemblies by adding a lining is a single-number rating called the ΔSTC. The ASTM standards do not define a rating like ΔSTC, but there is a counterpart in the ISO standards called ΔR_W. The calculation of the ΔSTC rating is adopted from the ISO standard with modification as explained in Appendix A2 of this Report. The ΔSTC rating is used for the calculation of the ASTC rating using the Simplified Method.

The linings evaluated on NLT assemblies for this study are described in Tables 2.2.2.1 to 2.2.2.3. The ΔSTC ratings for the measured linings are listed in Table 2.2.2.4. The ΔTL values for the measured linings are provided in Appendix A1.2. Because of the strong similarity to measured performance of the corresponding linings on the Base CLT assemblies, some results from Section 2.1 can also be used as the conservative estimates on the Base NLT assemblies, as discussed later in Section 2.2.2. Linings W02 and W06 were chosen to give the key data points for relating linings tested on CLT assemblies to expected performance on NLT assemblies.

Each Lining Code shown in Tables 2.2.2.1 to 2.2.2.3 begins with "ΔTL-NLT" to indicate that the lining applied to an NLT assembly has an effect on the direct sound transmission loss through the lined assembly. In some cases the thickness of the NLT assembly is indicated (as in "ΔTL-NLT235") if the result applies only to that thickness. For the three linings in Table 2.2.2.2 (W03, W04, and W05), the code does not indicate the thickness of the Base assembly because these are conservative estimates based on results for CLT assemblies (see Section 2.1.2) that are assumed to apply for all thicknesses of the NLT assemblies. The final part of the lining code is a letter (such as "W" to indicate a wall lining or "F" for a floor lining) followed by a unique number used to identify the lining in the table of ΔSTC ratings.

The Descriptive Short Code provides a compact physical description of each lining, which is used in the figure captions and in the examples throughout this Report. This code identifies the elements of the lining beginning at the exposed side and proceeding to the face of the supporting NLT wall or floor assembly. As detailed in the descriptions in Tables 2.2.2.1 to 2.2.2.3, each component of the lining is described by a short code. For example: G13 is gypsum board that is 12.7 mm thick, 2G13 is two connected G13 layers, and WFUR38 is a 38 mm x 38 mm wood furring. The distance between components such as adjacent studs is indicated by a number in parentheses which is the distance (on centre) between the components in millimetres.

The spacing and type of fasteners are not stated in the tables, but they are assumed to conform to standard industry practice as specified in the endnotes. Where sound absorbing material was included in a tested assembly, the code indicates the specific material that was tested, but applicability to other sound absorbing materials is assumed, as explained in the endnotes.

Table 2.2.2.1: Linings tested on Base NLT wall assemblies. Linings W02 and W06 were chosen to give the key points for interpolating to relate other linings tested on CLT assemblies to expected performance of the same linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-W02	2G13_WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board[2] screwed to 38 mm x 38 mm wood furring strips (spaced 400 mm on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts[6] filling the spaces between the gypsum board and the NLT
ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 mm x 38 mm wood studs (spaced 600 mm on center and offset 13 mm from the face of the NLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT

NOTES:
a. For the notes in this table please see the corresponding endnotes
b. The linings listed for wall assemblies may also be used on ceilings.

Table 2.2.2.2: Linings tested on Base CLT Wall Assemblies (See Section 2.1) that could be used as conservative estimates for matching linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-W01	2G13	Two layers of 12.7 mm thick fire-rated gypsum board[2]
ΔTL-NLT-W03	2G13_WFUR38(600)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT
ΔTL-NLT-W04	2G13_RC13(600)_ WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 13 mm resilient metal channels[3] (spaced 600 mm on center) that are screwed to 38 x 38 mm wood furring (spaced 400 mm on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT
ΔTL-NLT-W05	2G13_WFUR64(600)_GFB65	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood furring (spaced 600 mm on center and mechanically attached to the face of the NLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT

NOTES:
a. For the notes in this table please see the corresponding endnotes
b. The linings listed for wall assemblies may also be used on ceilings.

Table 2.2.2.3: Floor linings tested on Base CLT floor assemblies that could be used as conservative estimates for linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-F01	CON38(no bond)	38 mm thick concrete with no bond to the supporting NLT
ΔTL-NLT-F02	CON38_FOAM09	38 mm thick concrete on 9 mm thick closed-cell foam, covering the supporting NLT
ΔTL-NLT-F03	CON38_WFB13	38 mm thick concrete on 13 mm thick wood fiber board, covering the supporting NLT
ΔTL-NLT-F08	2CEMBRD12_WFB13	Two layers of 12 mm thick fiber-reinforced cement board on 13 mm thick wood fiber board, covering the supporting NLT
ΔTL-NLT-F09	GCON38_FOAM09	38 mm thick gypsum concrete on 9 mm thick closed-cell foam, covering the supporting NLT

NOTES: a. For all the floor linings listed, one short code applies for any of the NLT thicknesses considered in this Report..

Measured Change ΔTL due to Linings on NLT Assemblies

The trends in the measured sound transmission loss curves for the cases where linings were applied to NLT assemblies are presented and discussed in this Section.

The results may be applied as follows:

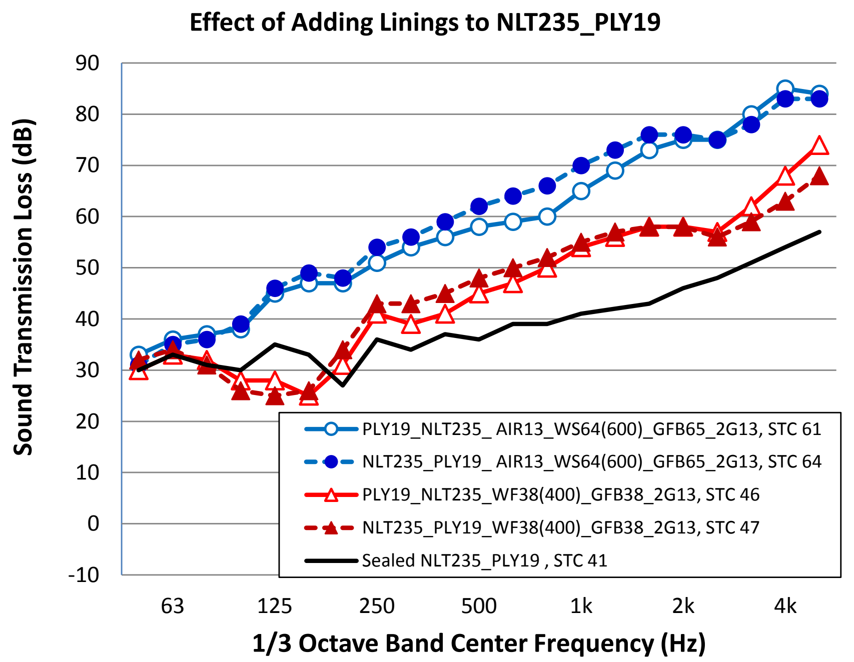
- The averaged one-third octave band changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the NLT assemblies are given in Table A1.2.2 of Appendix A1.2. The ΔTL data is needed for the calculation of the ASTC rating using the Detailed Method as presented in Report RR-331 and Chapter 4 of this Report.
- The corresponding single-number ΔSTC ratings for each lining are given in Table 2.2.2.4 of Section 2.2.2. The ΔSTC ratings are needed for the calculation of the ASTC rating using the Simplified Method as presented in Report RR-331 and in Chapter 4 of this Report.

Linings W02 and W06 were chosen to give the key points for relating linings tested on CLT assemblies to the expected performance on NLT assemblies. Each lining was tested with the lining applied on only one side of the Base NLT assembly which is comprised of the NLT and the plywood or OSB shear membrane fixed on one side. Because the Base assembly is asymmetric (with a shear membrane mechanically attached on one side of the NLT assembly) two configurations for each lining were tested:

a. With the lining applied on the same side as the plywood shear membrane
b. With the lining on the opposite side from the plywood shear membrane.

A comparison of the sound transmission loss curves for two linings (each installed first on the plywood side and then the opposite side of a Base NLT_PLY19 assembly) is presented in Figure 2.2.2.1.

Figure 2.2.2.1: Comparison of the transmission loss curves for the NLT235_PLY19 assembly with the W02 or W06 lining on either side of the assembly.



The results in Figure 2.2.2.1 illustrate the key features typical of all linings discussed in this Report:

- For each lining, there is a slight difference in the sound transmission loss if the lining is mounted over the plywood shear membrane or on the bare NLT on the opposite side.
- A higher STC rating is achieved if the lining is mounted on the same side as the plywood shear membrane. The same pattern was observed for all four thicknesses of NLT on which this set of linings was tested.

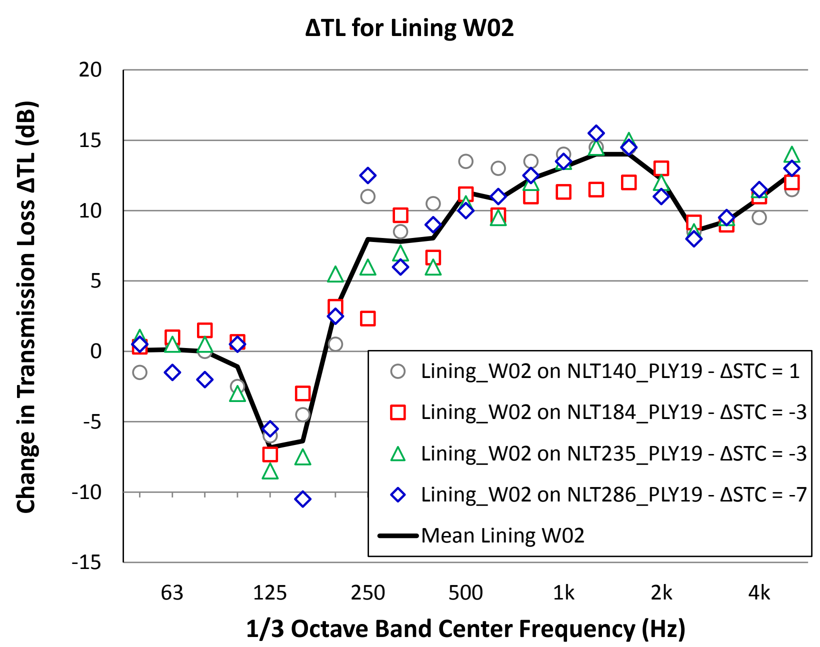
In order to prevent confusion when the linings are used on NLT assemblies in practice and for compatibility with the calculation method presented in Reports RR-331 and RR-335, the structural assemblies should be symmetrical and the effect of adding a lining should be the same when it is added on either side. To work within that framework, some conservative simplifications were made in the process for calculating the change in the sound transmission loss (ΔTL) due to the addition of the linings:

- The Base NLT assembly comprised of the NLT assembly and the shear membrane is treated as acoustically symmetric, despite the shear membrane on one side.
- Use the lower of the measurements for the lining applied on each side of the NLT assembly to calculate the ΔTL to remove the effect of whether the plywood is on the same side as the lining or the opposite side. This gives the correct result if the same lining is on both sides, and permits use of the Simplified Method for the calculation of the ASTC rating.

Data for NLT89 specimens were not included in this analysis, because that NLT assembly was not tested with the combination of a shear membrane and the gypsum board lining.

The values of ΔTL derived from the measurements for the W02 lining (2G13_WFUR38(400)_GFB38) are presented in Figure 2.2.2.2. There is some scatter in the results, but for the most part, the data points are within the range of the experimental uncertainty.

Figure 2.2.2.2:
Change in the sound transmission loss (ΔTL) due to the addition of the W02 lining (construction code 2G13_WFUR38(400)_GFB38) on the Base NLT assemblies of different thicknesses.



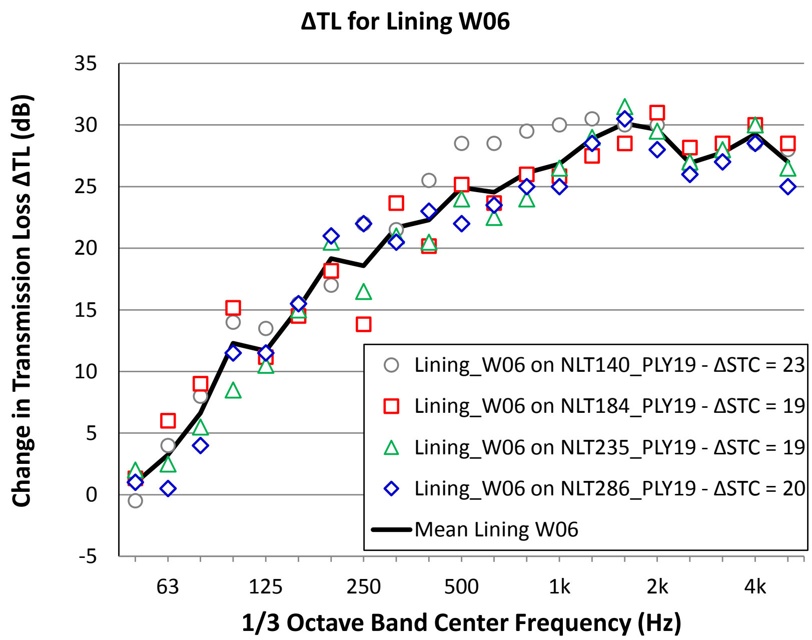
The ΔTL curves for lining W02 show similar trends for all of the thicknesses of the NLT assemblies with a well-defined mass-air-mass resonance at the 125 Hz one-third octave band and the gypsum board coincidence dip near the 2500 Hz one-third octave band. Note that due to the mass-air-mass resonance dip, the use of lining W02 negatively affects the transmission loss of the NLT assembly when it is applied.

There are differences in the magnitudes of the ΔTL curves and the ΔSTC rating for each thickness of NLT assembly. Therefore, the ΔTL curve and the ΔSTC rating used should be specific to the NLT assembly thickness rather than using an average of the values over all thicknesses for the calculation of the ASTC rating.

For the four NLT thicknesses that were tested, the full set of ΔTL values are listed in the tables in Appendix A1.2, and the ΔSTC calculations are presented in Table 2.2.2.3.

The values of ΔTL derived from the measurements for the W06 lining (2G13_WS64(600)_GFB65_AIR13) are presented in Figure 2.2.2.4. There is some scatter in the results, but the data points are within 5 dB.

Figure 2.2.2.3: Change in the sound transmission loss (ΔTL) due to the addition of the W06 lining (construction code 2G13_WS64(600)_GFB65_AIR13) on the Base NLT assemblies of different thicknesses.



The ΔTL curves for this lining show similar trends for all of the NLT thicknesses, with the mass-air-mass resonance well below the frequency range of interest and the gypsum board coincidence dip at the 2500 Hz one-third octave band. The full set of ΔTL values in one-third octave bands are listed in the tables in Appendix A1.2 for the four NLT thicknesses that were evaluated in this study.

ΔSTC Ratings for Linings on NLT Assemblies

To characterize the change in direct sound transmission loss due to adding a specific lining to a NLT assembly, a single-number rating called ΔSTC is introduced. ASTM does not define a rating like ΔSTC, but there is a counterpart (ΔR_W) in the ISO standards. The procedure used here is adapted from its ISO counterpart, as explained in Appendix A2.

Key points regarding the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed in Chapter 4.
- The ΔSTC ratings are calculated from the experimental data in this Report using the procedure described in Appendix A2. The ΔSTC ratings for the linings are given in Table 2.2.2.4, together with the intermediate calculation steps for each lining.
- Where the design intent is to leave the NLT assembly exposed on one side of a wall assembly, deviating from the standard ΔSTC calculation by using the ΔSTC rating calculated for a lining on only one side is justified, but for W02 the value for the chosen NLT thickness should be used.
- Readers of this Report can simply use the tabulated ΔSTC ratings from Table 2.2.2.4 in calculations like those in Chapter 4, without any need to perform the calculations detailed in Appendix A2.

Table 2.2.2.4: ΔSTC ratings for linings on NLT wall or floor surfaces.

Lining Code	Lining Descriptive Code	Base NLT	ΔSTC
	Wall Linings:		
ΔTL-NLT140-W02	2G13_WFUR38(400)_GFB38	NLT140	**1**
ΔTL-NLT184-W02	2G13_WFUR38(400)_GFB38	NLT184	**-3**
ΔTL-NLT235-W02	2G13_WFUR38(400)_GFB38	NLT235	**-3**
ΔTL-NLT286-W02	2G13_WFUR38(400)_GFB38	NLT286	**-7**
ΔTL-NLT140-W06	2G13_WS64(600)_GFB65_AIR13	NLT140	**23**
ΔTL-NLT184-W06	2G13_WS64(600)_GFB65_AIR13	NLT184	**19**
ΔTL-NLT235-W06	2G13_WS64(600)_GFB65_AIR13	NLT235	**19**
ΔTL-NLT286-W06	2G13_WS64(600)_GFB65_AIR13	NLT286	**20**
ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	NLT Mean	**21**
	Wall Lining Estimates from Linings on Base CLT:		
ΔTL-NLT-W01 [d]	2G13	Estimate, see note d	**0**
ΔTL-NLT-W03 [d]	2G13_WFUR38(600)_GFB38	Estimate, see note d	**8**
ΔTL-NLT-W04 [d]	2G13_RC13(600)_WFUR38(400)_GFB38	Estimate, see note d	**15**
ΔTL-NLT-W05 [f]	2G13_WFUR64(600)_GFB65	Estimate, see note d	**6**
	Floor Linings:		
ΔTL-NLT-F01	CON38(no bond)	NLT286	**8**
ΔTL-NLT-F02	CON38_FOAM09	NLT286	**12**
ΔTL-NLT-F03	CON38_WFB13	NLT286	**13**

NOTES:

a. See Appendix A2 for an explanation of the calculation of the ΔSTC ratings.
b. The ΔTL values were determined using the Base NLT as the reference case without lining(s) and these values were combined with a reference curve as described in Appendix A2.
c. The ΔSTC ratings should be appropriate for all walls or floor/ceilings with a core of NLT
d. For W01, W03, W04, and W05, each listed value was determined for application on a Base CLT assembly but gives a conservative estimate of the ΔSTC rating on the Base NLT.

Comparison of Linings Tested on NLT and CLT assemblies

The similarities in the ΔTL curves for linings applied to NLT and CLT assemblies can be seen in Figure 2.2.2.4 which compares the ΔTL curves of lining W02 installed on the different assemblies and in Figure 2.2.2.5 which compares the ΔTL curves of lining W06 installed on the different assemblies. Both figures show that there are strong similarities both in the frequency dependence of the individual curves and in the variation of the ΔSTC rating with the thickness of the Base assembly. However, the calculated ΔSTC ratings in Table 2.2.2.4 show that for lining W02 there is a strong variation in the results, from slight improvement to significant reduction of the ΔSTC rating, so using a mean value for all thicknesses of NLT is not recommended.

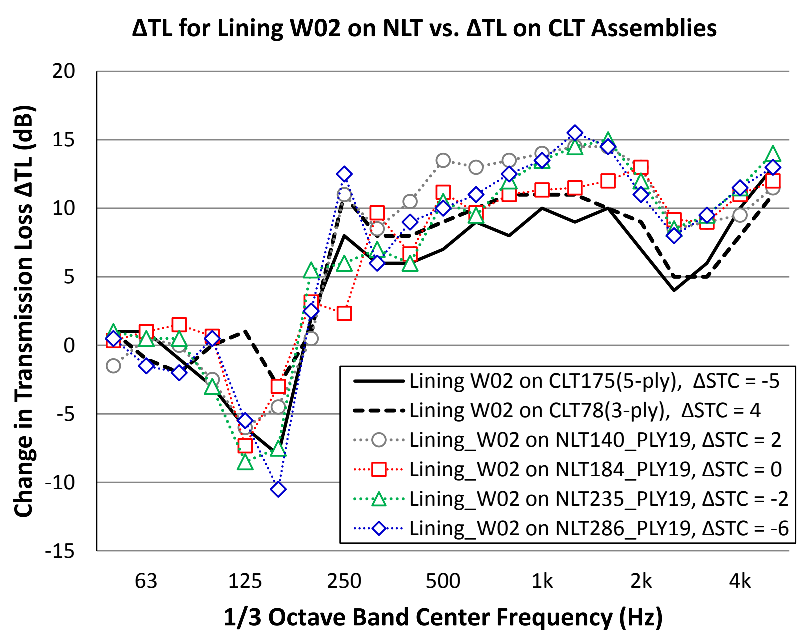
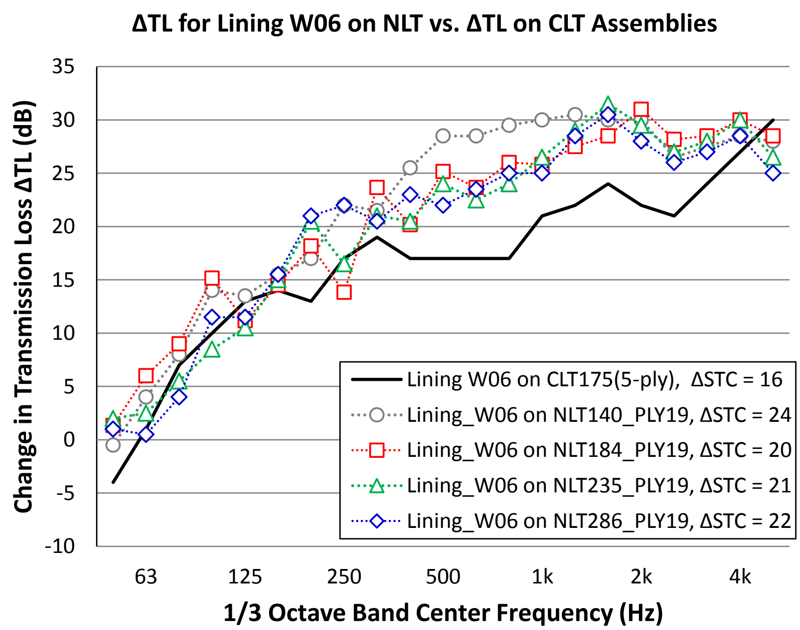


Figure 2.2.2.4: Change in the sound transmission loss (ΔTL) due to the addition of the W02 lining (construction code 2G13_WFUR38(400)_GFB38) on the Base NLT and CLT assemblies of different thicknesses.

<u>For lining W02</u>, the strong variation in the ΔSTC ratings versus thickness and weight of the assemblies results from the method of calculating the single number rating which can be limited by a sharp dip in the transmission loss curve. For lining W02, the sharp dip evident in the transmission loss and ΔTL results for lining W02 in the 125 and 160 Hz bands is caused by a mass-air-mass resonance around the 125 Hz one-third octave band. The dip results in <u>negative</u> values for the change in the transmission loss in the one-third octave bands at and below 160 Hz meaning that the addition of the linings decreases the transmission loss of the assembly. When the mass-air-mass resonance is shifted to a lower frequency by increasing the depth of the cavity between the gypsum board and the timber assembly (as for Lining W06), then the resonance and its adverse effect on the STC ratings are reduced as shown in Figure 2.2.2.5.

Figure 2.2.2.5:
Change in the sound transmission loss (ΔTL) due to the addition of the W06 lining (construction code 2G13_WS64(600)_GFB65_AIR13) on the Base NLT and CLT assemblies of different thicknesses.



For Lining W06, the variation in the ΔTL values with the thickness of the NLT assembly is small and there is no consistent trend in the ΔSTC rating for different thicknesses of the NLT assemblies. It is reasonable to use a mean value of the ΔSTC rating for lining W06 for all thicknesses of NLT when calculating the ASTC rating.

For both Lining W02 and W06, the measured values of ΔTL consistently show very similar frequency dependence when added to NLT or CLT assemblies, but are slightly higher when added to NLT assemblies.

The results demonstrate that it is reasonable to use ΔSTC ratings for linings W03, W04, and W05 which were measured for CLT assemblies (see Section 2.1) as credible but conservative estimates of the ΔSTC ratings for the same linings applied to NLT assemblies.

2.2.3 Structural Loss Factors for NLT Wall or Floor Assemblies

The structural loss factors required for the calculation of the ASTC rating using the Detailed Method were calculated from the structural reverberation times measured for each NLT assembly according to the standard, ISO 10848. Following ISO 10848, the structural loss factor η_{total} was calculated from the measured structural reverberation time such that:

$$\eta_{total} = \frac{2.2}{f T_s} \qquad \text{Eq. 2.2.3.1}$$

where f is the one-third octave band frequency in Hz and T_s is the structural reverberation time per one-third octave band in seconds. The resulting loss factors are compared in Figure 2.2.3.1.

Figure 2.2.3.1: Comparison of the structural loss factors, η_{total} for the five NLT Base assemblies.

These loss factors were calculated from the structural reverberation times which are tabulated in Appendix A1.2.

The average values indicate that over much of the frequency range the loss factors tend to be above 0.03, which is the threshold for ignoring edge corrections when using the Detailed Method to calculate the ASTC rating.

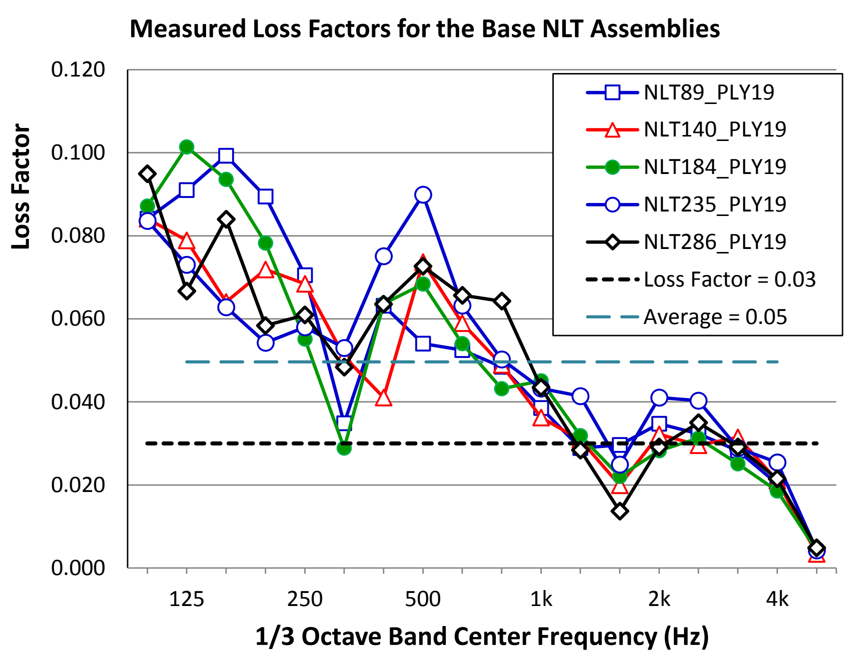


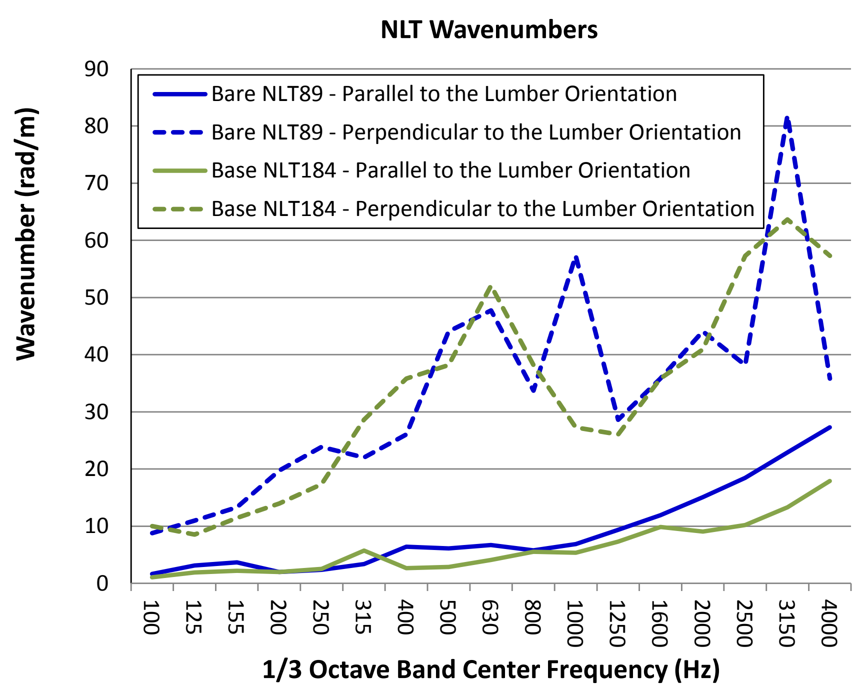
Figure 2.2.3.1 shows that over the frequency range used for the STC rating (125 Hz to 4000 Hz), the loss factors tend to be above 0.03 and the loss factor averaged across the frequency range of interest for each element is above 0.03. For the calculation of the ASTC rating using the Detailed Method, the effect of edge conditions may be ignored for building elements with structural loss factors greater than 0.03 which greatly simplifies the calculation of the ASTC rating for constructions which include NLT assemblies.

2.2.4 Bending Wavenumbers for the NLT Assemblies

The horizontal and vertical wavenumbers for bending waves travelling in the NLT assemblies were measured as a function of frequency following the procedure detailed in [12]. A Scanning Laser-Doppler Vibrometer (SLDV) was used to measure the surface velocity at 21 equally spaced points, each for the horizontal and vertical direction. In the context of the NLT measurements, the horizontal direction was parallel to the lumber orientation and the vertical direction was perpendicular to the lumber orientation. The wavenumbers were measured only for the Bare NLT89 and the Bare NLT184 assemblies.

The measured wavenumbers for the Bare NLT89 and the Bare NLT184 assemblies are shown in Figure 2.2.4.1 and the numerical results are listed in Appendix A1.2. The data shows that the wave propagation properties in NLT elements are orthotropic, as the wavenumbers are very different between the horizontal and vertical direction. However, the wavenumbers in each direction are very similar for both measured elements, showing that there is little dependence on the element thickness.

Figure 2.2.4.1
Comparison between the measured wavenumbers for the Bare NLT89 and Bare NLT184 assemblies.



2.3 Sound Transmission through DLT Wall and Floor Assemblies

The focus of this Section is on Dowel-Laminated Timber (DLT[5]) assemblies (wall or floor) without an added lining such as a gypsum board finish supported on some form of framing.

Each of the DLT assemblies was fabricated by joining individual pieces of planed lumber by press fitting hardwood dowels through predrilled holes perpendicular to the grain of the lumber as illustrated in Figure 2.3.1. The moisture differential between the dowels and the lumber causes to the hardwood dowels to swell, securing the lumber together to form a solid timber assembly. This report includes test results for three thicknesses of DLT wall or floor assemblies which are listed in Table 2.3.1.

Figure 2.3.1:
A DLT assembly with a shear membrane of 13 mm thick plywood mechanically attached to one side of the laminated assembly

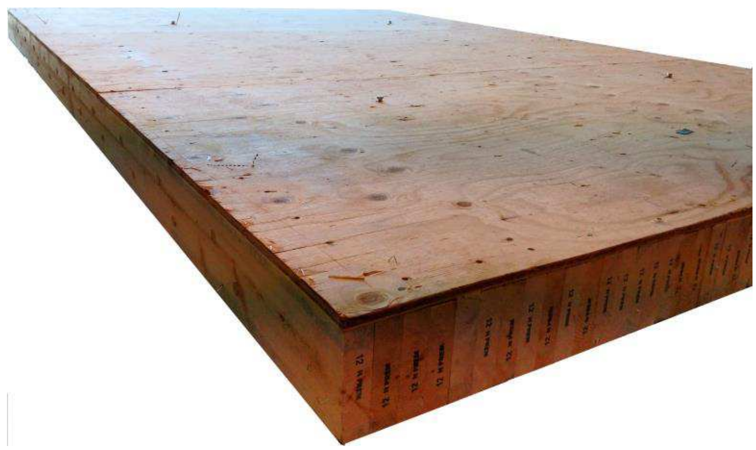


Table 2.3.1: Physical details of the three square-edged DLT assemblies evaluated in this report

DLT Designation	Common Timber Name	Mass / unit area (kg/m^2)	Fabrication
DLT89	2x4	44.4	Fabricated from 2x4 planed lumber of nominal cross-section 38 mm x 89 mm
DLT140	2x6	72.9	Fabricated from 2x6 planed lumber of nominal cross-section 38 mm x 140 mm
DLT186	2x8	95.9	Fabricated from 2x8 planed lumber of nominal cross-section 38 mm x 186 mm

NOTES:
a. All of the DLT assemblies considered for this Report also included a shear membrane of 13 mm thick plywood mechanically attached to one side of the laminated assembly.
b. In practice, the lumber is planed during the production of the DLT assemblies and the actual thickness of the DTL assemblies may be less than the nominal dimension (for example 86 mm instead of 89 mm).

While the transmission loss data provided in this Report is based on measurements conducted with DLT assemblies with the specific parameters listed in Table 2.3.1, the data may also be used as a conservative estimate for DLT assemblies of similar construction but greater thickness or higher mass. For example, a DLT wall which is more than 186 mm thick or has a mass per area of more than 96 kg/m^2 can in general be expected to have an STC rating at least as high as the value reported in this Report for DLT186.

The remainder of Section 2.3 is arranged as follows:

- **Section 2.3.1** focuses on the sound transmission loss of the base DLT assemblies without linings other than the PLY13 shear membrane fastened to one face.
- **Section 2.3.2** discusses the changes in the sound transmission loss due to adding various linings on one side or both sides of the single-leaf DLT assemblies.
- **Section 2.3.3** presents results for structural loss factors of the unlined DLT assemblies
- **Section 2.3.4** presents the bending wavenumbers of the DLT assemblies

2.3.1 DLT Walls and Floors without Linings

For the calculation of the ASTC rating of buildings comprised of DLT assemblies, it is important to determine the sound transmission loss of the sealed DLT assemblies without leakage. The transmission loss of the sealed DLT assemblies is also used as a conservative reference case for determining the change in the transmission loss due to adding linings to the DLT assemblies.

As with the other mass timber assemblies considered for this study, the appropriate Bare (with leakage) and the Base (no leakage) assemblies needed to be determined for the DLT assemblies. Based on the investigation discussed in detail below, it was concluded that the Bare assembly would be the DLT assembly with a plywood shear element on one side.

Note that:

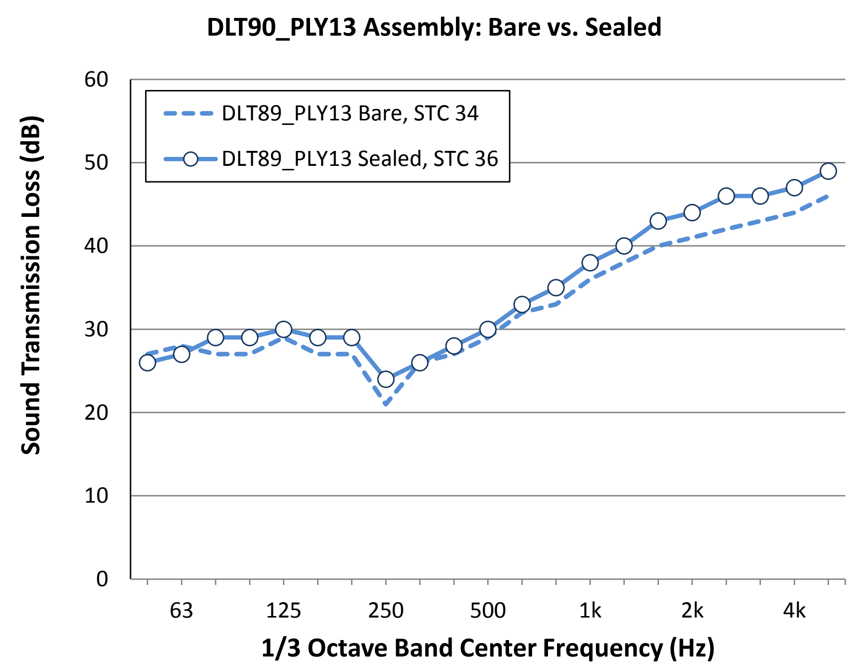
- The third-octave-band transmission loss data for the unsealed DLT assemblies with a plywood shear membrane on one side, referred to as the **Bare** assembly is shown in Appendix A1.3.
- The third-octave-band transmission loss data for the sealed DLT assemblies with a plywood shear membrane on one side, referred to as the **Base** assembly is shown in in Appendix A1.3.

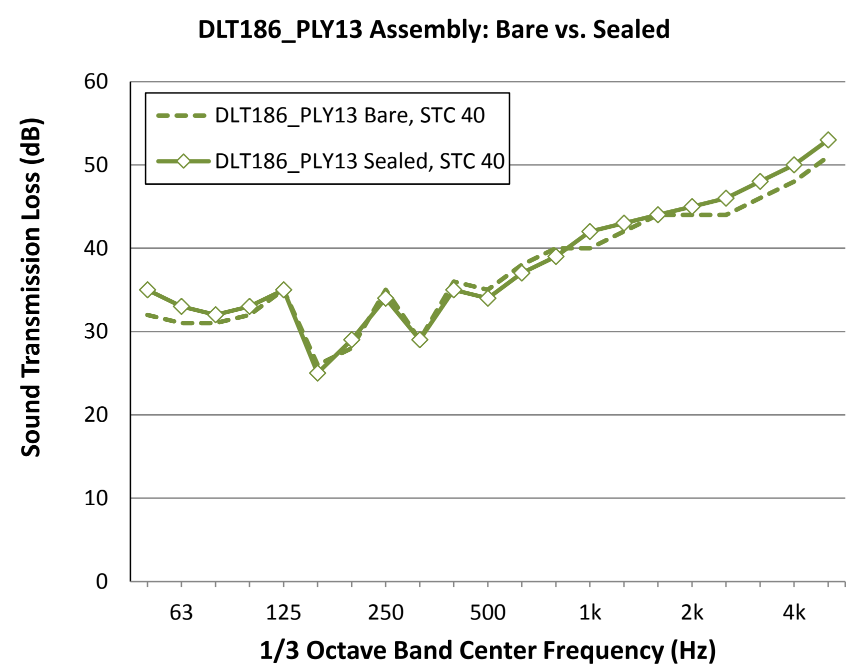
Each of the bare DLT assemblies listed in Table 2.3.1 was first tested with both surfaces of the assembly bare and then tested again with one or both of the surfaces parged with a thin layer of cementitious material that sealed the DLT assembly to stop the leakage of sound through the seams of the assembly. Figure 2.3.1.1 presents the direct sound transmission loss of the DLT89_PLY13 and DLT186_PLY13 both bare and sealed.

Figure 2.3.1.1
Comparison between the direct sound transmission loss for the bare and sealed DTL assemblies.

The upper graph shows transmission loss data for the bare and sealed DLT89_PLY13 assembly.

The lower graph shows transmission loss data for the bare and sealed DLT186_PLY13 assembly.





There are three main takeaways from the data in the figure:

- The transmission loss curve for the Bare DLT89_PLY13 assembly is below the transmission loss curve of the sealed DLT89_PLY13 assembly over the frequency range of interest.
- The effect of sealing the DLT assemblies becomes smaller as the thickness of the DLT assembly increases. For the DLT 186_PLY13 which was the thickest assembly evaluated for this study, the differences in the transmission loss curves of the Bare and sealed cases differed by 2 dB over the frequency range of interest and the STC ratings were the same.
- The effect of leakage is much smaller for DLT assemblies than that observed for the NLT assemblies presented in the preceding Section 2.2

The sound transmission loss data are shown in Figure 2.3.1.2 for the sealed base DLT assemblies of the three thicknesses evaluated in this study.

The magnitude and the frequency of the peaks and dips shown in the figure below 500Hz are not consistent from one thickness of DLT to another. The dips are more pronounced than the corresponding peaks evident in the low frequency “plateau region” of the transmission loss curves presented for CLT assemblies in Section 2.1 of this Report. The peaks and dips reflect the effect of the very different stiffness of the DLT assemblies in the directions parallel and perpendicular to the long axis of the timber elements of the DLT assembly.

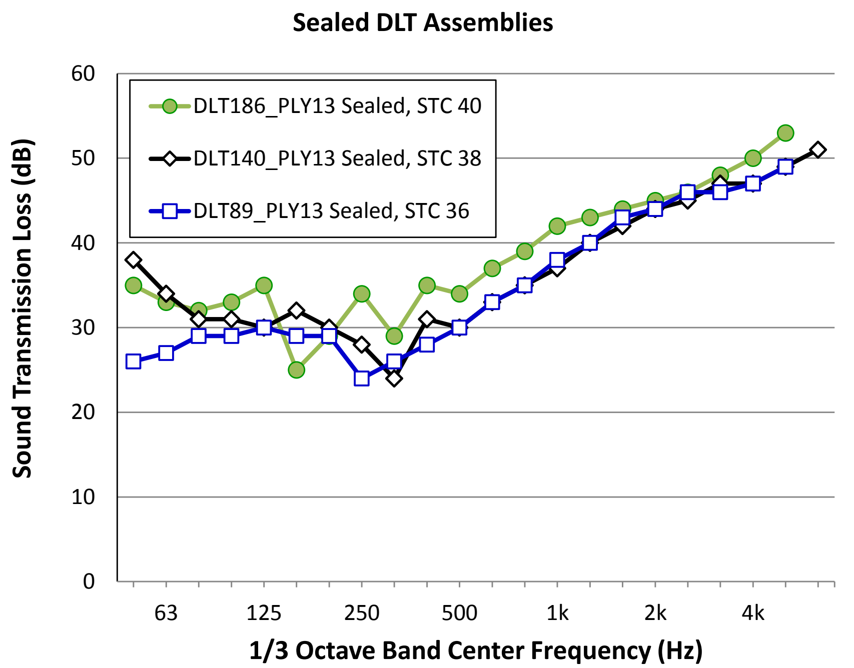
Despite the peaks and dips at the lower frequencies, one can still discern the division of the transmission loss curves into two regions: a region below 500 Hz where the curves show a plateau with dips due to the various critical frequencies and a region above about 500 Hz where the curve steadily increases with increasing frequency.

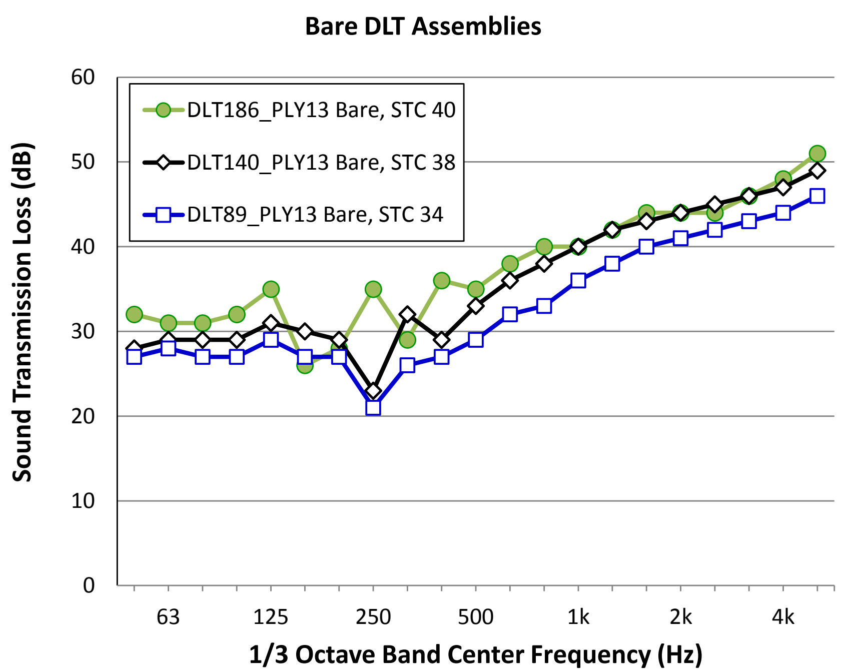
The STC ratings and one-third octave band direct sound transmission loss values for all the tested DLT assemblies are presented in the tables in Appendix A1.3.

Figure 2.3.1.2
Comparison between the direct sound transmission loss for the bare and sealed DLT assemblies

The upper graph shows transmission loss data for the sealed DLT assemblies.

The lower graph shows transmission loss data for the bare DLT assemblies.





2.3.2 Adding Linings on DLT Wall or Floor Assemblies

It is common practice, especially in residential buildings, to add finishing surfaces to the basic structural floor or wall assemblies to conceal both the bare structure surfaces as well as the building services such as electrical wiring, water pipes and ventilation ducts. The finishing on walls or ceilings is commonly comprised of gypsum board panels, framing used to support the gypsum board panels and sound absorptive material in the inter-framing cavities between the gypsum board and the face of the basic structural floor or wall assemblies. On floors, the finish may include toppings such as concrete or a floating floor as well as flooring such as hardwood or tiles. These elements are described in ISO 15712-1 as “linings” or “liners” or “layers” or “coverings”. The term “linings” is used in this Report.

Two methods of characterizing the change in the direct sound transmission loss of the DLT assemblies by adding a lining are used in this Report. The first method is the change in the transmission loss (ΔTL) which is calculated from the difference between the transmission loss values measured with the lining installed on the Base DLT assembly and the transmission loss values of the Base DLT assembly without a lining. The Base DLT assembly is the DLT assembly with the shear membrane attached to one side without leakage. The ΔTL is used for the calculation of the ASTC rating using the Detailed Method.

The second method of characterizing the change in the direct sound transmission loss of the DLT assemblies by adding a lining is a single-number rating called the ΔSTC. The ASTM standards do not define a rating like ΔSTC, but there is a counterpart in the ISO standards called ΔR_W. The calculation of the ΔSTC rating is adopted from the ISO standard with modification as explained in Appendix A2 of this Report. The ΔSTC rating is used for the calculation of the ASTC rating using the Simplified Method.

The linings evaluated on DLT assemblies for this study are described in Tables 2.3.2.1 and 2.3.2.2. The ΔSTC ratings for these linings are listed in Table 2.3.2.3. The ΔTL values for the measured linings are provided in Appendix A1.3. Because of the strong similarity to the measured performance of corresponding linings on Base CLT assemblies, some results from Section 2.1 can also be used as conservative estimates, as discussed later in Section 2.3.2. Linings W02 and W06 were chosen to give the key points for relating linings tested on DLT assemblies to expected performance on CLT assemblies.

<u>Each Lining Code</u> shown in Tables 2.3.2.1 and 2.3.2.2 begins with “ΔTL-DLT” to indicate that the lining applied to a DLT assembly has an effect on the direct sound transmission loss through the lined assembly. In some cases the thickness of the DLT assembly is indicated (as in “ΔTL- DLT235”) if the result applies only to that thickness. For the three linings in Table 2.3.2.1 (W03, W04, and W05), the code does not indicate the thickness of the Base assembly because these are conservative estimates based on results for CLT assemblies (see Section 2.1) that are assumed to apply for all thicknesses of the DLT assemblies. The final part of the lining code is a letter (such as “W” to indicate a wall lining or “F” for a floor lining) followed by a unique number used to identify the lining in the table of ΔSTC ratings.

The Descriptive Short Code provides a compact physical description of each lining, which is used in the figure captions and in the examples throughout this Report. This code identifies the elements of the lining beginning at the exposed side and proceeding to the face of the supporting DLT wall or floor assembly. As detailed in the descriptions in Tables 2.3.2.1 and 2.3.2.2, each component of the lining is described by a short code. For example: G13 is gypsum board that is 12.7 mm thick, 2G13 is two connected G13 layers, and WFUR38 is a 38 mm x 38 mm wood furring. The distance between components such as adjacent studs is indicated by a number in parentheses which is the distance (on centre) between the components in millimetres.

The spacing and type of fasteners are not stated in the tables, but they are assumed to conform to standard industry practice. Where sound absorbing material was included in a tested assembly, the code indicates the specific material that was tested, but applicability to other sound absorbing materials is assumed, as explained in the endnotes.

Table 2.3.2.1: Linings tested on the Base DLT wall assemblies. Linings W02 and W06 were chosen to give the key points for interpolating to relate other linings tested on the CLT assemblies to expected performance of the same linings on the DLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-DLT-W02	2G13_WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board[2] screwed to 38 mm x 38 mm wood furring strips (spaced 400 mm on center and mechanically attached to the face of the DLT) with 38 mm thick glass fiber batts[6] filling the spaces between the gypsum board and the DLT
ΔTL-DLT-W06	2G13_WS64(600)_GFB65_AIR13	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 mm x 38 mm wood studs (spaced 600 mm on center and offset 13 mm from the face of the DLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the DLT

NOTES:
a. For the notes in this table please see the corresponding endnotes
b. The linings listed for wall assemblies may also be used on ceilings.

Table 2.3.2.2: Linings tested on Base CLT Wall Assemblies (See Section 2.1) that could be used as conservative estimates for matching linings on DLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-DLT-W01	2G13	Two layers of 12.7 mm thick fire-rated gypsum board[2]
ΔTL-DLT-W03	2G13_WFUR38(600)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm on center and mechanically attached to the face of the DLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the DLT
ΔTL-DLT-W04	2G13_RC13(600)_ WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 13 mm resilient metal channels[3] (spaced 600 mm on center) that are screwed to 38 x 38 mm wood furring (spaced 400 mm on center and mechanically attached to the face of the DLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the DLT
ΔTL-DLT-W05	2G13_WFUR64(600)_GFB65	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood furring (spaced 600 mm on center and mechanically attached to the face of the DLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the DLT

NOTES:
a. For the notes in this table please see the corresponding endnotes
b. The linings listed for wall assemblies may also be used on ceilings.

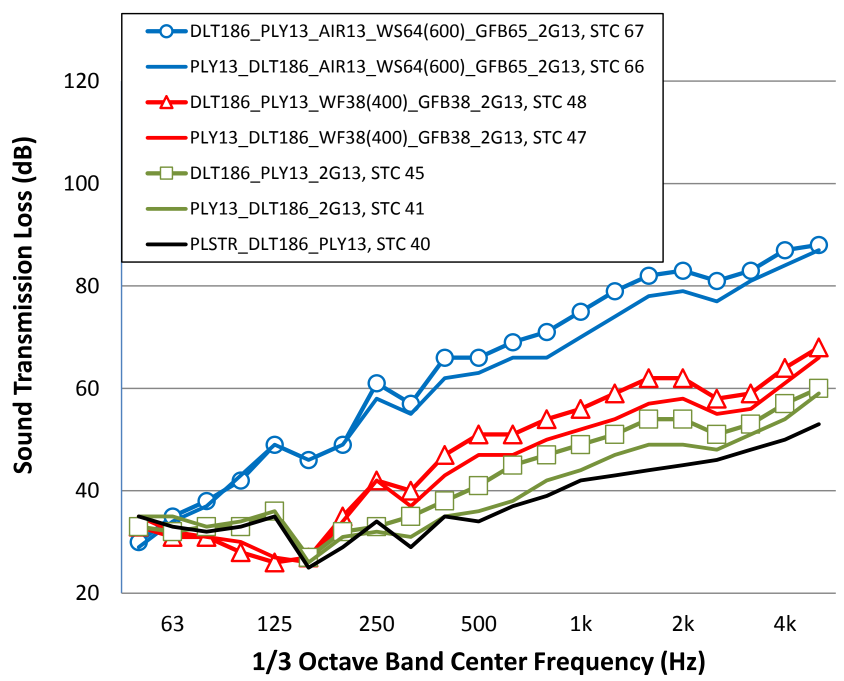
Measured Change ΔTL due to Linings on DLT Assemblies

The trends in the sound transmission loss results when linings are added to the DLT assemblies are presented and discussed in this Section.

Linings W02 and W06 were chosen to give the key points for relating linings tested on the CLT assemblies to the expected performance on the DLT assemblies. Each lining was tested with the lining applied on only one side of the Base DLT assembly which is comprised of the DLT and the shear membrane fixed on one side. Because the Base assembly is asymmetric (with a shear membrane mechanically attached on one side of the DLT assembly) two configurations for each lining were tested. The first configuration included the lining applied on the same side as the plywood shear membrane and the second configuration had the lining applied on the opposite side from the plywood shear membrane.

A comparison of the sound transmission loss curves for two linings (each installed first on the plywood side and then the opposite side of a Base DLT_PLY13 assembly is presented in Figure 2.3.2.1.

Figure 2.3.2.1: Comparison of the transmission loss curves for the DLT186_PLY13 assembly with linings applied on either the plywood side or the bare side of the assembly.



There are three main takeaways from the data presented in Figure 2.3.2.1:

- The transmission loss of the assembly with linings is determined in part by which side of the assembly with the plywood shear membrane the lining is attached.
- A higher STC rating is achieved if the lining is mounted on the same side as the plywood shear membrane. The same trend was observed for NLT assemblies in Section 2.2.

In order to prevent confusion when the linings are used on DLT assemblies in practice and for compatibility with the method of calculating the change in the transmission loss due to the addition of linings, the structural assemblies should be symmetrical and the effect of adding a lining should be the same when it is added on either side. To work within that framework, some conservative simplifications were made in the process for calculating the change in the sound transmission loss (ΔTL) due to the addition of the linings:

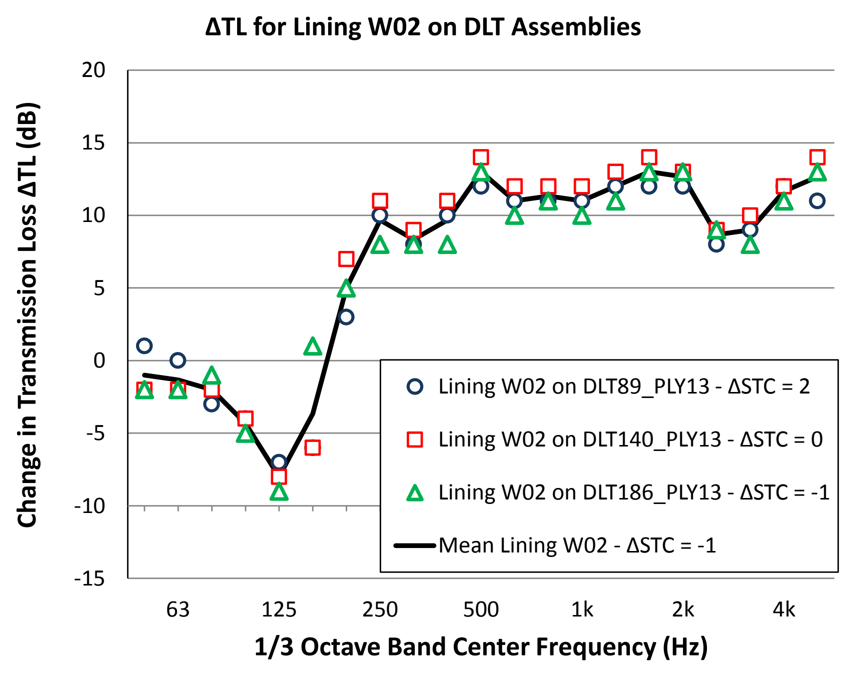
- The Base DLT assembly comprised of the DLT assembly and the shear membrane is treated as acoustically symmetric, despite the shear membrane attached on one side.
- The lower of the transmission loss values for the lining applied on each side of the DLT assembly was used to calculate the ΔTL value to remove the effect of whether the plywood is on the same side as the lining or the opposite side. This gives the correct result if the same lining is on both sides, and permits use of the Simplified Method for the calculation of the ASTC rating.

The results may be applied as follows:

- The averaged one-third octave band changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the DLT assemblies are given in Appendix A1.3. The ΔTL data is needed for the calculation of the ASTC rating using the Detailed Method as presented in Report RR-331 and Chapter 4 of this Report.
- The corresponding single-number ΔSTC ratings for each lining are given in Table 2.3.2.3 of Section 2.3.2. The ΔSTC ratings are needed for the calculation of the ASTC rating using the Simplified Method as presented in Report RR-331 and in Chapter 4 of this Report.

The values of ΔTL derived from the measurements for the W02 lining (2G13_WFUR38(400)_GFB38) installed on the DLT assemblies are presented in Figure 2.3.2.2. There is some scatter in the results, but for the most part, the data points are within the range of the experimental uncertainty.

Figure 2.3.2.2: Change in the transmission loss (ΔTL) due to the addition of the W02 lining on the Base DLT assemblies of different thicknesses.

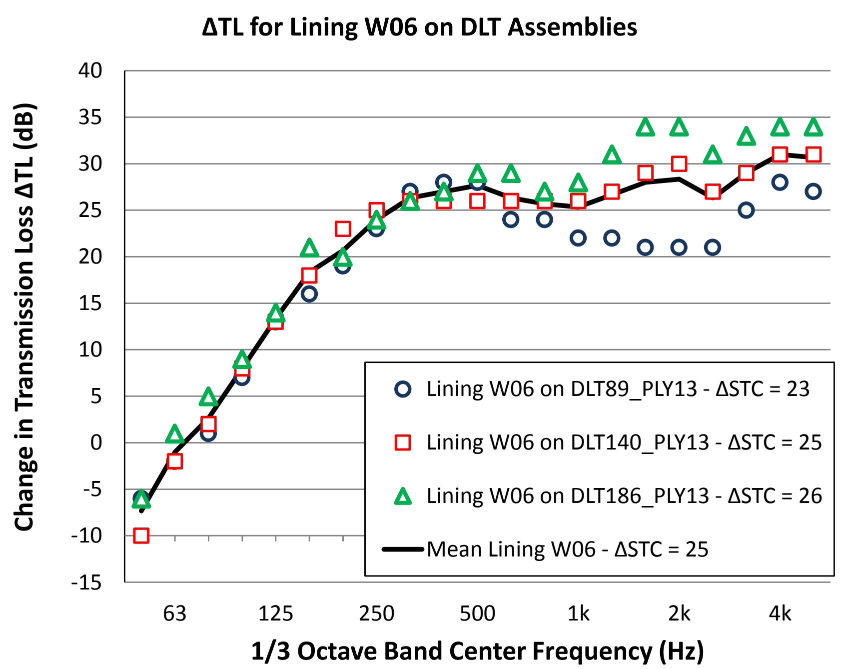


The ΔTL curves for lining W02 show similar trends for all of the thicknesses of the DLT assemblies with a well-defined mass-air-mass resonance at the 125 Hz one-third octave band and the gypsum board coincidence dip near the 2500 Hz one-third octave band. Note that due to the mass-air-mass resonance dip, the use of lining W02 negatively affects the transmission loss of the DLT assembly when it is applied.

For the three DLT thicknesses that were tested, the full set of ΔTL values are listed in Appendix A1.3, and the ΔSTC ratings are presented in Table 2.3.2.3.

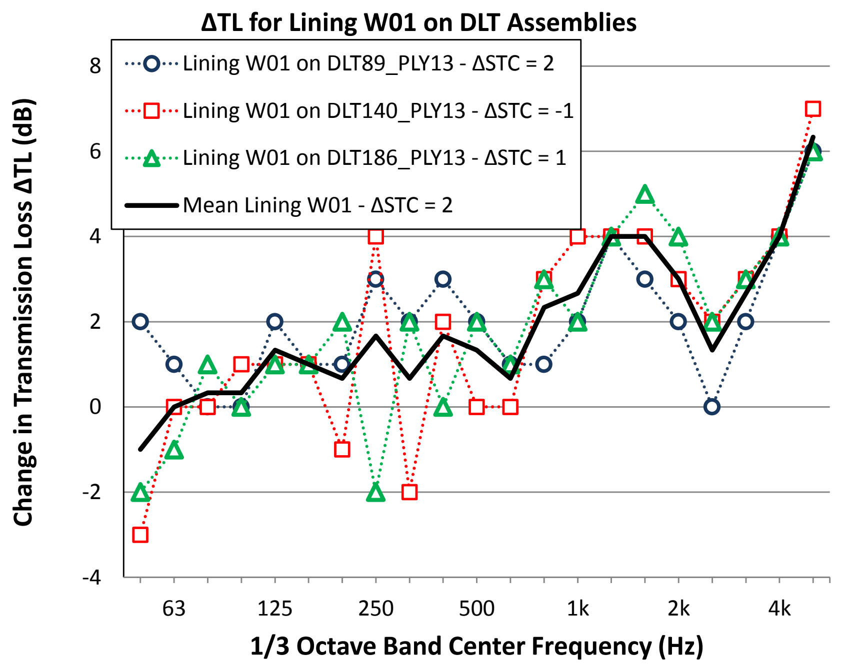
The values of ΔTL derived from the measurements for the W06 lining (2G13_WS64(600)_GFB65_AIR13) are presented in Figure 2.3.2.3. The full set of ΔTL values for the one-third octave bands are listed in Table A1.3.2 in Appendix A1.3.

Figure 2.3.2.3: Change in the transmission loss (ΔTL) due to the addition of the W06 lining on the Base DLT assemblies of different thicknesses.



The ΔTL curves for this lining show similar trends for all of the DLT thicknesses, with the mass-air-mass resonance well below the frequency range of interest and the gypsum board coincidence dip at the 2500 Hz one-third octave band. In the region below 500 Hz that generally controls the STC rating, the scatter is generally consistent with expected experimental scatter, with the variation small enough so that a mean transmission loss curve provides a valid representation for all cases.

The lining W01 (two layers of G13 directly fastened to one side of the DLT assembly) was also tested on all three thicknesses of DLT assemblies and the results are given in Figure 2.3.2.4.

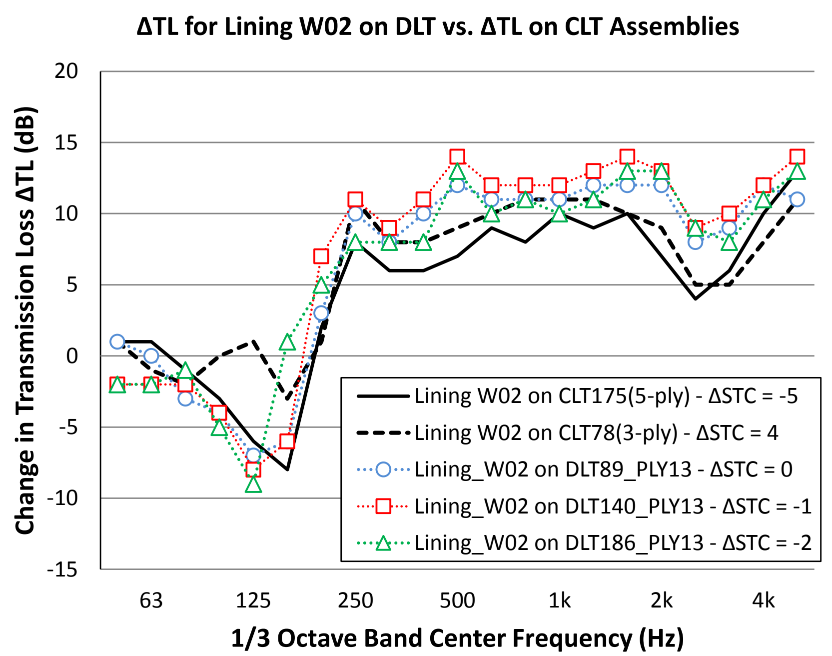
Figure 2.3.2.4: Change in the transmission loss (ΔTL) due to the addition of the W01 lining on the Base DLT assemblies of different thicknesses.	

The ΔTL curves for lining W01 show quite a bit of scatter below the 80 Hz third-octave band and again between the 160 and the 500 Hz third-octave bands. Overall, the transmission loss curves show similar trends over the frequency range of interest with a dip at 3150 Hz. The mean lining value is an average of the ΔTL curves for the three assemblies and the average tends to smooth out the scatter. The average of the ΔTL curves was used to calculate the mean ΔSTC rating.

Comparison of Linings Tested on DLT and CLT assemblies

The similarities in the ΔTL curves presented in Figures 2.3.2.2 to 2.3.2.4 suggest that it is reasonable to use the mean ΔTL values to characterize each of the linings on all of the thicknesses of the DLT assemblies. The results in the figures are more consistent between thicknesses than the results of applying the identical linings on the CLT or NLT assemblies where the variation in the ΔTL values for lining W02 resulted in a strong variation in the ΔSTC ratings. The ΔTL values for lining W02 installed on the DLT assemblies are compared with the results when the same lining was added on the CLT assemblies in Figure 2.3.2.5.

Figure 2.3.2.5: Change in the transmission loss (ΔTL) due to the addition of the W02 lining on the Base DLT and CLT assemblies of different thicknesses.

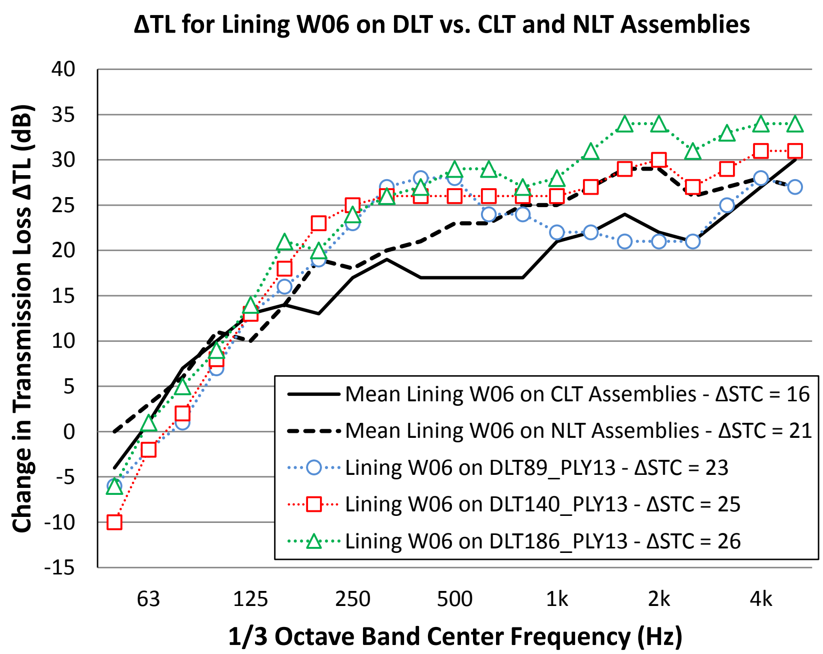


For lining W02, the strong variation in the ΔSTC ratings versus thickness and weight of the layered timber assemblies results from the method of calculating the STC rating which can be limited by a sharp dip in the transmission loss curve. For lining W02, the sharp dip evident in the transmission loss and ΔTL results for lining W02 in the 125 and 160 Hz one-third octave bands is caused by a mass-air-mass resonance around the 125 Hz one-third octave band. The dip results in negative values for the ΔTL in the one-third octave bands at and below 160 Hz meaning that the addition of the linings decreases the transmission loss of the assembly. In the case of the DLT assemblies, all of the DLT assemblies showed a similar dip in the 125 Hz one-third octave band, resulting in less of a difference in the ΔSTC ratings compared to the same lining applied to the CLT assemblies.

When the mass-air-mass resonance is shifted to a lower frequency by increasing the depth of the cavity between the gypsum board and the timber assembly (as for Lining W06), then the resonance and its adverse effect on the STC ratings are reduced as shown in Figure 2.3.2.6.

Figure 2.3.2.6 compares the results for lining W06 installed on the DLT and CLT assemblies. There are strong similarities in the frequency dependence of the individual curves, but the ΔTL values for the DLT assemblies tend to be higher than the ΔTL values for the CLT assemblies, especially above the 200 Hz one-third octave band.

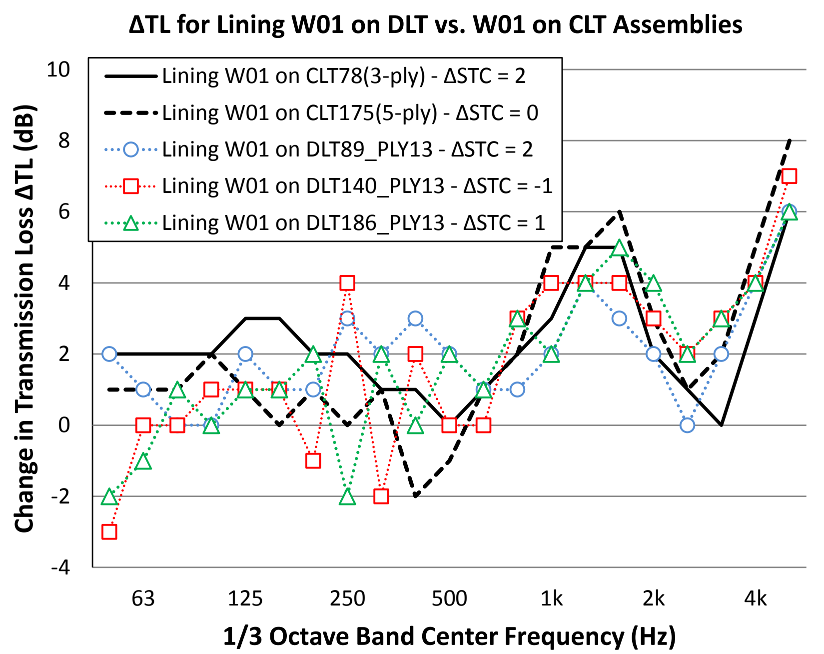
Figure 2.3.2.6: Change in the transmission loss (ΔTL) due to the addition of the W06 lining on the Base DLT, NLT and CLT assemblies of different thicknesses.



<u>For Lining W06</u>, the variation in ΔTL with the thickness of the DLT assembly is small over most of the frequency range of interest and there is no consistent trend in the ΔSTC rating for different thicknesses of the DLT assemblies. It is reasonable to use a mean value of the ΔSTC rating for lining W06 for all thicknesses of DLT assemblies when calculating the ASTC rating.

A comparison of the improvement due to the installation of lining W01 (two layers of G13 directly fastened to one side of the DLT assembly) on the DLT and CLT assemblies is presented in Figure 2.3.2.7.

Figure 2.3.2.7: Change in the transmission loss (ΔTL) due to the addition of the W01 lining on the Base DLT and CLT assemblies of different thicknesses.



<u>For lining W01</u>, although ΔTL data for Lining W01 was available for only a few of the CLT specimens at the time this Report was published, it was tested on all thicknesses of the DLT assemblies. The general trends on DLT and CLT assemblies seem similar, but the improvement due to the lining is higher for the DLT assemblies above 300 Hz, and the ΔSTC ratings of the DLT specimens are slightly higher and more consistent. While it is reasonable to use the average ΔSTC rating for all thicknesses, it must be recognised that this value is currently based on an incomplete dataset, so comparisons with the corresponding CLT specimens should be treated as tentative.

For both Lining W02 and W06, the measured values of ΔTL consistently show similar frequency dependence when added to base assemblies of DLT or CLT assemblies, but are slightly higher when the linings are added to DLT assemblies.

This provides a reasonable basis for assuming that for linings W03, W04, and W05 (which were tested only on CLT assemblies but showed negligible variation with CLT thickness) the ΔSTC ratings obtained from the CLT data in Section 2.1 may also be used for those linings on DLT as credible but conservative estimates.

ΔSTC Ratings for Linings on DLT Assemblies

To characterize the change in the direct sound transmission loss due to adding a specific lining to a DLT assembly, a single-number rating called ΔSTC is introduced. ASTM does not define a rating like ΔSTC, but there is a counterpart (ΔR_W) in the ISO standards. The procedure used here is adapted from its ISO counterpart, as explained in Appendix A2.

Key points regarding the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed in Chapter 4.
- The ΔSTC ratings are calculated from the experimental data in this Report using the procedure described in Appendix A2. The ΔSTC ratings for the linings are given in Table 2.3.2.3, together with the intermediate calculation steps for each lining.
- Where the design intent is to leave the DLT assembly exposed on one side of a wall assembly, deviating from the standard ΔSTC calculation by using the ΔSTC rating calculated for a lining on only one side is justified, but for W02 the value for the chosen DLT thickness should be used.
- Readers of this Report can simply use tabulated ΔSTC ratings from Table 2.3.2.3 in calculations like those in Chapter 4, without any need to perform the calculations detailed in Appendix A2.

Table 2.3.2.3: ΔSTC ratings for linings on DLT wall or floor surfaces.

Lining Code	Lining Descriptive Code	Base DLT	ΔSTC
Wall Linings:			
ΔTL-DLT89-W01	2G13	DLT89	**2**
ΔTL-DLT140-W01	2G13	DLT140	**-1**
ΔTL-DLT186-W01	2G13	DLT186	**1**
ΔTL-DLT-W01	2G13	DLT Mean	**2**
ΔTL-DLT89-W02	2G13_WFUR38(400)_GFB38	DLT89	**0**
ΔTL-DLT140-W02	2G13_WFUR38(400)_GFB38	DLT140	**-1**
ΔTL-DLT186-W02	2G13_WFUR38(400)_GFB38	DLT186	**-2**
ΔTL-DLT-W02	2G13_WS64(600)_GFB65_AIR13	DLT Mean	**-1**
ΔTL-DLT89-W06	2G13_WS64(600)_GFB65_AIR13	DLT89	**23**
ΔTL-DLT140-W06	2G13_WS64(600)_GFB65_AIR13	DLT140	**25**
ΔTL-DLT186-W06	2G13_WS64(600)_GFB65_AIR13	DLT186	**26**
ΔTL-DLT-W06	2G13_WS64(600)_GFB65_AIR13	DLT Mean	**25**
Wall Lining Estimates from Linings on Base CLT:			
ΔTL-DLT-W03 [d]	2G13_WFUR38(600)_GFB38	Estimate, see note d	**8**
ΔTL-DLT-W04 [d]	2G13_RC13(600)_WFUR38(400)_GFB38	Estimate, see note d	**15**
ΔTL-DLT-W05 [d]	2G13_WFUR64(600)_GFB65	Estimate, see note d	**6**

NOTES:
a. See Appendix A2 for an explanation of the calculation of the ΔSTC ratings.
b. The ΔTL values were determined using the Base DLT as the reference case without lining(s) and these values were combined with a reference curve as described in Appendix A2.
c. The ΔSTC ratings should be appropriate for all walls or floor/ceilings with a core of DLT.
d. For W03, W04, and W05, each listed value was determined for application on a Base CLT assembly but gives a conservative estimate of the ΔSTC rating on the Base DLT.

2.3.3 Structural Loss Factors for DLT Wall or Floor Assemblies

The structural loss factors required for the calculation of the ASTC rating using the Detailed Method were calculated from the structural reverberation times measured for each DLT assembly according to the standard, ISO 10848. Following ISO 10848, the structural loss factor η_{total} was calculated from the measured structural reverberation time such that:

$$\eta_{total} = \frac{2.2}{fT_s} \quad \text{Eq. 2.2.3.1}$$

where f is the one-third octave band frequency in Hz and T_s is the structural reverberation time per one-third octave band in seconds. The resulting loss factors are compared in Figure 2.3.3.1.

Figure 2.3.3.1

Structural loss factors, η_{total} for the three DLT base assemblies with plywood shear bracing presented in this Report.

These loss factors were calculated from the structural reverberation times which are tabulated in Appendix A1.3.

The average values indicate that over much of the frequency range the loss factors tend to be above 0.03, which is the threshold for ignoring edge corrections when using the Detailed Method to calculate the ASTC rating.

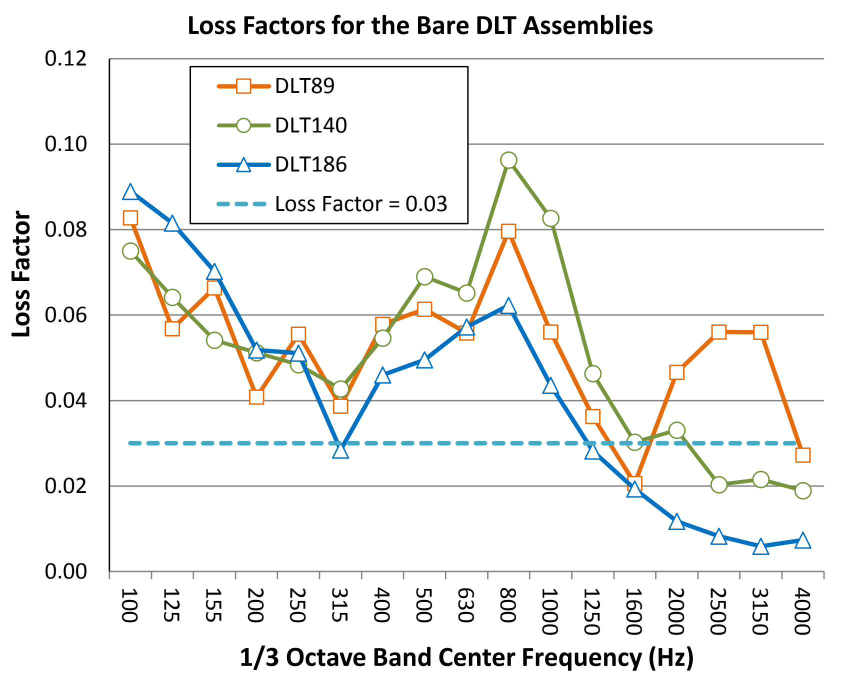


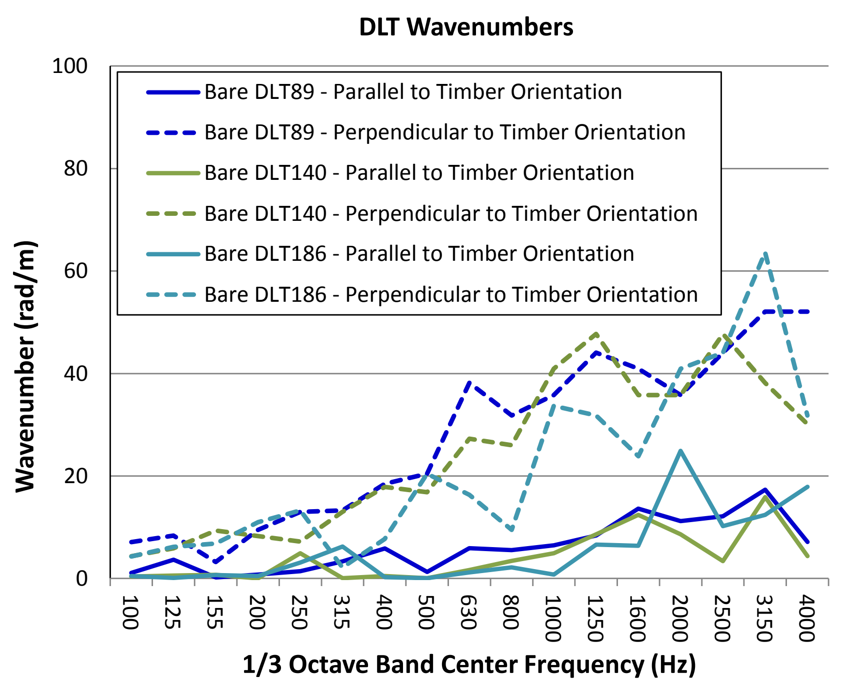
Figure 2.3.3.1 shows that over the frequency range used for the STC rating (125 Hz to 4000 Hz), the loss factors tend to be above 0.03 and the loss factor averaged across the frequency range of interest for each element is above 0.03. For the calculation of the ASTC rating using the Detailed Method, the effect of edge conditions may be ignored for building elements with structural loss factors greater than 0.03 which greatly simplifies the calculation of the ASTC rating for constructions which include DLT assemblies.

2.3.4 Bending Wavenumbers for the DLT Wall or Floor Assemblies

The horizontal and vertical wavenumbers for bending waves travelling in the DLT assemblies were measured as a function of frequency following the procedure detailed in [12]. A Scanning Laser-Doppler Vibrometer (SLDV) was used to measure the surface velocity at 21 equally spaced points, each for the horizontal and vertical direction. In the context of the DLT measurements, the horizontal direction was parallel to the timber and the vertical direction was perpendicular to the timber. The wavenumbers were measured for the Bare DLT89, the Bare DLT140 and the Bare DLT186 assemblies.

The measured wavenumbers for the DLT assemblies are shown in Figure 2.3.4.1 and the numerical results are listed in Appendix A1.3. The data shows that the wave propagation properties in DLT elements are orthotropic, as the wavenumbers are very different between the horizontal and vertical direction. However, the wavenumbers are very similar for all measured elements, showing that there is no dependence on the element thickness.

Figure 2.3.4.1
Comparison between the measured wavenumbers for the Bare DLT89, Bare DLT140 and Bare DLT186 assemblies.



3 Flanking Sound Transmission in CLT Constructions

One of the inputs required for the calculation of the transmission loss along flanking paths is the vibration reduction index (K_{ij}) which describes the vibrational power transmission through a junction between structural elements, normalized to make it an invariant quantity. The K_{ij} values are specific to the assemblies which are joined at a junction and the connections between them. The standard, ISO 10848 describes a procedure for determining the K_{ij} values for wall-wall junctions or for wall-floor/ceiling junctions through measurements made on full scale mock-up junctions.

This chapter presents the results of experiments made on a series of full scale mock-up junctions between CLT wall assemblies and between CLT wall and floor assemblies in accordance with the standard, ISO 10848. The mock-up junctions included a set of full-size wall-wall and wall-floor junctions as shown in Figure 3.1 (a) and (b) and in Figure 3.2 (a) and (b). Both cross-junctions (X-junctions) as well as T-junctions were evaluated for the vertical (wall-wall) and for the horizontal (floor-wall) junctions.

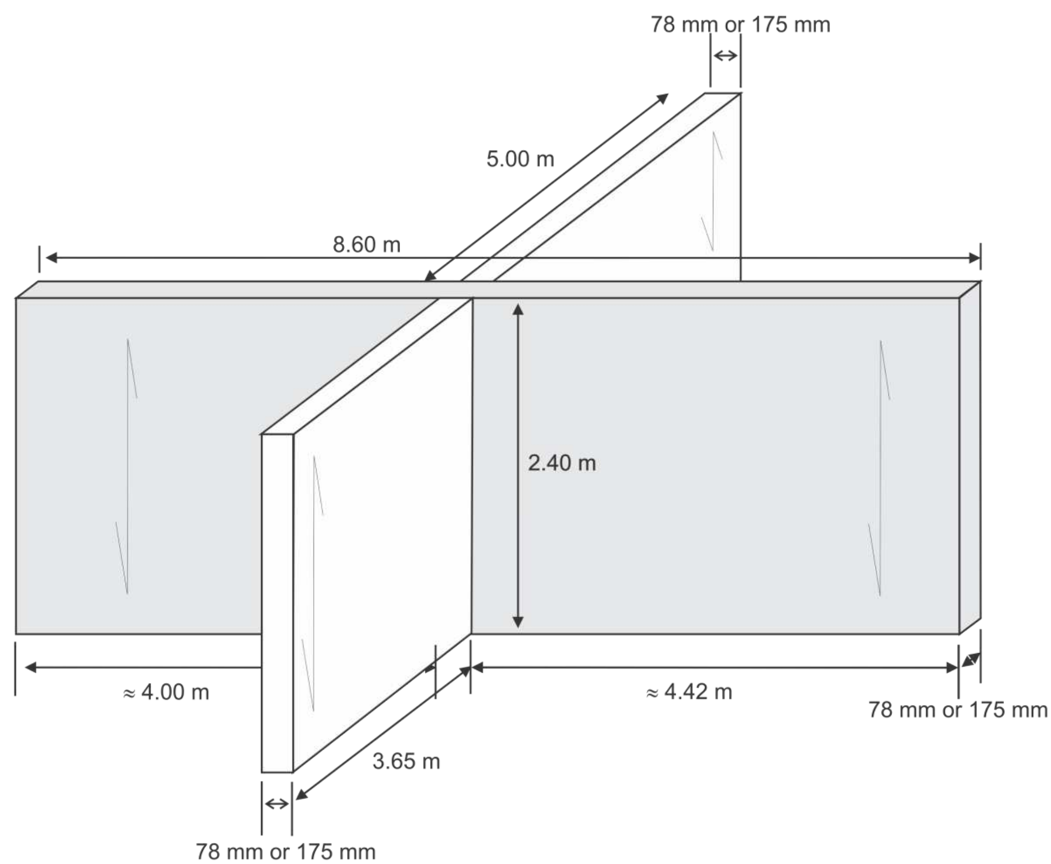


Figure 3.1(a): Dimensions of the vertical (wall-wall) junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for wall-wall cross- (X-) junctions

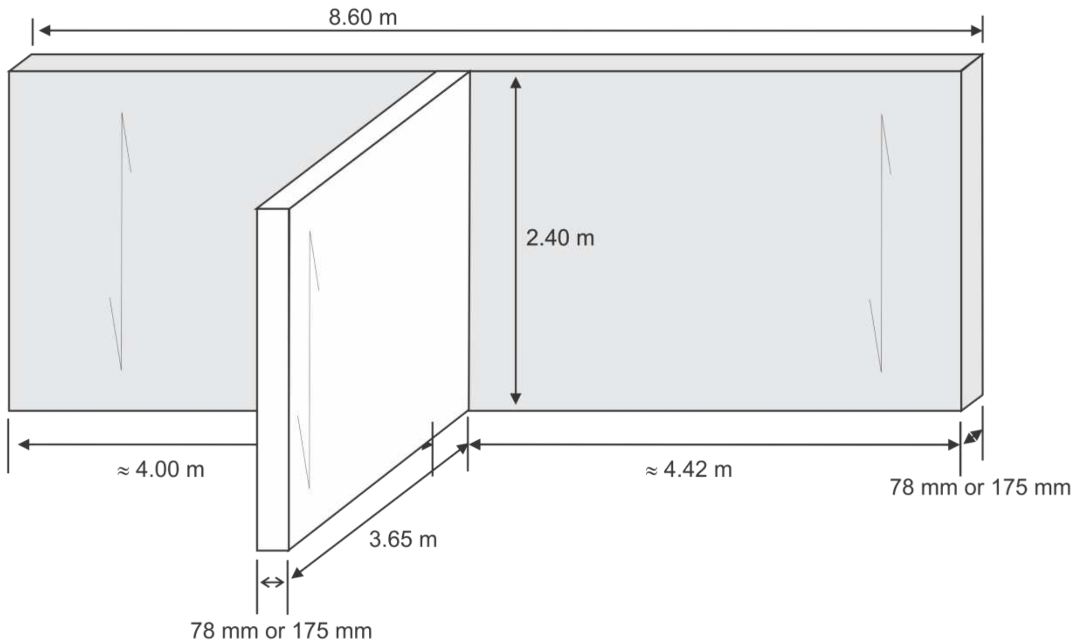


Figure 3.1(b): Dimensions of the vertical (wall-wall) junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for wall-wall T-junctions

The dimensions of the mock junctions were in accordance with the requirements of ISO 10848. For the vertical junctions, the length of all coupled wall assemblies differed by at least 10% to avoid the coupling of resonant modes. For the horizontal junctions, the length of the floors differed by 10%, but the height of the two walls were the same which is typical of the situation in real buildings.

The wall-wall junctions were free-standing structures which stood on a massive, rigid concrete floor. To further suppress structure-borne sound transmission from the walls into the rigid floor and back into the other wall, rubber pads were placed between the CLT wall assemblies and the concrete floor.

For the floor-wall junctions, the lower CLT wall was also placed on rubber pads on the rigid concrete floor. The CLT floor was then placed on top of the lower CLT wall and was supported by adjustable scaffolding at the free edges with rubber pads between the scaffolding and the surface of the CLT assembly. The upper wall was free standing on the CLT floor. To simulate compression forces that act on the junction in real buildings due to the dead load of upper stories, a steel loading beam spanned over the top wall on which a static force of 8000 lbs could be applied by four hydraulic cylinders (see Figure 3.3). This load is sufficient to compress voids in the junction that could change the junction mechanics. Initial tests showed that the measured K_{ij} values did not change significantly when the applied load was increased from 4000 lbs to 8000 lbs.

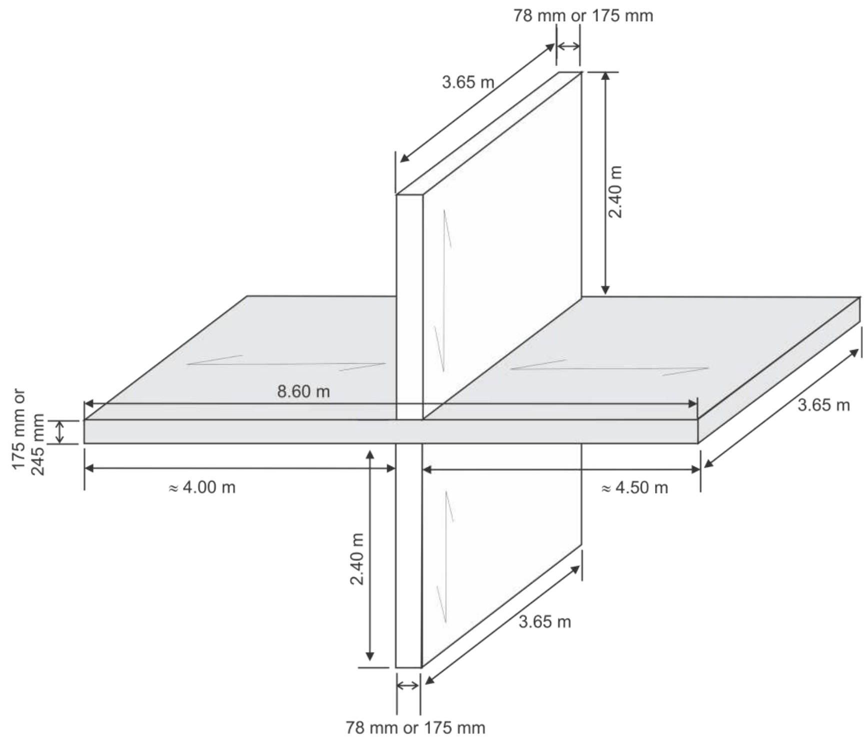


Figure 3.2(a): Dimensions of the horizontal floor-wall junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for floor-wall cross- (X-) junctions

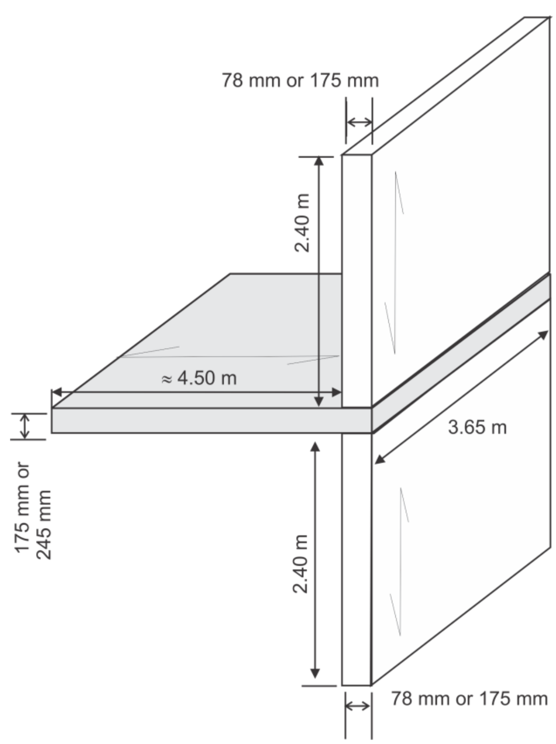


Figure 3.2(b): Dimensions of the horizontal floor-wall junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for floor-wall T-junctions

Figure 3.3 shows one of the tested floor-wall junctions. A static load was applied to the top of the upper wall by the hydraulic cylinders (shown in red) located between the CLT wall and the metal frame.

Figure 3.3: CLT floor-wall junction mock-up with loading frame and measurement system

The vibration reduction index K_{ij} for elements with internal loss factors greater than 0.03 is defined in Equation 3.1 as a function of the direction-averaged velocity level difference $\overline{D_{v,ij}}$ between the elements i and j, with the junction length l_{ij}, the reference length l_0 = 1 m, and the areas S_i and S_j of the coupled elements.

$$K_{ij} = \overline{D_{v,ij}} + 10 \cdot \log_{10} \frac{l_{ij} \cdot l_0}{\sqrt{S_i S_j}} \quad , \qquad with\ \overline{D_{v,ij}} = \frac{D_{v,ij} + D_{v,ji}}{2} \qquad \text{Eq. 3.1}$$

The average $\overline{D_{v,ij}}$ is the mean of the velocity level differences of $D_{v,ij}$ and $D_{v,ji}$ that are measured in opposite transmission directions. For $D_{v,ij}$ element "i" is excited and the difference of the velocity levels on both coupled elements "i" and "j" is measured, while for $D_{v,ji}$ element "j" is excited and the difference of the velocity levels on both coupled elements is measured.

The velocity levels were measured with sixteen accelerometers connected to a 16-channel data acquisition system at the cross-junctions and with twelve accelerometers at the T-junctions. In both cases, four accelerometers were distributed randomly on each element in the area defined by ISO 10848. During the measurement, the velocity levels were measured simultaneously with all channels while one element of the junction was excited with a hammer. For the excitation, the so-called rain-on-the-roof method was applied where the source element was hit with repeated hammer blows in an approximately 1 m^2 area during a thirty second long measurement interval. Each of the coupled elements was excited in four different areas and for each excitation point four different accelerometer positions were used on all elements. In total the velocity levels were measured at sixteen positions on each element for every source element. The analysis of the measurement data was done in compliance with ISO 10848.

3.1 Junctions of CLT Floors with CLT Walls

The mean vibration reduction index (K_{ij}) values determined from each of the mock-up junctions between the CLT floor and wall assemblies are presented in the following tables. For each table:

- A generic description is given of the details of the wall and floor/ceiling assemblies and their connection.
- The general features of the junction are shown in a figure.
- Note that each cross-junction of wall and floor/ceiling assemblies can be viewed in several ways:
  (a) as the wall-floor junction between two side-by-side rooms above the floor,
  (b) as the wall-ceiling junction between two side-by-side rooms below the ceiling, and
  (c) as the junction of a flanking wall with the floor/ceiling assembly separating two rooms that are one-above-the-other.
- Each T-junction of wall and floor/ceiling assemblies involves only option (c).
- Junction cases (a) to (c) are presented in the rows below, with stylized drawings to identify the paths in each case, and the mean vibration reduction index (K_{ij}) values for each flanking path.
- The naming convention for the junctions follows a simple coding in four segments:
  - The first segment of the code indicates that the junction consists of CLT assemblies.
  - The second segment of the code indicates the junction type:
    - WF = wall-floor,
    - WC = wall-ceiling,
    - FW = floor-wall.
  - The third segment of the code indicates the nature of the junction itself:
    - the first letter (X or T) indicates junction geometry,
    - the second letter (a, b, c, etc.) indicates how the elements are attached at their junction.
  - The fourth segment of the code is a unique number for that junction detail.
- The mean vibration reduction index (K_{ij}) is presented as a single number rating. The procedure used to calculate the single-number rating of the vibration reduction index differs from the procedure outlined in ISO 15712-1. The standard states that: "If the values for the vibration reduction index depend on frequency, the value at 500 Hz may be taken as a good approximation, but the result can then be less accurate." Rather than follow this procedure, the single-number ratings for the vibration reduction indices were calculated as the average value of the nine one-third octave bands between 200 Hz and 1250 Hz, inclusive. The mean K_{ij} values are used in the calculation of the ASTC rating as described in Chapter 4.

Note that the floor-wall junctions were tested ***only*** for the cases where:

- The component lumber pieces of the face ply of the CLT floor assembly were perpendicular to the connected wall.
- The component lumber pieces of the face ply of the wall assembly were vertical.
- For cross-junctions, the CLT floor assembly was continuous across the junction.

These cases were considered to provide the worst case for sound transmission to the adjoining rooms, and therefore may be used as conservative estimates for cases where the orientation of the CLT or the connections differs.

Table 3.1.01: Transmission Paths

Wall assembly:

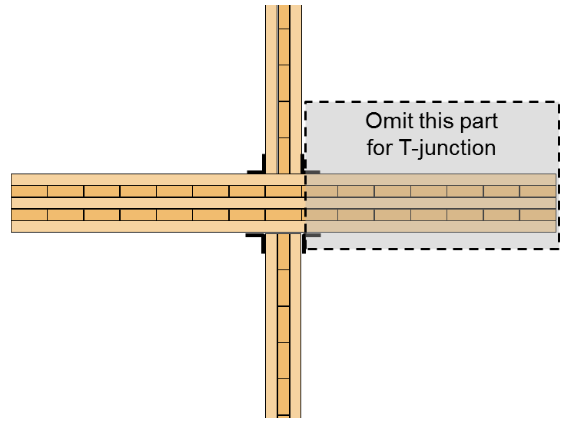
- CLT78(3)[1] assembly (78 mm thick, 42.4 kg/m²)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- CLT175(5)[1] assembly (175 mm thick, 91.4 kg/m²)

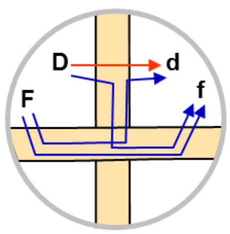
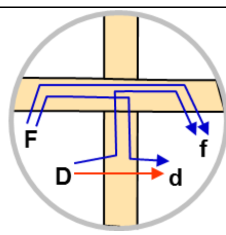
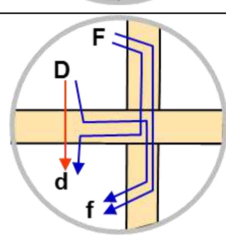
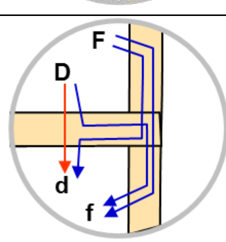
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction, but ends beyond the junction for the T-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall for X-junction and on one side of the wall for T-junction



Floor-Wall X-/T-junction for CLT constructions.

Vertical section, not to scale.

Junction	Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xa-01 Wall-Floor X-junction 	Ff	1.1
	Fd	10.5
	Df	10.5
CLT-WC-Xa-01 Wall-Ceiling X-junction 	Ff	1.1
	Fd	10.5
	Df	10.5
CLT-FW-Xa-01 Floor-Wall X-junction 	Ff	19.4
	Fd	10.5
	Df	10.5
CLT-FW-Ta-01 Floor-Wall T-junction 	Ff	15.7
	Fd	7.2
	Df	7.2

For the notes in this table please see the corresponding endnotes.

Table 3.1.02: Transmission Paths

(same as 3.1.01 except different wall connection)

Wall assembly:

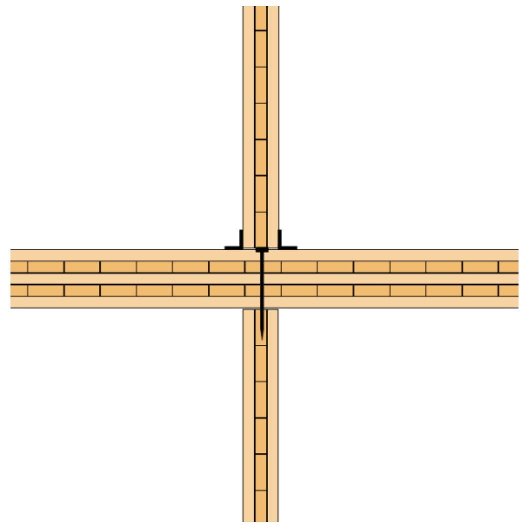
- CLT78(3)[1] (78 mm thick, 42.4 kg/m^2)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

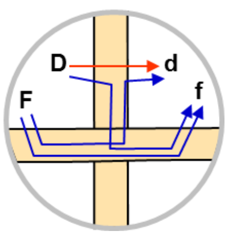
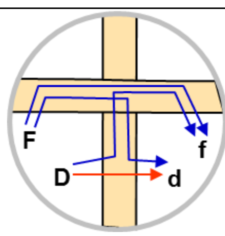
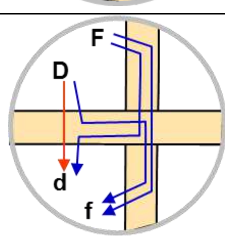
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Upper wall connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Lower wall connected using 280 mm self-tapping screws spaced 300 mm o.c. that pass through the floor/ceiling assembly into the core of the wall below



Floor-Wall X-junction for CLT constructions.

Vertical section, not to scale.

Junction	Diagram	Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xc-02 Wall-Floor X-junction	 	Ff Fd Df	0.7 9.5 9.5
CLT-WC-Xc-02 Wall-Ceiling X-junction	 	Ff Fd Df	0.7 13.8 13.8
CLT-FW-Xc-02 Floor-Wall X-junction	 	Ff Fd Df	21.4 9.5 13.8

For the notes in this table please see the corresponding endnotes.

Table 3.1.03: Transmission Paths

(same as 3.1.01 except different wall connections)

Wall assembly:

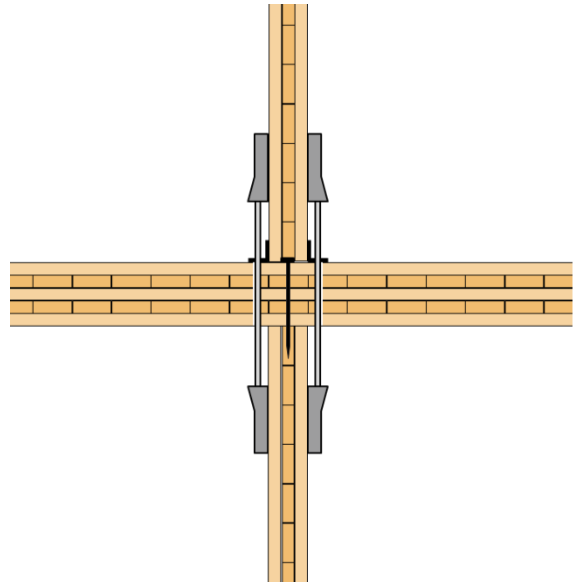
- CLT78(3)[1] (78 mm thick, 42.4 kg/m²)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m²)

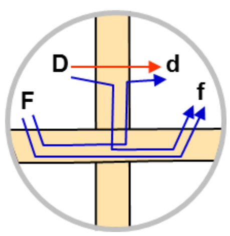
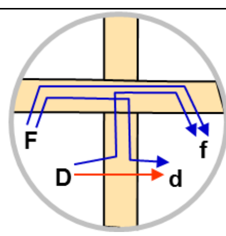
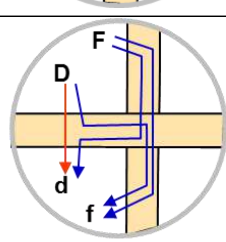
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Upper wall connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Lower wall connected using 280 mm self-tapping screws spaced 300 mm o.c. that pass through the floor/ceiling assembly into the core of the wall below
- Two hold-down brackets on each side of the wall, above and below the floor/ceiling



Floor-Wall X-junction for CLT constructions.

Vertical section, not to scale.

Junction		Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xb-03 Wall-Floor X-junction		Ff Fd Df	-2.1 7.6 7.6
CLT-WC-Xb-03 Wall-Ceiling X-junction		Ff Fd Df	-2.1 10.6 10.6
CLT-FW-Xb-03 Floor-Wall X-junction		Ff Fd Df	12.4 7.6 10.6

For the notes in this table please see the corresponding endnotes.

Table 3.1.04: Transmission Paths

Wall assembly:

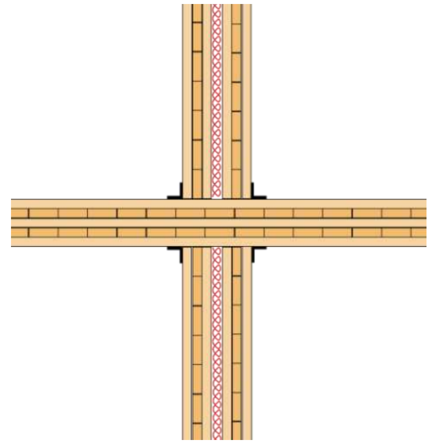
- Two leafs of CLT78(3)[1] with glass fibre batts[6] filling the cavity between the leafs
- Above and below the floor/ceiling assembly
- Combined 181 mm thick, 89.6 kg/m^2

Floor/ceiling assembly:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

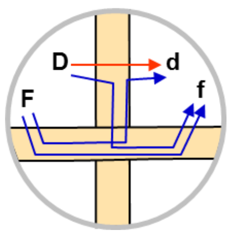
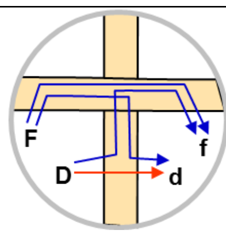
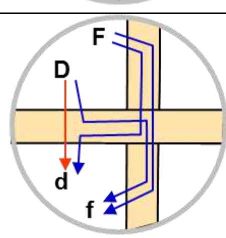
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall



Floor-Wall X-junction for CLT constructions.

Vertical section, not to scale.

Junction		Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xa-04 Wall-Floor X-junction		Ff Fd Df	1.8 13.0 13.0
CLT-WC-Xa-04 Wall-Ceiling X-junction		Ff Fd Df	1.8 13.0 13.0
CLT-FW-Xa-04 Floor-Wall X-junction		Ff Fd Df	19.5 8.2 8.2

For the notes in this table please see the corresponding endnotes.

Table 3.1.05: Transmission Paths

Wall assembly:

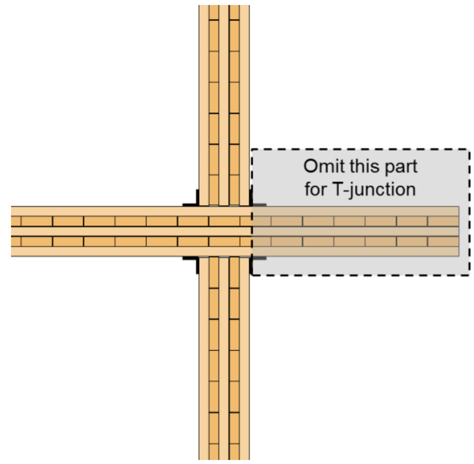
- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

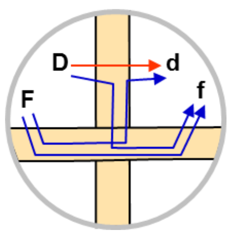
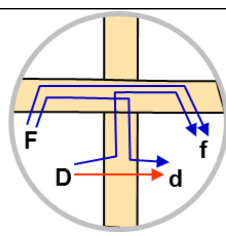
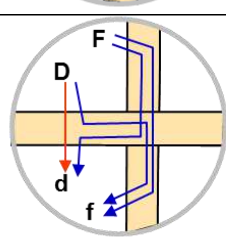
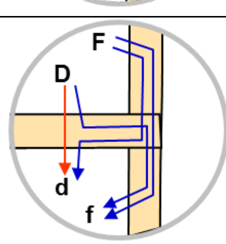
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction, but ends beyond the junction for the T-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall for X-junction and on one side of the wall for T-junction



Floor-Wall X-/T-junction for CLT constructions.

Vertical section, not to scale.

Junction	Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xa-05 Wall-Floor X-junction 	Ff	0.6
	Fd	10.2
	Df	10.2
CLT-WC-Xa-05 Wall-Ceiling X-junction 	Ff	0.6
	Fd	10.2
	Df	10.2
CLT-FW-Xa-05 Floor-Wall X-junction 	Ff	17.6
	Fd	10.2
	Df	10.2
CLT-FW-Ta-05 Floor-Wall T-junction 	Ff	12.9
	Fd	6.8
	Df	6.8

For the notes in this table please see the corresponding endnotes.

Table 3.1.06: Transmission Paths

(same as 3.1.05 except different wall connections)

<u>Wall assembly:</u>

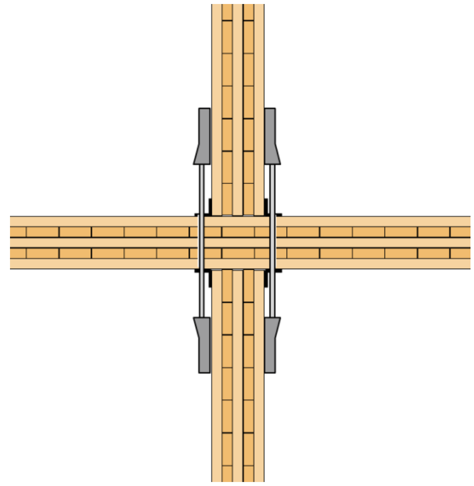
- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)
- Above and below the floor/ceiling assembly

<u>Floor/ceiling assembly:</u>

- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

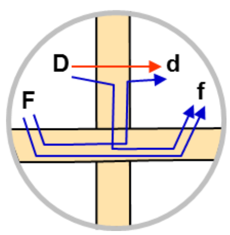
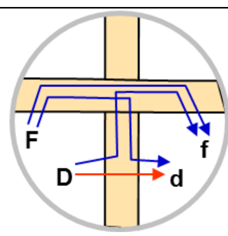
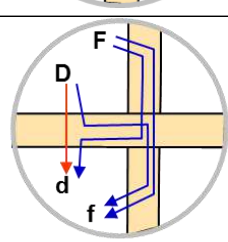
<u>Junction of wall with floor/ceiling assembly:</u>

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Two hold-down brackets on each side of the wall, above and below the floor/ceiling



Floor-Wall X-junction for CLT constructions.

Vertical section, not to scale.

Junction		Path	Vibration Reduction Index, K_{ij}
CLT-WF-Xb-06 Wall-Floor X-junction		Ff Fd Df	-2.0 3.3 3.3
CLT-WC-Xb-06 Wall-Ceiling X-junction		Ff Fd Df	-2.0 3.3 3.3
CLT-FW-Xb-06 Floor-Wall X-junction		Ff Fd Df	5.3 3.3 3.3

For the notes in this table please see the corresponding endnotes.

3.2 Trends in the Vibration Reduction Index for the Floor-Wall Junctions

To date, only a limited selection of floor-wall junction cases have been evaluated:

- All of the cases which were evaluated in this study included CLT78(3) assemblies or CLT175(5) assemblies or a combination of CLT78(3) and CLT175(5) assemblies. None of the tested cases evaluated CLT245(7) or CLT292(9) assemblies. A process to partially compensate for this limited selection is discussed in Section 3.5.
- The tested wall-floor junctions included both cross-junctions (where the floor assembly was continuous across the junction) and T-junctions (where walls were attached to top and bottom of the floor assembly, very close to its end). In all cases, the wall-wall path was discontinuous – the upper and lower wall assemblies were mechanically attached to top and bottom of the intervening floor assembly.
- Different connections between the floor and walls were evaluated as part of this study. All of the connections included a mechanical attachment of the walls to the floor assembly, but in some cases, the attachment of the upper wall differed from that of the lower wall.

Basic Wall-Floor Cross-Junctions

Clear trends were apparent in the mean vibration reduction index values for wall-floor cross-junctions where the walls were joined to the floors with 90 mm angle brackets spaced 300 mm on center. Figure 3.2.1 shows the mean K_{ij} values as a function of the mass ratio between the floor assembly and the wall assemblies.

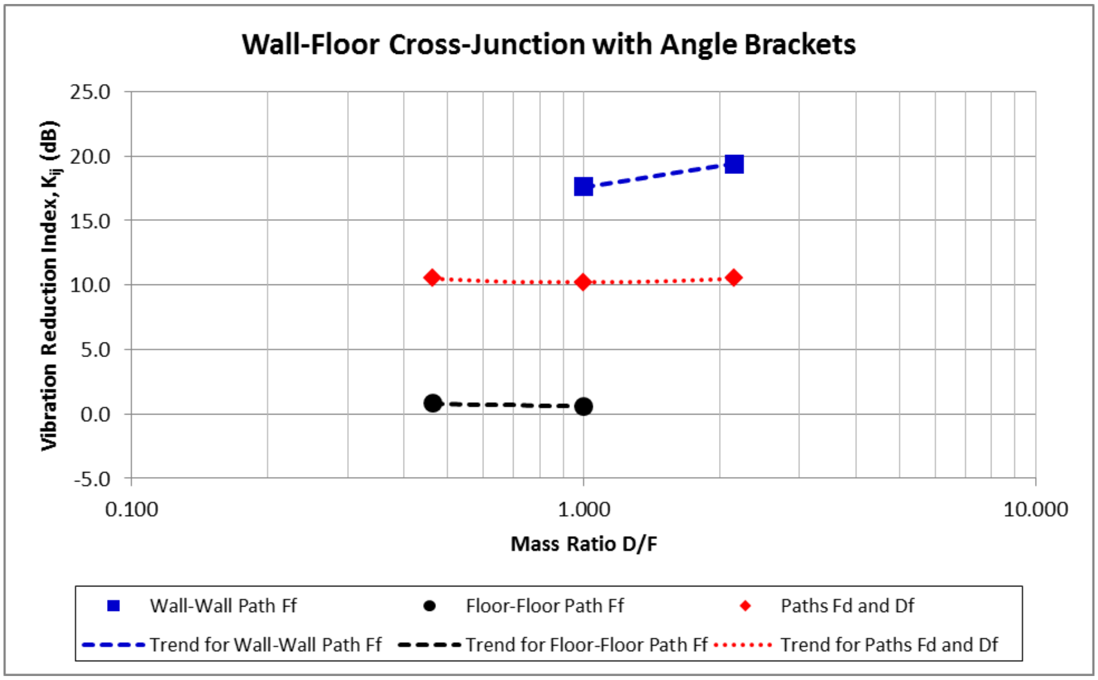


Figure 3.2.1: Mean K_{ij} values and best fit curves for each transmission path for the cross-junctions where 90 mm angle brackets spaced 300 mm on enter connected the wall assemblies to the top and bottom of a continuous CLT175(5) floor assembly.

The measured values fall in three distinct ranges, one for each type of transmission path:

- The wall-wall path (designated Ff for the case where one room is above the other with the floor as the separating assembly) has the highest K_{ij} values, indicating high attenuation and therefore a relatively weak connection.
- The floor-floor path (designated Ff for the case where one room is beside the other with the wall as the separating assembly) has the lowest K_{ij} values, indicating little attenuation through the junction and therefore a very effective connection for the transmission of structure-borne sound across the continuous floor assembly.
- The floor-wall paths Fd and Df fall midway between.

The limited data sets available at the time this Report was published make it difficult to predict the trends in the data. Although further testing on more junctions is planned, the limited data currently available reduces the trends to straight lines for the wall-wall and floor-floor paths and a simple quadratic fit for the floor-wall paths. The changes in the mean K_{ij} values due to changes in the mass ratio are shown to be quite small for the data available. These curves which indicate the performance for the simple cross-junction case in Figure 3.2.1 were re-used as reference curves in the following graphs to facilitate comparisons between the graphs.

Comparison of Wall-Floor T-Junctions Versus Cross-Junctions

The mean vibration reduction index values for wall-floor T-junctions with where the walls were joined to the floors with 90 mm angle brackets spaced 300 mm on center are shown in Figure 3.2.2.

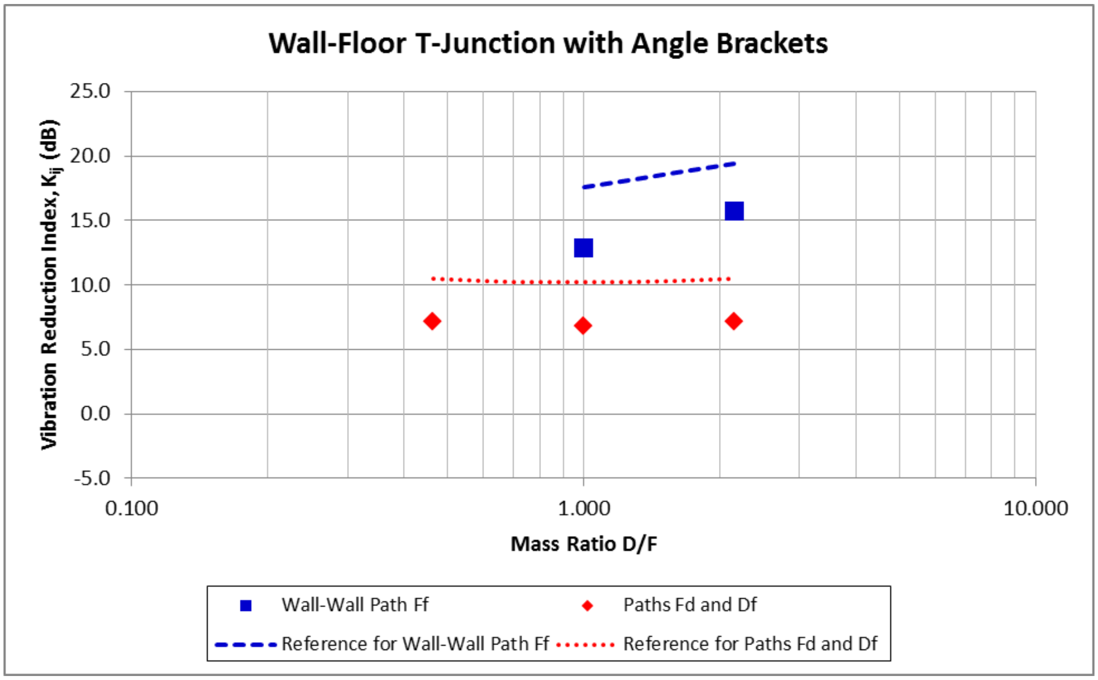


Figure 3.2.2: Measured K_{ij} values for each path for the T-junction cases with angle brackets attaching the wall assemblies to the top and bottom of the CLT175(5) floor assembly. The dashed curves show the trends for the corresponding cross-junction for reference.

Changes from the corresponding cross-junctions are evident when comparing the reference curves from the cross-junctions to the data for the T-junctions. All of the mean K_{ij} values for the T-junction were lower than the trends for the cross-junctions by several dB. The difference is about 4 or 5 dB for the wall-wall path and about 3 dB for paths Fd and Df indicating less attenuation for these paths for the T-junction than for the cross-junction.

Comparison of Wall-Floor Cross-Junctions with Different Attachment Details

More complicated changes relative to the basic cross-junction were evident in the mean K_{ij} values for wall-floor cross-junctions which were constructed using different methods of attaching the wall assemblies to the floor assemblies as shown in Figures 3.2.3 and 3.2.4.

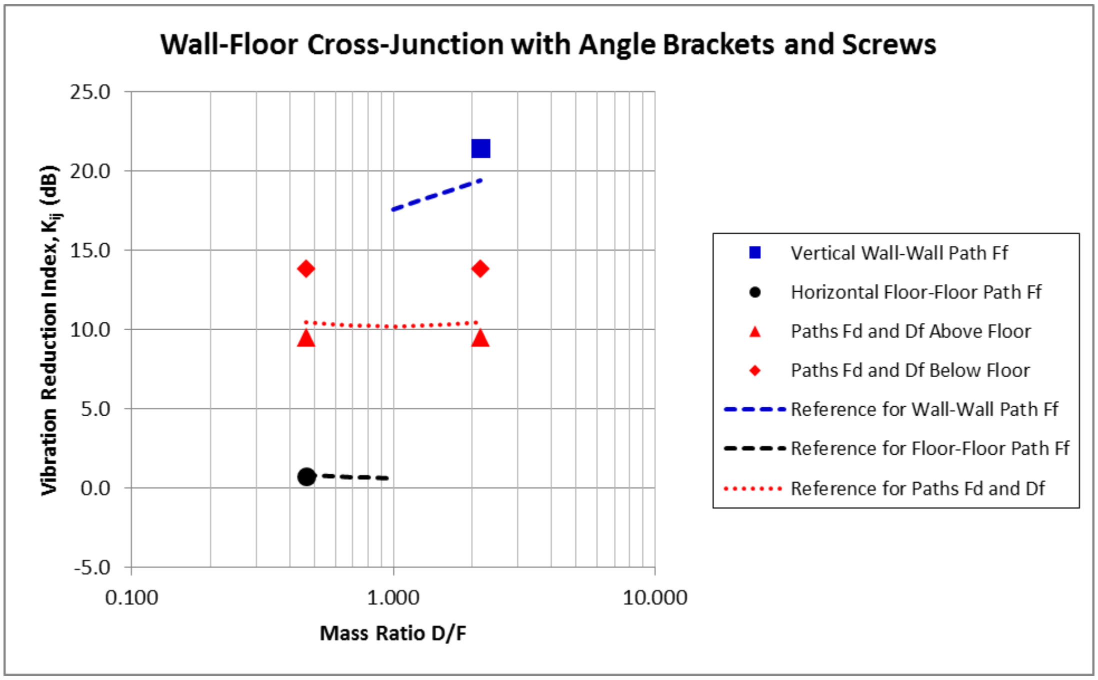


Figure 3.2.3: Measured K_{ij} values for each path for the cross-junctions for the case where angle brackets were used to attach the wall assemblies to the bottom of the CLT175(5) floor assemblies and for the case where screws were used. The dashed curves show the trends for the corresponding cross-junction with assemblies attached with 90 mm angle brackets spaced 300 mm on centre for reference.

The change from brackets to screws for joining the CLT assemblies altered the mean K_{ij} values.

1. The reference case (dashed lines) used 90 mm angle brackets spaced 300 mm on center to join the CLT wall assemblies above and below the continuous floor.
2. The second case (shown by individual markers for each type of path) used screw attachments instead of angle brackets to join the walls to the floor. For the floor-floor path this change had little effect and the mean K_{ij} values remained close to 0 dB. For the vertical wall-wall path the mean K_{ij} value rose by about 2 dB, but remained close to 20 dB. The paths Fd and Df exhibited noticeable asymmetry with slightly higher mean K_{ij} values for the Fd and Df paths to the wall below the floor and slightly lower values for the paths to the wall above the floor. The mean value rose slightly (by less than 2 dB). Overall, these changes suggest slightly weaker attachment of the wall assembly below the floor.

Significantly larger changes were evident when hold-downs were used to join the CLT assemblies as shown in Figure 3.2.4.

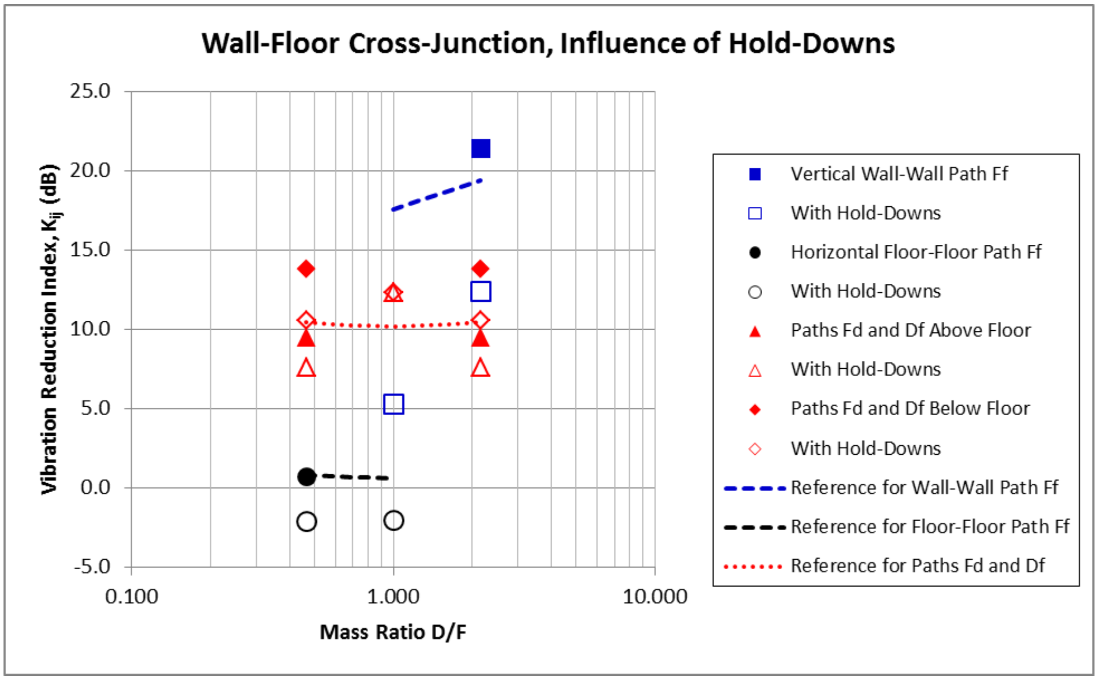


Figure 3.2.4: Measured change in the mean K_{ij} values for each path for the cross-junction cases where hold-downs were added to the floor/wall junctions, as presented in Tables 3.1.03 and 3.1.06. The dashed curves show the trends for the corresponding cross-junction with 90 mm angle brackets spaced 300 mm on center used above and below the floor for reference.

Adding hold-downs changed the mean K_{ij} values from 2 dB to 12 dB, depending on the flanking sound transmission path and the other attachments of the wall assemblies.

1. The reference case (dashed lines) used 90 mm angle brackets spaced 300 mm on center to join the CLT wall assemblies above and below the continuous floor with no hold-downs.
2. The individual filled markers show (as in the preceding Figure 3.2.3) the slightly altered mean K_{ij} values when screw attachments replaced the 90 mm angle brackets holding the lower wall assembly.
3. The corresponding open markers show the mean K_{ij} values when hold-downs were added to the assemblies. For all of the transmission paths, the mean K_{ij} values when hold-down were used differed appreciably from the corresponding case without hold-downs.
4. When the lower wall was attached with angle brackets, adding hold-downs changed the mean K_{ij} values most dramatically: +2 dB for paths Fd and Df, but lower by 12 dB for the wall-wall path and lower by 3 dB for the floor-floor path (changes relative to the dashed curves, for the cases at mass ratio of 1.00),.
5. When the lower wall was attached with screws, all of the mean K_{ij} values decreased by about 3 dB, except for the vertical wall-wall path which decreased by about 7 dB, indicating less attenuation at the junction.

The effect of the changes in the attachment of the CLT assemblies is complicated and given the limited samples size included in this study, the trends presented in the figures should be treated as unreliable until further data can be included in the figures.

However, some overall trends between the different attachment details can be seen:

- The vertical wall-wall paths had the highest mean K_{ij} values (13 dB to 22 dB).
- The floor/floor paths had the lowest mean K_{ij} values (-2 dB to 3 dB).
- The floor/wall paths Fd and Df were between these extremes (7 dB to 15 dB).
- The T-junctions had lower mean K_{ij} values than the corresponding cross-junctions (lower by 3 dB to 5 dB).
- The addition of hold-downs resulted in much lower mean K_{ij} values for the vertical wall-wall paths (indicating much better connection between the upper and lower walls) but had smaller effects on the other paths.

3.3 Trends in the Vibration Reduction Index for Wall-Wall Junctions

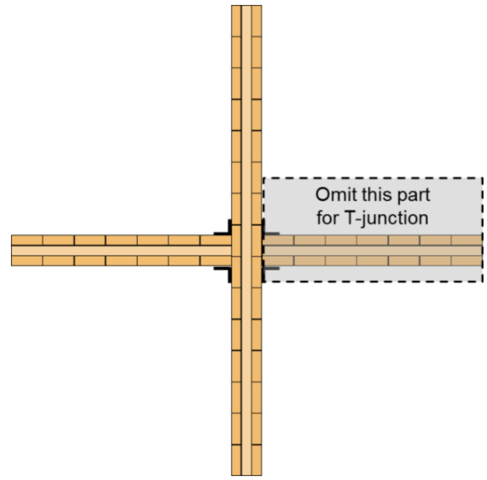
The mean vibration reduction index (K_{ij}) values determined from each of the mock-up junctions between CLT wall assemblies are presented in the following tables. For each table:

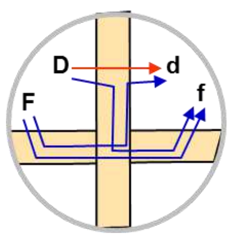
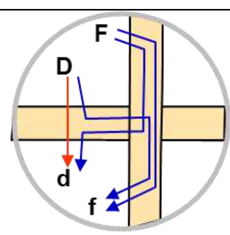
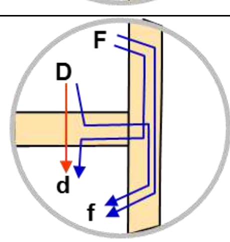
- A generic description is given of the details of the wall assemblies and their connection.
- The general features of the junction are shown in a figure.
- Note that each cross-junction of wall assemblies represents a combination of separating wall and flanking walls for two side-by-side rooms, but all the cases studied involved one wall assembly that was continuous across the junction. The continuous assembly could be either the separating wall or a flanking wall.
- Each T-junction of wall and floor/ceiling assemblies involves only option (c).
- Junction cases are presented, with stylized drawings to identify the paths in each case, and the mean vibration reduction index (K_{ij}) values for each flanking path.
- The naming convention for the junctions follows a simple coding in four segments:
  - The first segment of the code indicates that the junction consists of CLT assemblies.
  - The second segment of the code indicates the junction type: WW = wall-wall.
  - The third segment of the code indicates the nature of the junction itself:
    - the first letter (X or T) indicates junction geometry,
    - the second letter (a, b, c, etc.) indicates how the elements are attached at their junction.
  - The fourth segment of the code is a unique number for that junction detail.
- The mean vibration reduction index (K_{ij}) is presented as a single number ratings. The procedure used to calculate the single-number rating of the vibration reduction index differs from the procedure outlined in ISO 15712-1. The standard states that: "If the values for the vibration reduction index depend on frequency, the value at 500 Hz may be taken as a good approximation, but the result can then be less accurate." Rather than follow this procedure, the single-number ratings for the vibration reduction indices were calculated as the average value of the nine one-third octave bands between 200 Hz and 1250 Hz, inclusive. The mean K_{ij} values are used in the calculation of the ASTC ratings as described in Chapter 4.

Note that the wall-wall junctions were tested ***only*** for the cases where:

- Component lumber pieces of the face ply of the wall assembly were vertical.
- For all wall-wall junctions, one of the CLT assemblies was continuous across the junction.

These cases were considered to provide the worst case for transmission to the adjoining rooms, and hence may be used as conservative estimates for cases where the CLT orientation or connection differs.

<table>
<tr><th>Table 3.3.01: Transmission Paths</th><td colspan="2" rowspan="2">

Wall-Wall X-/T-junction for CLT constructions.
Horizontal section, not exactly to scale.</td></tr>
<tr><td rowspan="2">Continuous wall assembly:
• CLT78(3)[1] (78 mm thick, 42.4 kg/m²)
Connected wall assemblies:
• CLT78(3)[1] (78 mm thick, 42.4 kg/m²)
• Terminating where they butt against the continuous wall assembly
Junction:
• X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
• T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.</td></tr>
<tr><th>Path</th><th>Vibration Reduction Index, K_{ij}</th></tr>
<tr><td>CLT-WW-Xa-01
Wall-Wall X-junction with continuous separating wall

</td><td>Ff
Fd
Df</td><td>9.9
5.8
5.8</td></tr>
<tr><td>CLT-WW-Xb-01
Wall-Wall X-junction with continuous flanking walls

</td><td>Ff
Fd
Df</td><td>5.2
5.8
5.8</td></tr>
<tr><td>CLT-WW-Tb-01
Wall-Wall T-junction with continuous flanking walls

</td><td>Ff
Fd
Df</td><td>3.5
5.7
5.7</td></tr>
</table>

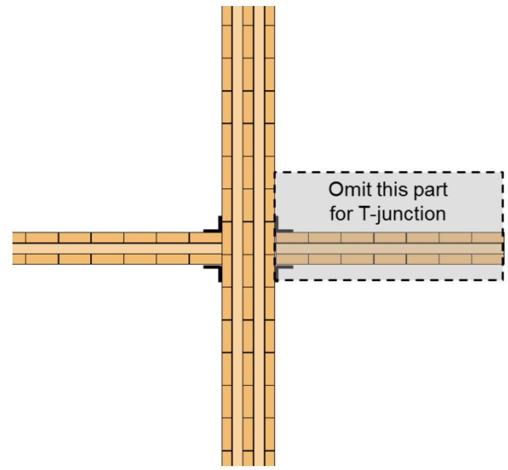
For the notes in this table please see the corresponding endnotes.

Table 3.3.02: Transmission Paths

<u>Continuous wall assembly:</u>
- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

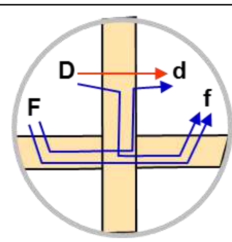
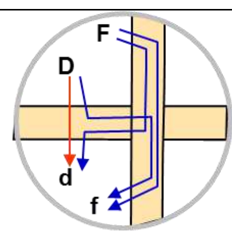
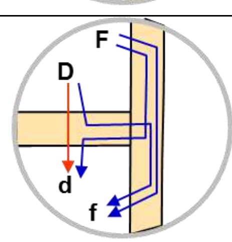
<u>Connected wall assemblies:</u>
- CLT78(3)[1] (78 mm thick, 42.4 kg/m^2)
- Terminating where they butt against the continuous wall assembly

<u>Junction:</u>
- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assemblies, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.



Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

Junction		Path	Vibration Reduction Index, K_{ij}
CLT-WW-Xa-02 Wall-Wall X-junction with continuous separating wall		Ff	17.0
		Fd	9.1
		Df	9.1
CLT-WW-Xb-02 Wall-Wall X-junction with continuous flanking walls		Ff	2.6
		Fd	9.1
		Df	9.1
CLT-WW-Tb-02 Wall-Wall T-junction with continuous flanking walls		Ff	2.2
		Fd	9.8
		Df	9.8

For the notes in this table please see the corresponding endnotes.

Table 3.3.03: Transmission Paths

Continuous wall assembly:

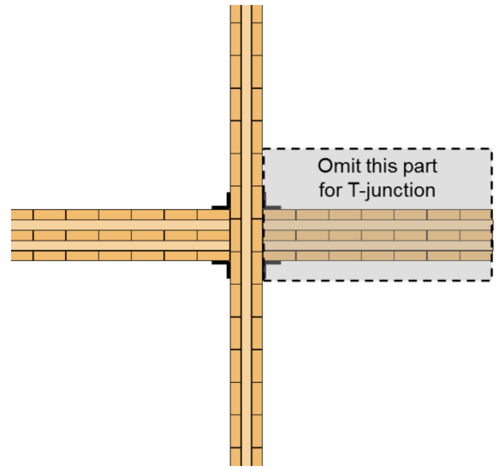
- CLT78(3)[1] (78 mm thick, 42.4 kg/m^2)

Connected wall assemblies:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m^2)

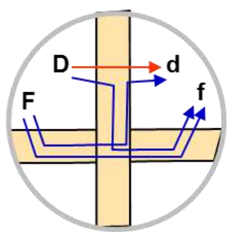
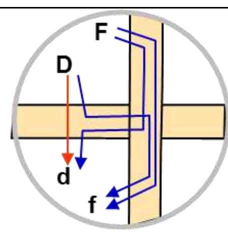
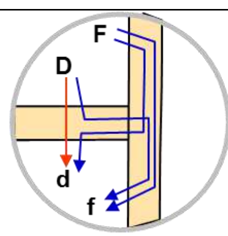
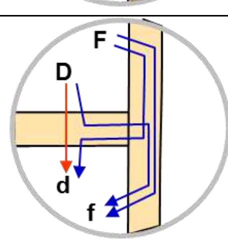
Junction:

- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assemblies, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.



Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

Junction	Path	Vibration Reduction Index, K_{ij}
CLT-WW-Xa-03 Wall-Wall X-junction with continuous separating walls 	Ff Fd Df	11.0 8.7 8.7
CLT-WW-Xb-03 Wall-Wall X-junction with continuous flanking walls 	Ff Fd Df	5.4 8.7 8.7
CLT-WW-Tb-03 Wall-Wall T-junction with continuous flanking walls 	Ff Fd Df	1.0 7.7 7.7
CLT-WW-Tg-03 Like CLT-WW-Tb-03, but bonded with construction adhesive 	Ff Fd Df	9.1 5.3 5.3

For the notes in this table please see the corresponding endnotes.

Table 3.3.04: Transmission Paths

Continuous wall assembly:

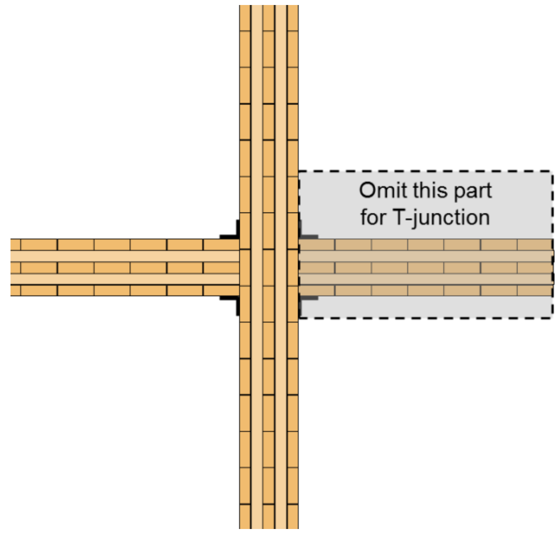
- CLT175(5)[1] (175 mm thick, 91.4 kg/m²)

Connected wall assemblies:

- CLT175(5)[1] (175 mm thick, 91.4 kg/m²)
- Terminating where they butt against the continuous wall assembly

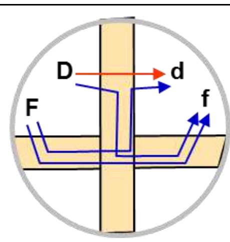
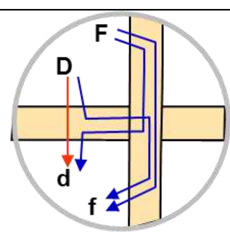
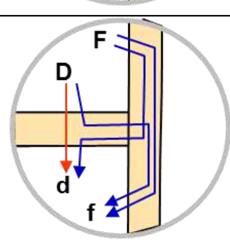
Junction:

- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.



Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

Junction	Diagram	Path	Vibration Reduction Index, K_{ij}
CLT-WW-Xa-04 Wall-Wall X-junction with continuous separating walls		Ff Fd Df	15.6 9.3 9.3
CLT-WW-Xb-04 Wall-Wall X-junction with continuous flanking walls		Ff Fd Df	2.4 9.3 9.3
CLT-WW-Tb-04 Wall-Wall T-junction with continuous flanking walls		Ff Fd Df	-0.7 10.1 10.1

For the notes in this table please see the corresponding endnotes.

3.4 Trends in Junction Attenuation for Wall-Wall Junctions

To date, only a limited selection of wall-wall junction cases have been evaluated:

- All of the cases which were evaluated in this study included CLT78(3) assemblies or CLT175(5) assemblies or a combination of CLT78(3) and CLT175(5) assemblies. None of the tested cases evaluated CLT245(7) or CLT292(9) assemblies. A process to partially compensate for this limited selection is discussed in Section 3.5.
- The tested wall-wall junctions included both cross-junctions and T-junctions.
- All of the wall-wall junctions included one wall which was continuous across the junction.
- Most wall-wall cases were tested with the same mechanical attachment using 90 mm angle brackets spaced 600 mm on center.
- One wall-wall junction was tested both with the assemblies mechanically attached using angle brackets and with the combination of the same mechanical attachment plus a construction adhesive.

Wall-Wall Cross-Junctions

Although the small sample size of junctions evaluated to date limits the conclusions that can be drawn from the data, there are a number of observable trends in the mean K_{ij} values shown in Figure 3.4.1.

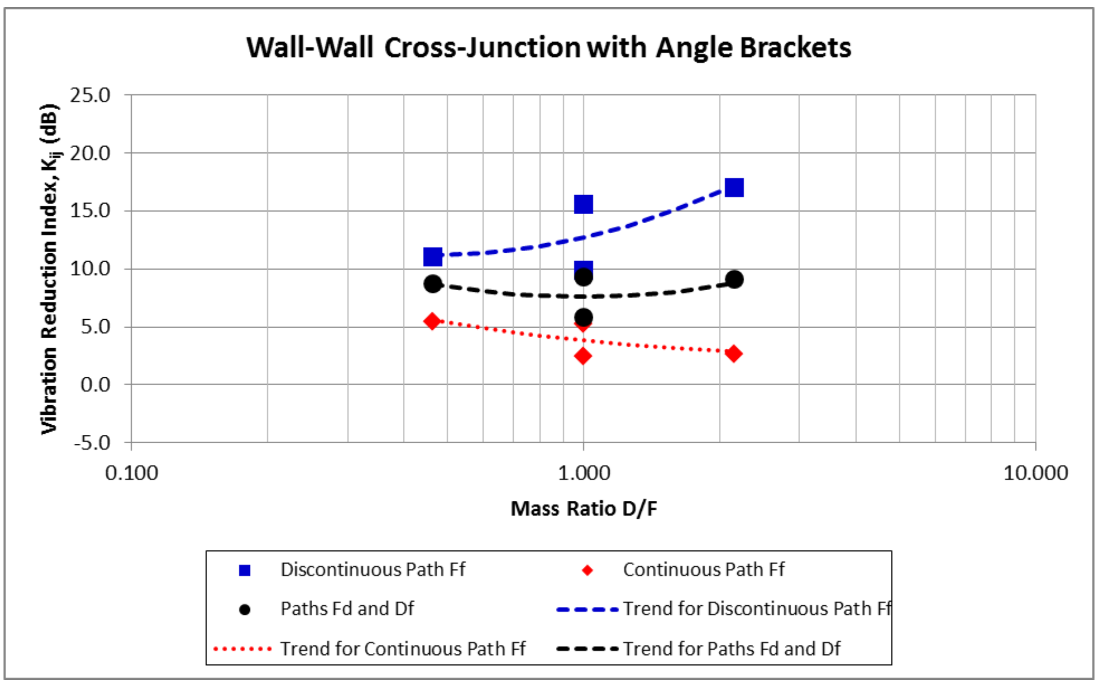


Figure 3.4.1: The mean K_{ij} values and best fit curves for cross-junctions using angle brackets.

The dashed lines are simple quadratic fits that pass through the mean of each pair of values with a mass ratio of D/F=1. These dashed lines indicate the typical K_{ij} values for the simple cross-junction case and are used as reference curves in the following graph to facilitate comparisons between the graphs.

The figure shows that the mean K_{ij} values fall into three distinct ranges, one for each type of transmission path:

- The discontinuous wall-wall path (designated Ff for the case where part of the continuous wall separates the adjacent rooms and the two flanking walls are attached to the continuous wall) had the highest K_{ij} values, indicating high attenuation and therefore a relatively weak connection.
- The continuous wall-wall path (designated Ff for the case where the continuous wall is a flanking wall for both adjacent rooms and one of the attached assemblies is the separating wall between the two rooms) had the lowest K_{ij} values, indicating little attention through the junction and therefore a very effective connection for the transmission of structure-borne sound across the continuous wall assembly.
- The wall-wall paths Fd and Df fell midway between the other two cases.

Within each of these three sets of results, it is clear that the mass ratio does not fully account for the trends shown for the mean K_{ij} values. For each set of data, the cases where the mass ratio is 1.0 are at or near the two extremes in the mean K_{ij} values which indicates that a factor other the mass ratio affected the results. The other factor may be the attachment between the CLT assemblies but more measurement data is required to confirm this.

Comparison of Wall-Wall T-Junctions Versus Cross-Junctions

Figures 3.4.2 compares the mean K_{ij} values for the comparable wall-wall cross-junctions and T-junctions, both with the CLT assemblies attached with 90 mm angle brackets spaced 600 mm on center.

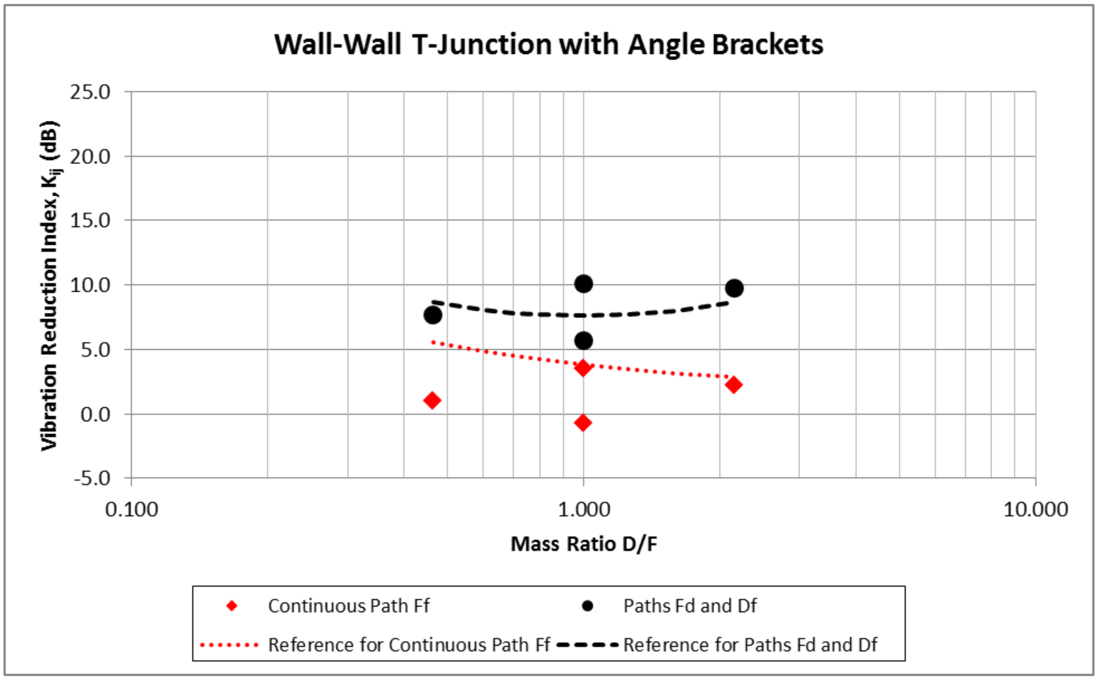


Figure 3.4.2: Measured K_{ij} values for each path for the T-junction cases with angle brackets attaching the wall assemblies. As a reference, the dashed curves show the trends for the corresponding cross-junction.

The figure shows that the mean K_{ij} values of the continuous path Ff measured for the T-junction were lower than those measured for the cross-junction, but the mean K_{ij} values measured for paths Fd and Df were similar for the two junction types. Note that there was no discontinuous wall-wall path Ff for the T-junctions since the flanking wall was continuous for all the T-junctions that were evaluated. However, without data for junctions which include CLT245(7) or CLT292(9) assemblies, a trend can not be clearly established.

3.5 Extensions to Include Junction Cases That Have Not Been Tested

At the time that this edition of this Report was published, there was not enough K_{ij} measurement data available for the wall-wall or wall-floor junctions to be able to establish trends in the data to permit useful interpolation. It is clear from the results that the mean K_{ij} values are affected by factors other than the ratio of the mass per unit area of the assemblies connected at a junction, and this is especially so for the wall-wall junctions. However, without further tests which include both heavier CLT assemblies and a broader range of mass ratios, the range of CLT wall and floor combinations for which one can predict the overall ASTC rating is limited.

The evaluation of junctions between CLT assemblies which include thicknesses up to a 9-ply CLT assembly has been planned and the results of the measurements are planned to be included in the next edition of this Report.

4 Predicting Sound Transmission in Cross-laminated Timber Buildings

This chapter presents the calculation of the apparent sound transmission loss (ATL), and the apparent sound transmission class (ASTC) rating between adjacent rooms in a building where the walls and floors are cross-laminated timber assemblies. The calculation approaches use empirical calculation methods that combine laboratory measured data for the sound transmission loss of individual CLT wall and floor assemblies with the vibration reduction index values measured on full scale mock-up junctions between the CLT assemblies using the procedures of ISO 10848. With this extension, the calculation approaches described in this chapter follow the procedures of the international standard, ISO 15712-1 as explained in The Guide RR-331.

All of the procedures presented in this chapter start from the concepts presented in Chapter 1 of this Report. The sound transmitted between two rooms is calculated from the combination of the airborne sound transmission loss through the separating assembly and the structure-borne sound transmission via the set of first-order flanking paths at each of the edges of the separating assembly where it connects to the flanking assemblies.

The data required for the calculation of the ASTC rating and the details of the calculation procedure depend on the type of wall and floor constructions comprising the building as well as the choice of calculation method (Simplified or Detailed). Each calculation method is explained in the following sections:

- ***Section 4.1*** explains the ASTC rating calculation using the **Simplified Method of ISO 15712-1** for buildings where CLT wall assemblies are connected to CLT floor assemblies. The Simplified Method is less rigorous than the Detailed Method, but also much less complicated. The Simplified Method uses single number values for the sound transmission loss (STC and ΔSTC) and the values of the junction attenuation (K_{ij}) to determine the sound transmission via each transmission path (Dd, Ff, Fd, and Df). This method directly calculates the ASTC rating using Equation 1.2 of this Report to combine the sound energy transmitted by the direct and flanking paths.
- ***Section 4.2*** explains the ASTC rating calculation using the **Detailed Method of ISO 15712-1** for buildings where CLT walls are connected to CLT floor assemblies. The Detailed Method uses frequency band data for sound transmission loss (TL and ΔTL) for the wall and floor assemblies with values of vibration reduction index (K_{ij}) to determine the sound transmission via each transmission path (Dd, Ff, Fd, and Df). This method directly calculates the apparent sound transmission loss, ATL for each frequency band using Equation 1.1 of this Report to combine the sound energy transmitted by the direct and the flanking paths. From the apparent sound transmission loss for the standard set of frequency bands, the ASTC rating can then be calculated using the procedure described in ASTM E413.

Standard Scenario for the Worked Examples in this Report

The prediction of the sound transmitted in buildings depends not only on the construction details of the transmission paths, but also on the size and shape of each of the room surfaces and on the sound absorption in the receiving room. The ability to adjust the calculation to fit the dimensions in a specific building or to normalize the data to different receiving room conditions enables a skilled designer to obtain more accurate predictions of the ASTC rating.

For purposes of this Report, the meaningful comparison of results is facilitated by using a common set of room geometry and dimensions for all of the examples. This is particularly useful where only small changes are made between the construction details between the examples, since any change in the ASTC rating can then be attributed to just the changes that were made in the construction details.

A Standard Scenario has been adopted for all the examples, with the following constraints:

- Sound is transmitted between adjacent rooms, either side-by-side or one-above-the-other.
- The adjacent rooms are mirror images of each other with one side of the separating assembly facing each room and constituting one complete face of each rectangular room.

The Standard Scenario is illustrated in Figures 4.1 and 4.2, for the cases where one room is beside the other and one room is above the other, respectively.

Figure 4.1:

Standard Scenario for the "horizontal room pair" case where the pair of rooms are side-by side with a separating wall assembly between the two rooms.

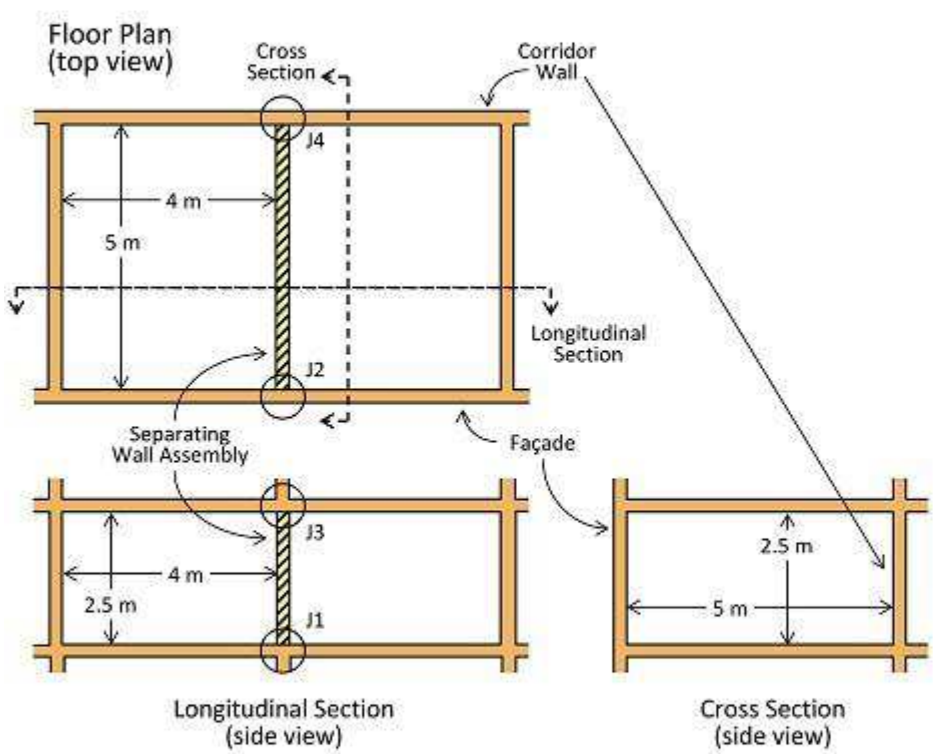
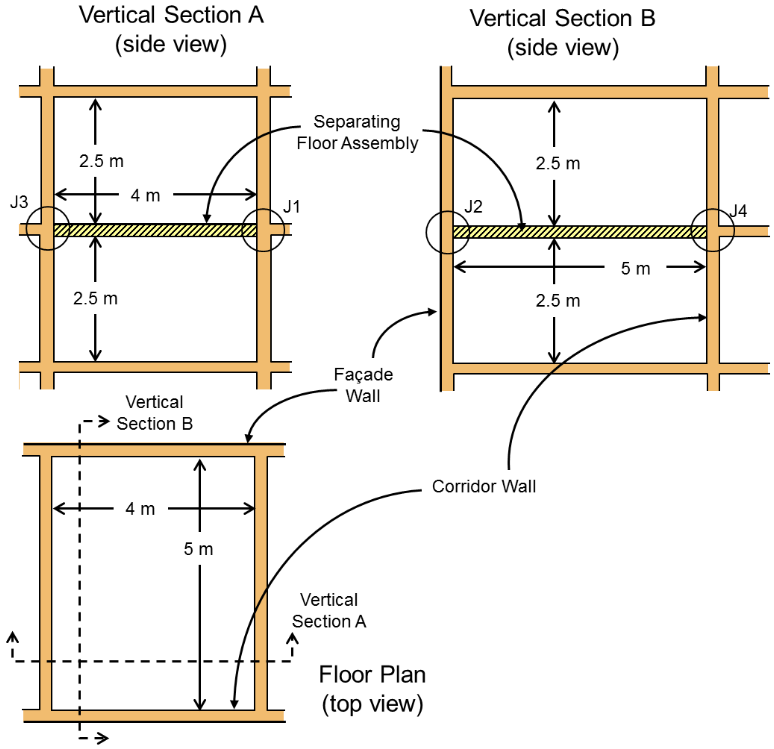


Figure 4.2:

Standard Scenario for the "vertical room pair" case where one of the pair of rooms is above the other, with the floor/ceiling assembly between the two rooms.



The pertinent dimensions and junction details are shown in Figures 4.1 and 4.2.

- Note that the junctions at the four edges of the separating assembly have been labeled (J1 to J4) in Figures 4.1 and 4.2. These junction designations are used in the examples throughout this Report.
- For the horizontal room pair (the rooms are side-by-side), the separating wall is 2.5 m high by 5 m wide, the flanking floor/ceilings are 4 m by 5 m and the flanking walls are 2.5 m high by 4 m wide.
- For the vertical room pair (one room is above the other) the separating floor/ceiling is 4 m by 5 m wide and the flanking walls in both rooms are 2.5 m high.
- In general, it is assumed that the junctions at one side of the room (at the separating wall if rooms are side-by-side) are cross junctions, while one or both of the other two junctions are T-junctions. This enables the examples to illustrate the typical differences between the two common junction cases.
- For the horizontal room pair, the separating wall has T-junctions with the flanking walls at both the façade and corridor sides and cross-junctions at the floor and ceiling.
- For the vertical room pair, the façade wall has a T-junction with the separating floor, but the opposing corridor wall has a cross-junction, as do the other two walls.

Deviations from the rooms of the Standard Scenario, such as rooms with different dimensions or different junction types (a cross-junction instead of a T-junction, for example) can be calculated by substituting the appropriate room dimensions and junction details in the calculation procedures and in the worked examples in this Report.

Following the labeling convention described in Figure 1.3 of Chapter 1, the labels for the flanking surfaces of the Standard Scenarios are detailed in the following Table 4.1.

Table 4.1: Surfaces (D, d, F and f) for flanking paths at each junction, as in the Standard Scenario.

Room Pair	**Surfaces D and d**	**Flanking Surfaces F and f**	**Junction**
Horizontal (Fig. 4.1)	Separating wall	Junction 1: floor F and f Junction 2: façade wall F and f Junction 3: ceiling F and f Junction 4: corridor wall F and f	Cross-junction T-junction Cross-junction T-junction
Vertical (Fig. 4.2)	Separating floor/ceiling	Junction 1: wall F and f Junction 2: façade wall F and f Junction 3: wall F and f Junction 4: corridor wall F and f	Cross-junction T-junction Cross-junction Cross-junction

Calculation Spreadsheets for the Worked Examples

The calculation of the ASTC rating for each worked example is illustrated step by step in a spreadsheet. Figure 4.3 shows images of the calculation spreadsheets using the Simplified Method and using the Detailed Method.

Color highlights are used to indicate the input and output values in the worked examples:

- Light reddish brown is used to indicate input data values
- Blue is used to indicate the direct sound transmission loss, including the effects of in-situ loss corrections and any added lining(s) added to the separating assembly
- Pale yellow is used to indicate the calculated values of the combined flanking sound transmission loss due to a set of flanking paths at a junction
- Green is used to indicate the final result for the ASTC rating

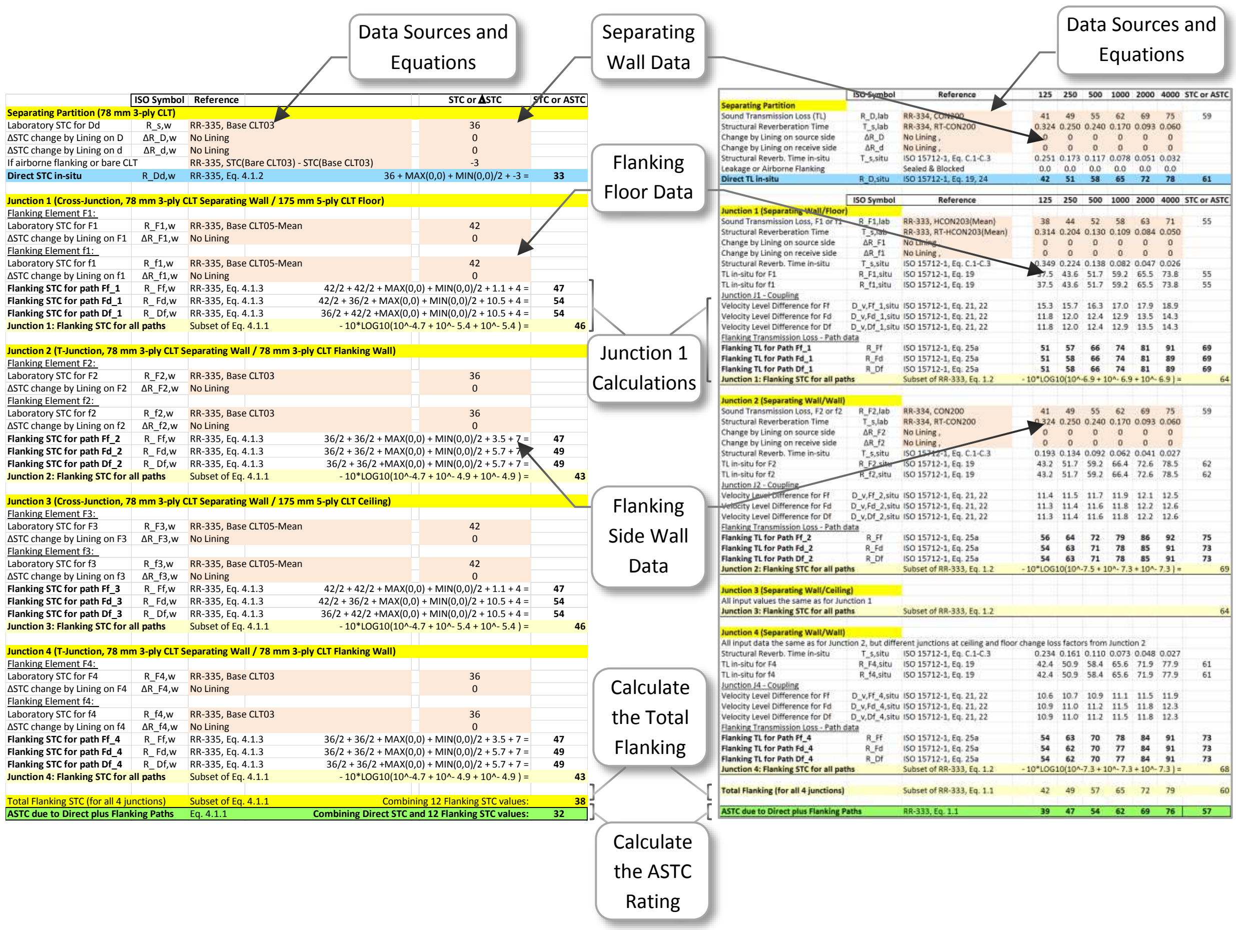


Figure 4.3: Examples of the calculation spreadsheets for the determination of the ASTC rating. The layout is similar for the Simplified Method (on the left) and the Detailed Method (on the right), but the latter presents more detailed information. Larger (and more legible) versions of these images are given in the following discussion of each calculation method.

Calculation Spreadsheets for Worked Examples using the Simplified Method

Worked examples that demonstrate the calculation of the ASTC rating using the Simplified Method are presented in Section 4.1.

Under the heading "STC or ΔSTC", the examples show the input data as determined from laboratory tests including the:

- Laboratory measured STC ratings for wall or floor assemblies
- The ΔSTC ratings determined from laboratory measurements for the change in the transmission loss due to adding a lining to the specified wall or floor assembly as explained in Appendix A2 of this Report
- For lightweight framed construction types, if applicable, the flanking STC ratings for each flanking path at each junction measured following ISO 10848 and re-normalized using Eq. 4.1.3

The numeric calculations are presented step-by-step in each worked example using compact notation consistent with the spreadsheet expressions. Specifically:

- For the calculation of the Direct STC rating and the Flanking STC ratings, the expressions show the calculation required to take into account linings installed on one or both sides of the assembly. These results are rounded to the nearest integer for consistency with the corresponding measured values.
- For combining the sound power transmitted via specific paths, the calculation of Eq. 1.2 is presented in several stages. Note that in the compact notation, a term for transmitted sound power fraction such as $10^{-0.1 \cdot STC_{ij}}$ becomes $10^{-7.4}$, if STC_{ij} = 74.
- At each stage (such as the Flanking STC rating for the three paths at a given junction) the result is converted into decibel form by calculating -10*$\log_{10}$ (transmitted sound power fraction) to facilitate comparison of each path or junction with the Direct STC rating and the final ASTC rating.

For each worked example, the "Reference" column presents the source of the input data. The source may be indicated by a NRC report number and identifier for a laboratory test result or the applicable equations and sections of ISO 15712-1 or their counterparts using ASTM ratings used to determine the input data. Symbols and subscripts identifying the corresponding variable in ISO 15712-1 are given in the adjacent column.

The Simplified Method worksheet of Example 4.1-H1 (for side-by-side rooms separated by a wall assembly) is shown in Figure 4.4.

	ISO Symbol	Reference		STC or ΔSTC	STC or ASTC
Separating Partition (78 mm 3-ply CLT)					
Laboratory STC for Dd	R_s,w	RR-335, Base CLT03		36	
ΔSTC change by Lining on D	ΔR_D,w	No Lining		0	
ΔSTC change by Lining on d	ΔR_d,w	No Lining		0	
If airborne flanking or bare CLT		RR-335, STC(Bare CLT03) - STC(Base CLT03)		-3	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	36 + MAX(0,0) + MIN(0,0)/2 + -3 =		**33**
Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)					
Flanking Element F1:					
Laboratory STC for F1	R_F1,w	RR-335, Base CLT05-Mean		42	
ΔSTC change by Lining on F1	ΔR_F1,w	No Lining		0	
Flanking Element f1:					
Laboratory STC for f1	R_f1,w	RR-335, Base CLT05-Mean		42	
ΔSTC change by Lining on f1	ΔR_f1,w	No Lining		0	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 =		**47**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4) =		**46**
Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)					
Flanking Element F2:					
Laboratory STC for F2	R_F2,w	RR-335, Base CLT03		36	
ΔSTC change by Lining on F2	ΔR_F2,w	No Lining		0	
Flanking Element f2:					
Laboratory STC for f2	R_f2,w	RR-335, Base CLT03		36	
ΔSTC change by Lining on f2	ΔR_f2,w	No Lining		0	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 =		**47**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9) =		**43**
Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)					
Flanking Element F3:					
Laboratory STC for F3	R_F3,w	RR-335, Base CLT05-Mean		42	
ΔSTC change by Lining on F3	ΔR_F3,w	No Lining		0	
Flanking Element f3:					
Laboratory STC for f3	R_f3,w	RR-335, Base CLT05-Mean		42	
ΔSTC change by Lining on f3	ΔR_f3,w	No Lining		0	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 =		**47**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4) =		**46**
Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)					
Flanking Element F4:					
Laboratory STC for F4	R_F4,w	RR-335, Base CLT03		36	
ΔSTC change by Lining on F4	ΔR_F4,w	No Lining		0	
Flanking Element f4:					
Laboratory STC for f4	R_f4,w	RR-335, Base CLT03		36	
ΔSTC change by Lining on f4	ΔR_f4,w	No Lining		0	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 =		**47**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9) =		**43**
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining 12 Flanking STC values:		**38**
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**		**32**

Data Sources and Equations
Separating Wall Data
Direct STC rating
Flanking Floor Data
Junction 1 Calculations
Flanking Wall Data
Junction 2 Calculations
Flanking Ceiling Data
Junction 3 Calculations
Flanking Wall Data
Junction 4 Calculations
Calculate the Total Flanking
Calculate the ASTC Rating

Figure 4.4: Image of an example of the worksheet for the calculation of the ASTC rating using the Simplified Method.

Calculation Spreadsheets for Examples using the Detailed Method

Worked examples demonstrating the calculation of the ASTC rating using the Detailed Method are presented in Section 4.2.

The spreadsheets for the Detailed Method use a number of conventions to make the calculations easier to follow and to make it easier to assess the importance of each flanking path. The calculations are made in each of the sixteen one-third octave frequency bands between 125 Hz and 4000 Hz, but it was not possible to present all of the data in this Report in a font size that was readable. Therefore, data is only presented in six of the one-third octave bands (125, 200, 500, 1000, 2000 and 4000 Hz) in the spreadsheet. It should be understood that the data presented in the calculation spreadsheets is just a subset of the actual data used for the calculations.

The spreadsheets show the single number ratings at intermediate stages of the calculations, each calculated from a set of one-third octave band data according to ASTM E413 including the:

- STC ratings for the laboratory sound transmission loss of wall or floor assemblies
- In-situ STC ratings for the calculated in-situ sound transmission loss of wall and floor assemblies
- Direct STC ratings for the in-situ sound transmission loss through the separating assembly including the effect of linings
- Flanking STC ratings calculated for each flanking sound transmission path at each junction including the effect of linings

Note that these single number ratings are only presented as a reference to provide a convenient indication of the relative strength of the 13 sound transmission paths. The actual calculation at each step is performed in the individual one-third octave bands, not from the single number ratings. The sound transmission loss values for the 13 paths are combined to arrive at the overall apparent sound transmission loss (ATL) for each frequency band. The ASTC rating is then calculated from the values for apparent sound transmission loss in the sixteen one-third octave frequency bands between 125 Hz and 4000 Hz.

For each worked example, the “Reference” column presents the source of the input data. The source may be indicated by a NRC report number and identifier for a laboratory test result or the applicable equations and sections of ISO 15712-1 or their counterparts using ASTM ratings used to determine the input data. Symbols and subscripts identifying the corresponding variable in ISO 15712-1 are given in the adjacent column.

The Detailed Method worksheet of Example 4.2-H1 (for side-by-side rooms separated by a wall assembly) is shown in Figure 4.5.

Data Sources and Equations

Data for a Subset of the Frequency Bands

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	No lining	0	0	0	0	0	0	
ΔTL change by Lining on d	ΔR_d	No lining	0	0	0	0	0	0	
If airborne flanking or bare CLT		RR-335, TL(Bare CLT78) - TL(Base CLT78)	-1	-3	-3	-3	-4	-1	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**25**	**25**	**28**	**34**	**42**	**49**	**33**
Junction 1: Separating Wall/Floor									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f1	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-WF-Xa-01	1.1	1.1	1.1	1.1	1.1	1.1	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**35**	**44**	**48**	**57**	**54**	**47**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	36	34	42	47	56	53	46
Junction 2: Separating Wall/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
ΔTL change by Lining on F	ΔR_F2	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f2	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-WW-Tb-01	3.5	3.5	3.5	3.5	3.5	3.5	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**39**	**42**	**48**	**57**	**61**	**47**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	33	35	38	44	53	57	43
Junction 3: Separating Wall/Ceiling									
All values the same as for Junction 1									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**35**	**44**	**48**	**57**	**54**	**47**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	36	34	42	47	56	53	46
Junction 4: Separating Wall/Wall									
All values the same as for Junction 2									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**39**	**42**	**48**	**57**	**61**	**47**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	33	35	38	44	53	57	43
Total Flanking (for all 4 junctions)		Subset of Eq. 1.1	28	29	34	39	48	49	38
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**23**	**23**	**27**	**33**	**41**	**46**	**32**

Separating Wall Data

Direct STC rating

Flanking Floor Data

Junction 1 Calculations

Flanking Wall Data

Junction 2 Calculations

Junction 3 Calculations

Junction 4 Calculations

Calculate the Total Flanking

Calculate the ASTC Rating

Figure 4.5: Image of an example of the worksheet for the ASTC rating calculation using the Detailed Method.

Rounding and Precision in the Worked Examples

The value of the ASTC rating obtained in each worked example slightly depends on the precision of the input data and on the rounding of results at each stage of the calculation. There is no rounding approach explicitly specified in ISO 15712-1, but the worked examples in the ISO standard show input and calculated sound reduction index values rounded to 0.1 dB which is consistent with the requirements for presentation of results in the ISO standards for measuring laboratory sound transmission loss. The ASTM standards for the measurement of sound transmission loss in the laboratory and in the field (ASTM E90 and ASTM E336, respectively) specify that sound transmission loss values should be rounded to the nearest integer, which is arguably more representative of meaningful precision of the result.

The examples in this document follow the ASTM convention of rounding to the nearest integer for input sound transmission loss data from laboratory tests of wall or floor assemblies, for measured or calculated values of flanking sound transmission loss for individual paths and for the apparent sound transmission loss calculated from the combination of direct and flanking paths. For input values measured according to ISO standards for which there is no ASTM counterpart, specific rounding rules were used as noted below:

- Structural reverberation times measured for laboratory wall or floor specimens or calculated for laboratory results according to Annex C of ISO 15712-1 were rounded to 3 decimal places.
- Values of the vibration reduction index (K_{ij}) at junctions between a separating assembly and each attached assembly were rounded to the nearest 0.1 dB, both for results measured according to ISO 10848 and for those calculated using the equations from Annex E of ISO 15712-1.

Between the input values and the flanking transmission loss results for each path (which were rounded to the nearest integer), the worked examples are calculated to the full precision of the spreadsheet and interim values are presented to slightly higher precision to permit detailed comparisons for users treating these examples as benchmarks for their own worksheets.

When the calculated Flanking TL or the Flanking STC rating for a given path exceeds 90 dB, the value is limited to 90 dB to allow for the inevitable effect of higher order flanking paths which make the higher calculated value unrepresentative of the true situation. Further enhancements to elements in these paths will give negligible benefit. The consequence of this limit is that the Junction STC rating for the set of three paths at each edge of the separating assembly cannot exceed 85 dB, and the Total Flanking STC rating for all four edges cannot exceed 79 dB.

The rounding and limiting approaches used in this Report provide a reasonable representation of data precision, and should permit unambiguous interpretation of the worked examples presented here. However, it is possible that a jurisdiction could specify other rounding approaches. Other rounding approaches could change the calculated ASTC ratings by ± 1.

4.1 Simplified ASTC Calculation Procedure for CLT Walls and Floors

The standard, ISO 15712-1 presents a Simplified Method for calculating structure-borne transmission. This Simplified Method has some clearly stated limitations, and some implicit cautions. ISO 15712-1 states that the application of the Simplified Method "is restricted to primarily homogeneous constructions", further restricted here to homogeneous, lightly-damped structural assemblies. Here, "lightly-damped" implies a reverberant vibration field that can be characterized by a mean vibration level and "homogeneous" implies similar bending stiffness in all directions across the surface. These definitions result in wood-framed and steel-framed assemblies being excluded from calculations using the Simplified Method, but typical CLT floor and wall assemblies are close enough to homogeneous to be considered appropriate for the Simplified Method.

The Simplified Method uses two main simplifications:

- The losses to connected assemblies are dealt with "in an average way," ignoring the difference between the losses for laboratory specimens and the (usually higher) in-situ sound transmission loss due to edge losses to adjoining wall and floor constructions in the building.
- The inputs for the calculation of the ASTC rating according to Eq. 4.1.1 are only single number quantities, STC ratings for the wall and floor assemblies, ΔSTC ratings for any linings, and mean K_{ij} values for the junction attenuation.

These simplifications eliminate much of the calculation process required to use the Detailed Method. However, a drawback of the Simplified Method is that it tends to predict an ASTC rating which is slightly lower than that calculated using the Detailed Method described in Section 4.2 of this Report, especially if linings are applied to the assemblies.

Summary of the Calculation Process

The ASTC rating between two rooms (neglecting sound that is by-passing the building structure, e.g. through leaks or ducts) is estimated using the Simplified Method from the logarithmic expression of the combination of the STC rating (STC_{Dd}) of the separating wall or floor assembly and the combined flanking STC ratings of the three flanking paths for every junction at the four edges of the separating assembly according to Eq. 4.1.1.

$$ASTC = -10\log_{10}\left[10^{-0.1\cdot STC_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1\cdot STC_{Ff}} + 10^{-0.1\cdot STC_{Fd}} + 10^{-0.1\cdot STC_{Df}}\right)\right] \quad \text{Eq. 4.1.1}$$

Eq. 4.1.1 is appropriate for all types of building systems with the geometry of the Standard Scenario and is equivalent to Equation 1.2 in Chapter 1 of this Report and to Eq. 26 in Section 4.4 of ISO 15712-1. The Simplified Procedure is summarized in Figure 4.1.1 and outlined in the steps that follow the figure.

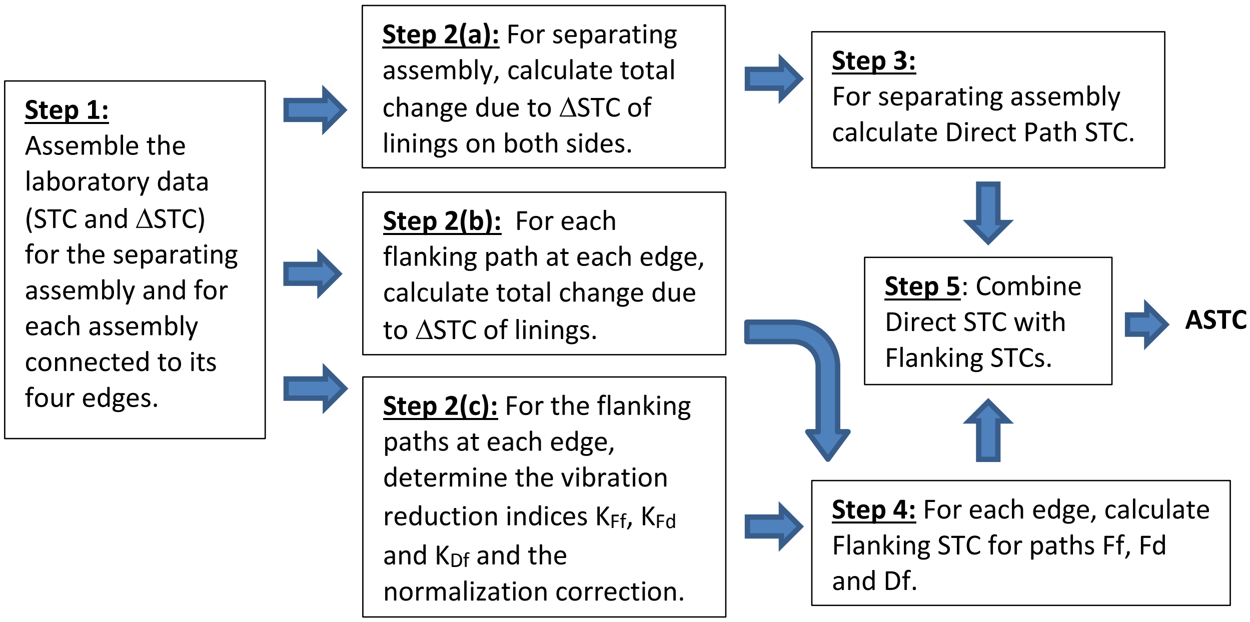


Figure 4.1.1: Steps to calculate the ASTC rating using the Simplified Method.

Step 1: Assemble the required laboratory test data for the constructions:

- Laboratory sound transmission class (STC) values based on direct sound transmission loss data measured according to ASTM E90 for the bare floor and wall assemblies
- Mass per unit area for the unlined wall and floor assemblies
- Measured change in sound transmission class (ΔSTC) determined according to Sections 2.2 and 2.3 for each lining that will be added to the base floor or wall assemblies.

Step 2: Calculate the following:

a) Correction to the separating assembly due to linings. For linings applied to the separating assembly, the correction ΔSTC_{Dd} is the sum of the larger of the ΔSTC ratings for the linings plus half of the smaller ΔSTC rating.

b) Correction to the flanking elements due to linings. For each flanking path ij, the correction ΔSTC_{ij} for linings on the source surface i and/or the receiving surface j is the sum of the larger of the ΔSTC ratings for these two linings plus half of the smaller ΔSTC rating.

c) For each edge of the separating assembly, determine suitable values the vibration reduction indices K_{Ff}, K_{Fd}, and K_{Df} for the flanking paths between the assembly in the source room (D or F) and the attached assembly in the receiving room (f or d) using the appropriate test result from the tested cases in Chapter 3. These values were measured for a range of CLT assemblies following the procedures of ISO 10848. These values depend on the junction geometry and the ratio of the mass per unit area for the connected assemblies. Also calculate the normalization correction, which depends on the length of the flanking junction and the area of the separating assembly.

Step 3: Calculate the Direct STC rating for the direct sound transmission through the separating assembly (STC_{Dd}) including the correction for the linings according to Eq. 4.1.2 (adapted from Eq. 27 and Eq. 30 of ISO 15712-1) using the laboratory STC rating of the unlined assembly and any correction for linings ΔSTC_{Dd} from Step 2(a) due to linings on source "D" and/or receiving side "d" of the separating assembly such that:

$$STC_{Dd} = STC_{lab} + \max(\Delta STC_D, \Delta STC_d) + \frac{\min(\Delta STC_D, \Delta STC_d)}{2} \qquad \text{Eq. 4.1.2}$$

Note that if a lining is applied to only one side of the separating assembly then $\min(\Delta STC_D, \Delta STC_d) = 0$.

Step 4: For each of the flanking paths, calculate the Flanking STC rating, STC_{ij} using Eq. 4.1.3 (Adapted from Eq. 28a of ISO 15712-1) where index i and j refer to the coupled flanking assemblies; thus, "i" can either be "D" or "F" and "j" can be "f" or "d".

$$STC_{ij} = \frac{STC_i}{2} + \frac{STC_j}{2} + K_{ij} + \max(\Delta STC_i, \Delta STC_j) + \frac{\min(\Delta STC_i, \Delta STC_j)}{2} + 10 \cdot \log_{10} \frac{S_S}{l_0 \cdot l_{ij}} \qquad \text{Eq. 4.1.3}$$

The equation uses the following inputs:

- The laboratory STC rating for each of the unlined assemblies (STC_i and STC_j) plus the lining corrections (ΔSTC_i and ΔSTC_j) from Step 2(b), if applicable
- The K_{ij} value and the normalization correction for this path from Step 2(c).

Step 5: The ASTC rating between two rooms (neglecting sound that is by-passing the building structure, e.g. through leaks or ducts) is estimated from the logarithmic expression of the combination of the STC rating (STC_{Dd}) of the separating wall or floor assembly and the combined flanking STC ratings (STC_{ij}) of the three flanking paths for every junction at the four edges of the separating assembly according to Eq. 4.1.1.

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EXAMPLE 4.1-H1: (SIMPLIFIED METHOD)

- **Rooms side-by-side**
- **Bare CLT Floors and CLT Walls**

Separating wall assembly (loadbearing) with:

- CLT78(3)[1] wall assembly with mass per unit area 42.4 kg/m^2, oriented so that face ply strands are vertical
- No added linings on either side

Junction 1: Bottom Junction (separating wall / floor) with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added topping or flooring

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added linings

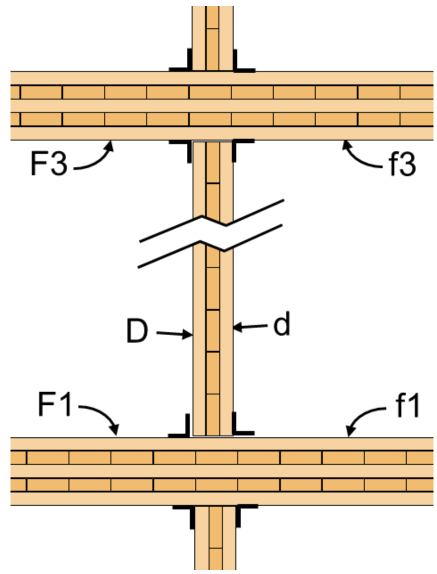
Junction 3: Top Junction (separating wall / ceiling) with:

- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added ceiling lining

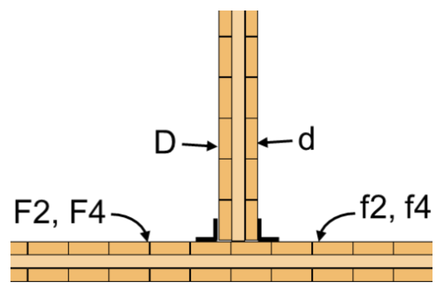
Acoustical Parameters:

Separating partition area (m^2) =			12.5	
Floor/separating wall junction length (m) =			5.0	
Wall/separating wall junction length (m) =			2.5	
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3:				
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01
For Junctions 2 and 4:				
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference		STC or ΔSTC	STC or ASTC
Separating Partition					
Laboratory STC for Dd	R_s,w	RR-335, Base CLT78(3)		36	
ΔSTC change by Lining on D	ΔR_D,w	No lining		0	
ΔSTC change by Lining on d	ΔR_d,w	No lining		0	
If airborne flanking or bare CLT		RR-335, TL(Bare CLT78) - TL(Base CLT78)		-3	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	36 + MAX(0,0) + MIN(0,0)/2 + -3 =		**33**
Junction 1: Separating Wall/Floor					
Flanking Element F1:					
Laboratory STC for F1	R_F1,w	RR-335, Base CLT175(5)-Mean		42	
ΔSTC change by Lining on F1	ΔR_F1,w	No lining		0	
Flanking Element f1:					
Laboratory STC for f1	R_f1,w	RR-335, Base CLT175(5)-Mean		42	
ΔSTC change by Lining on f1	ΔR_f1,w	No lining		0	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 =		**47**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4) =		46
Junction 2: Separating Wall/Wall					
Flanking Element F2:					
Laboratory STC for F2	R_F2,w	RR-335, Base CLT78(3)		36	
ΔSTC change by Lining on F2	ΔR_F2,w	No lining		0	
Flanking Element f2:					
Laboratory STC for f2	R_f2,w	RR-335, Base CLT78(3)		36	
ΔSTC change by Lining on f2	ΔR_f2,w	No lining		0	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 =		**47**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9) =		43
Junction 3: Separating Wall/Ceiling					
Flanking Element F3:					
Laboratory STC for F3	R_F3,w	RR-335, Base CLT175(5)-Mean		42	
ΔSTC change by Lining on F3	ΔR_F3,w	No lining		0	
Flanking Element f3:					
Laboratory STC for f3	R_f3,w	RR-335, Base CLT175(5)-Mean		42	
ΔSTC change by Lining on f3	ΔR_f3,w	No lining		0	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 =		**47**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 =		**54**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4) =		46
Junction 4: Separating Wall/Wall					
Flanking Element F4:					
Laboratory STC for F4	R_F4,w	RR-335, Base CLT78(3)		36	
ΔSTC change by Lining on F4	ΔR_F4,w	No lining		0	
Flanking Element f4:					
Laboratory STC for f4	R_f4,w	RR-335, Base CLT78(3)		36	
ΔSTC change by Lining on f4	ΔR_f4,w	No lining		0	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 =		**47**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 =		**49**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9) =		43
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining 12 Flanking STC values:		38
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**		**32**

EXAMPLE 4.1-H2: (SIMPLIFIED METHOD)

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  (Same as example 4.1-H1, plus linings)

<u>Separating wall assembly (loadbearing) with:</u>

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material in cavities

<u>Junction 1: Bottom Junction (separating wall / floor) with:</u>

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

<u>Junction 2 or 4: Each Side (separating wall / abutting side wall) with:</u>

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c. absorptive material[6] in cavities

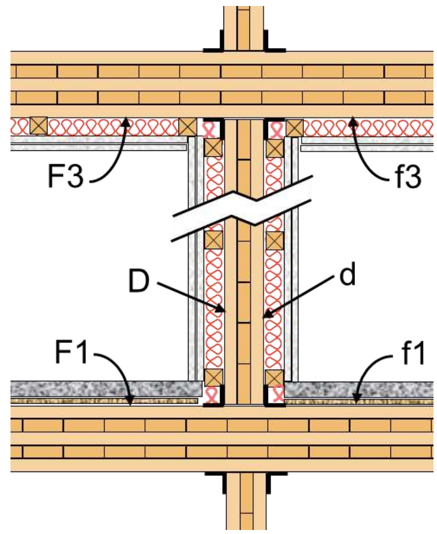
<u>Junction 3: Top Junction (separating wall / ceiling) with:</u>

- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

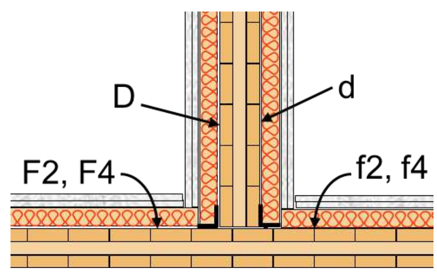
<u>Acoustical Parameters:</u>

Separating partition area (m^2) =			12.5	
Floor/separating wall junction length (m) =			5.0	
Wall/separating wall junction length (m) =			2.5	
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3:				
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01
For Junctions 2 and 4:				
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	STC or ΔSTC	STC or ASTC
Separating Partition				
Laboratory STC for Dd	R_s,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on D	ΔR_D,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
ΔSTC change by Lining on d	ΔR_d,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
If airborne flanking or bare CLT		N/A	N/A	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	36 + MAX(9,9) + MIN(9,9)/2 =	**50**
Junction 1: Separating Wall/Floor				
Flanking Element F1:				
Laboratory STC for F1	R_F1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F1	ΔR_F1,w	RR-335, ΔTL-CLT-F03	10	
Flanking Element f1:				
Laboratory STC for f1	R_f1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f1	ΔR_f1,w	RR-335, ΔTL-CLT-F03	10	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(10,10) + MIN(10,10)/2 + 1.1 + 4 =	**62**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(10,9) + MIN(10,9)/2 + 10.5 + 4 =	**68**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(9,10) + MIN(9,10)/2 + 10.5 + 4 =	**68**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.2 + 10^- 6.8 + 10^- 6.8) =	60
Junction 2: Separating Wall/Wall				
Flanking Element F2:				
Laboratory STC for F2	R_F2,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on F2	ΔR_F2,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking Element f2:				
Laboratory STC for f2	R_f2,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on f2	ΔR_f2,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 =	**60**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 =	**62**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 =	**62**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6 + 10^- 6.2 + 10^- 6.2) =	56
Junction 3: Separating Wall/Ceiling				
Flanking Element F3:				
Laboratory STC for F3	R_F3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F3	ΔR_F3,w	RR-335, ΔTL-CLT-C01	7	
Flanking Element f3:				
Laboratory STC for f3	R_f3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f3	ΔR_f3,w	RR-335, ΔTL-CLT-C01	7	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(7,7) + MIN(7,7)/2 + 1.1 + 4 =	**58**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(7,9) + MIN(7,9)/2 + 10.5 + 4 =	**66**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(9,7) + MIN(9,7)/2 + 10.5 + 4 =	**66**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-5.8 + 10^- 6.6 + 10^- 6.6) =	57
Junction 4: Separating Wall/Wall				
Flanking Element F4:				
Laboratory STC for F4	R_F4,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on F4	ΔR_F4,w	RR-335, ΔTL-CLT-W03	9	
Flanking Element f4:				
Laboratory STC for f4	R_f4,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on f4	ΔR_f4,w	RR-335, ΔTL-CLT-W03	9	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 =	**60**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 =	**62**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 =	**62**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6 + 10^- 6.2 + 10^- 6.2) =	56
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining 12 Flanking STC values:	51
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**	**48**

EXAMPLE 4.1-H3: (SIMPLIFIED METHOD)

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  (Same as example 4.1-H2, except enhanced linings)

Separating wall assembly (loadbearing) with:
- CLT78(3) wall assembly with mass per unit area 42.4 kg/m², oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[2] on resilient metal channels[3] spaced 600 mm o.c., on 38 x 38 mm wood furring spaced 400 mm o.c. with absorptive material[6] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:
- CLT175(5) floor assembly with mass per unit area 91.4 kg/m², continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

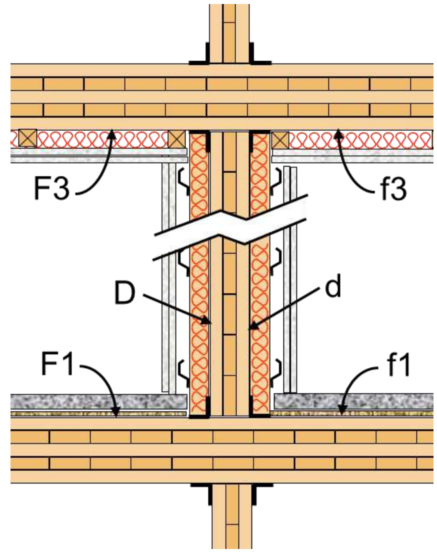
Junction 2 or 4: Each Side (separating wall / abutting side wall) with:
- CLT78(3) wall assembly with mass per unit area 42.4 kg/m², continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

Junction 3: Top Junction (separating wall / ceiling) with:
- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m², continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

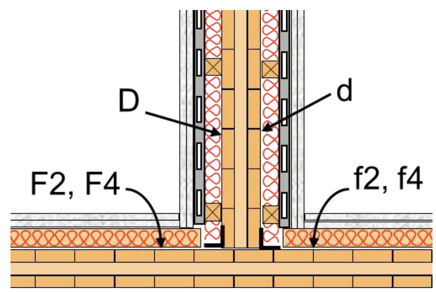
Acoustical Parameters:

Separating partition area (m²) =			12.5	
Floor/separating wall junction length (m) =			5.0	
Wall/separating wall junction length (m) =			2.5	
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3:				
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01
For Junctions 2 and 4:				
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	STC or ΔSTC	STC or ASTC
Separating Partition				
Laboratory STC for Dd	R_s,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on D	ΔR_D,w	RR-335, ΔTL-CLT-W04	15	
ΔSTC change by Lining on d	ΔR_d,w	RR-335, ΔTL-CLT-W04	15	
If airborne flanking or bare CLT		N/A	N/A	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	36 + MAX(15,15) + MIN(15,15)/2 =	**59**
Junction 1: Separating Wall/Floor				
Flanking Element F1:				
Laboratory STC for F1	R_F1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F1	ΔR_F1,w	RR-335, ΔTL-CLT-F03	10	
Flanking Element f1:				
Laboratory STC for f1	R_f1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f1	ΔR_f1,w	RR-335, ΔTL-CLT-F03	10	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(10,10) + MIN(10,10)/2 + 1.1 + 4 =	**62**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(10,15) + MIN(10,15)/2 + 10.5 + 4 =	**74**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(15,10) + MIN(15,10)/2 + 10.5 + 4 =	**74**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.2 + 10^- 7.4 + 10^- 7.4) =	61
Junction 2: Separating Wall/Wall				
Flanking Element F2:				
Laboratory STC for F2	R_F2,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on F2	ΔR_F2,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking Element f2:				
Laboratory STC for f2	R_f2,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on f2	ΔR_f2,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 =	**60**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,15) + MIN(9,15)/2 + 5.7 + 7 =	**68**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(15,9) + MIN(15,9)/2 + 5.7 + 7 =	**68**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6 + 10^- 6.8 + 10^- 6.8) =	59
Junction 3: Separating Wall/Ceiling				
Flanking Element F3:				
Laboratory STC for F3	R_F3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F3	ΔR_F3,w	RR-335, ΔTL-CLT-C01	7	
Flanking Element f3:				
Laboratory STC for f3	R_f3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f3	ΔR_f3,w	RR-335, ΔTL-CLT-C01	7	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(7,7) + MIN(7,7)/2 + 1.1 + 4 =	**58**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 36/2 + MAX(7,15) + MIN(7,15)/2 + 10.5 + 4 =	**72**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 42/2 +MAX(15,7) + MIN(15,7)/2 + 10.5 + 4 =	**72**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-5.8 + 10^- 7.2 + 10^- 7.2) =	58
Junction 4: Separating Wall/Wall				
Flanking Element F4:				
Laboratory STC for F4	R_F4,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on F4	ΔR_F4,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking Element f4:				
Laboratory STC for f4	R_f4,w	RR-335, Base CLT78(3)	36	
ΔSTC change by Lining on f4	ΔR_f4,w	RR-335, ΔTL-CLT(3-ply)-W03	9	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 =	**60**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	36/2 + 36/2 + MAX(9,15) + MIN(9,15)/2 + 5.7 + 7 =	**68**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	36/2 + 36/2 +MAX(15,9) + MIN(15,9)/2 + 5.7 + 7 =	**68**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6 + 10^- 6.8 + 10^- 6.8) =	59
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining all 12 Flanking STC values:	53
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**	**52**

EXAMPLE 4.1-V1: (SIMPLIFIED METHOD)

- **Rooms one-above-the-other**
- **Bare CLT Floors and CLT Walls**

Separating floor assembly with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- No added linings (floor topping or ceiling)

Junction 1, 3 or 4: Separating floor / walls with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- No added lining on walls

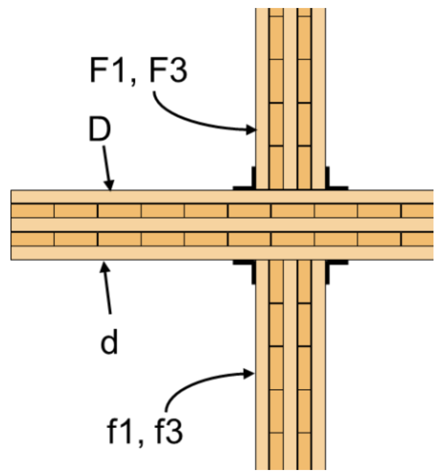
Junction 2: Separating floor / walls with:

- 5 CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- No added lining on walls

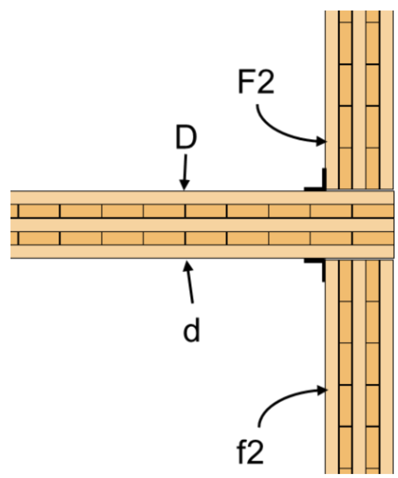
Acoustical Parameters:

Separating partition area (m^2) =	20.0			
Wall/separating floor junction length (m) =	5.0			
Wall/separating floor junction length (m) =	4.0			
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3 and 4:				
Kij [dB] =	17.6	10.2	10.2	RR-335, CLT-FW-Xa-05
10*log(Sep. Area/Junction) =	6.0	For Junctions 1 and 3		
10*log(Sep. Area/Junction) =	7.0	For Junction 4		
For Junction 2:				
Kij [dB] =	12.9	6.8	6.8	RR-335, CLT-FW-Ta-05
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a separating floor of CLT175(5) with CLT175(5) wall assemblies above and below. (Side view of Junctions 1, 3 and 4, except the orientation of the floor assemblies differs for Junction 4)



T-junction of a CLT175(5) floor with CLT175(5) wall assemblies above and below. (Side view of Junction 2)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	STC or ΔSTC	STC or ASTC
Separating Partition				
Laboratory STC for Dd	R_s,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on D	ΔR_D,w	No lining	0	
ΔSTC change by Lining on d	ΔR_d,w	No lining	0	
If airborne flanking or bare CLT		RR-335, TL(Bare CLT175) - TL(Base CLT175)	-1	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	42 + MAX(0,0) + MIN(0,0)/2 + -1 =	**41**
Junction 1: Separating Floor/Wall				
Flanking Element F1:				
Laboratory STC for F1	R_F1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F1	ΔR_F1,w	No lining	0	
Flanking Element f1:				
Laboratory STC for f1	R_f1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f1	ΔR_f1,w	No lining	0	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 6 =	**66**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 =	**58**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 =	**58**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.6 + 10^- 5.8 + 10^- 5.8) =	55
Junction 2: Separating Floor/Wall				
Flanking Element F2:				
Laboratory STC for F2	R_F2,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F2	ΔR_F2,w	No lining	0	
Flanking Element f2:				
Laboratory STC for f2	R_f2,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f2	ΔR_f2,w	No lining	0	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 12.9 + 7 =	**62**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 6.8 + 7 =	**56**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 6.8 + 7 =	**56**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.2 + 10^- 5.6 + 10^- 5.6) =	52
Junction 3: Separating Floor/Wall				
Flanking Element F3:				
Laboratory STC for F3	R_F3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F3	ΔR_F3,w	No lining	0	
Flanking Element f3:				
Laboratory STC for f3	R_f3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f3	ΔR_f3,w	No lining	0	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 6 =	**66**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 =	**58**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 =	**58**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.6 + 10^- 5.8 + 10^- 5.8) =	55
Junction 4: Separating Floor/Wall				
Flanking Element F4:				
Laboratory STC for F4	R_F4,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F4	ΔR_F4,w	No lining	0	
Flanking Element f4:				
Laboratory STC for f4	R_f4,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f4	ΔR_f4,w	No lining	0	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 7 =	**67**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 7 =	**59**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 7 =	**59**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-6.7 + 10^- 5.9 + 10^- 5.9) =	56
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining all 12 Flanking STC values:	48
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**	**40**

EXAMPLE 4.1-V2: (SIMPLIFIED METHOD)

- **Rooms one-above-the-other**
- **CLT Floors and CLT Walls**
  (Same as example 4.1-V1, plus linings)

Separating floor assembly with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board
- Ceiling lining of 15.9 mm gypsum board[2] fastened to hat-channels supported on cross-channels hung on wires, cavity of 150 mm between CLT and ceiling, with 140 mm absorptive material[6]

Junction 1, 3 or 4: (separating floor / flanking walls) with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

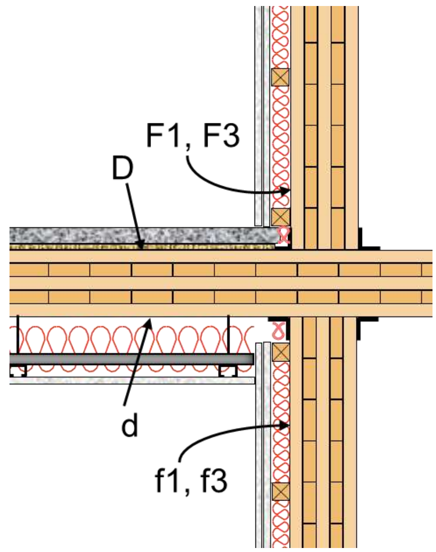
Junction 2: Each Side (separating floor / flanking walls) with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

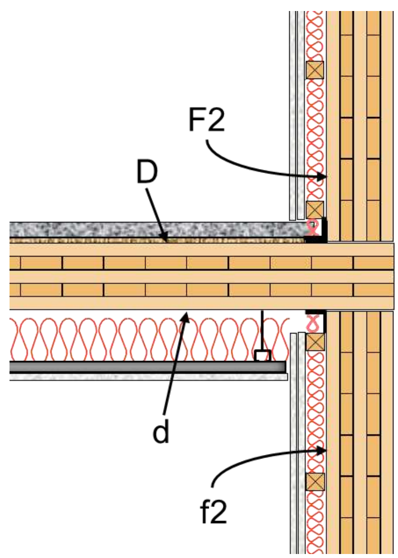
Acoustical Parameters:

Separating partition area (m^2) =			20.0	
Wall/separating floor junction length (m) =			5.0	
Wall/separating floor junction length (m) =			4.0	
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3 and 4:				
Kij [dB] =	17.6	10.2	10.2	RR-335, CLT-FW-Xa-05
10*log(Sep. Area/Junction) =	6.0	For Junctions 1 and 3		
10*log(Sep. Area/Junction) =	7.0	For Junction 4		
For Junction 2:				
Kij [dB] =	12.9	6.8	6.8	RR-335, CLT-FW-Ta-05
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a separating floor of CLT175(5) with CLT175(5) wall assemblies above and below.
(Side view of Junctions 1, 3 and 4, except the orientation of the floor assemblies differs for Junction 4)



T-junction of a CLT175(5) floor with CLT175(5) wall assemblies above and below.
(Side view of Junction 2)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	STC or ΔSTC	STC or ASTC
Separating Partition				
Laboratory STC for Dd	R_s,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on D	ΔR_D,w	RR-335, ΔTL-CLT-F03	10	
ΔSTC change by Lining on d	ΔR_d,w	RR-335, ΔTL-CLT-C03	25	
If airborne flanking or bare CLT		N/A	0	
Direct STC in-situ	R_Dd,w	RR-335, Eq. 4.1.2	42 + MAX(10,25) + MIN(10,25)/2 =	**72**
Junction 1: Separating Floor/Wall				
Flanking Element F1:				
Laboratory STC for F1	R_F1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F1	ΔR_F1,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking Element f1:				
Laboratory STC for f1	R_f1,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f1	ΔR_f1,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking STC for path Ff_1	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 6 =	**78**
Flanking STC for path Fd_1	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 6 =	**87**
Flanking STC for path Df_1	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 6 =	**72**
Junction 1: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-7.8 + 10^- 8.7 + 10^- 7.2) =	71
Junction 2: Separating Floor/Wall				
Flanking Element F2:				
Laboratory STC for F2	R_F2,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F2	ΔR_F2,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking Element f2:				
Laboratory STC for f2	R_f2,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f2	ΔR_f2,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking STC for path Ff_2	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 12.9 + 7 =	**74**
Flanking STC for path Fd_2	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 6.8 + 7 =	**85**
Flanking STC for path Df_2	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 6.8 + 7 =	**70**
Junction 2: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-7.4 + 10^- 8.5 + 10^- 7) =	68
Junction 3: Separating Floor/Wall				
Flanking Element F3:				
Laboratory STC for F3	R_F3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F3	ΔR_F3,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking Element f3:				
Laboratory STC for f3	R_f3,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f3	ΔR_f3,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking STC for path Ff_3	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 6 =	**78**
Flanking STC for path Fd_3	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 6 =	**87**
Flanking STC for path Df_3	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 6 =	**72**
Junction 3: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-7.8 + 10^- 8.7 + 10^- 7.2) =	71
Junction 4: Separating Floor/Wall				
Flanking Element F4:				
Laboratory STC for F4	R_F4,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on F4	ΔR_F4,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking Element f4:				
Laboratory STC for f4	R_f4,w	RR-335, Base CLT175(5)-Mean	42	
ΔSTC change by Lining on f4	ΔR_f4,w	RR-335, ΔTL-CLT(5-ply)-W03	8	
Flanking STC for path Ff_4	R_ Ff,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 7 =	**79**
Flanking STC for path Fd_4	R_ Fd,w	RR-335, Eq. 4.1.3	42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 7 =	**88**
Flanking STC for path Df_4	R_ Df,w	RR-335, Eq. 4.1.3	42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 7 =	**73**
Junction 4: Flanking STC for all paths		Subset of Eq. 4.1.1	- 10*LOG10(10^-7.9 + 10^- 8.8 + 10^- 7.3) =	72
Total Flanking STC (for all 4 junctions)		Subset of Eq. 4.1.1	Combining all 12 Flanking STC values:	64
ASTC due to Direct plus Flanking Paths		Eq. 4.1.1	**Combining Direct STC and 12 Flanking STC values:**	**64**

Summary for Section 4.1: Calculation Examples using the Simplified Method

The worked examples (4.1-H1 to H3 and 4.1-V1 to V2) illustrate the use of the Simplified Method for calculating the sound transmission between rooms in a building with CLT floor and wall assemblies, with or without linings added to some or all of the walls and floors.

The examples show the performance for two cases with bare CLT assemblies without linings (Examples 4.1-H1 and 4.1-V1) and for three cases with improvements in direct and/or flanking sound transmission loss via specific paths due to the addition of some common types of linings using gypsum board, supporting framing, and sound absorbing material. Many other lining options are possible using the ΔSTC ratings for linings in Section 2.1 of this Report.

For a side-by-side pair of rooms, Examples 4.1-H2 and 4.1-H3 show typical improvements relative to Example 4.1-H1. Even with the rather light CLT78(3) separating wall assembly, the addition of a gypsum board lining screwed directly to wood furring on all wall surfaces (Example 4.1-H2) increases the ASTC rating to 48. Inspection of the path STC ratings in Example 4.1-H2 shows that the direct sound transmission through the separating wall is dominant, and that the flanking paths involving the surfaces of the separating wall are also significant. Improving these weak paths by adding resilient channels to the lining on the separating wall increases the Direct STC rating to 59 and the overall ASTC rating to 52. Further improvement is possible but it would require changes to all the flanking surfaces to achieve an ASTC rating above 60.

For a vertical room pair, Example 4.1-V2 shows the improvement relative to Example 4.1-V1 when some typical linings are added. Even with rather basic wall linings with a ΔSTC rating of 8, the ASTC rating is increased to 64. Higher values could be achieved by better wall linings and/or improvements to the floor surface.

Section 4.2 presents worked examples for the same set of constructions presented in Section 4.1, but uses the Detailed Method for calculating the sound transmission between rooms. A comparison of the corresponding examples in the two sections provides a clear indication of the difference in results with the two calculation methods.

4.2 Detailed Calculation Procedure for Cross-laminated Timber Constructions

The calculation process of the Detailed Method of ISO 15712-1 is designed for constructions involving heavy, homogeneous building elements which support reverberant vibration fields. Although cross-laminated timber assemblies have lower mass and higher internal losses than the heavy concrete and masonry walls and floor assemblies considered in Chapter 2 of The Guide RR-331, the flanking sound transmission in buildings composed of CLT assemblies can also be predicted using the Detailed Method of ISO 15712-1. However, the differences between CLT assemblies and walls or floors of bare concrete or masonry require some changes to the calculation approach and alters the laboratory test data required for the calculations.

There are five key changes in the calculations due to properties of CLT assemblies and their junctions:

1. The internal loss factors for CLT assemblies are much higher than those typical of concrete and masonry (which range from 0.006 for solid concrete to 0.015 for typical concrete masonry). For CLT assemblies, measurements of the loss factors for laboratory wall and floor assemblies have established values of 0.03 or higher for most of the frequency range of interest (See Section 2.1.4 in this Report.). This is above the threshold specified in ISO 15712-1 for which corrections need to be made to convert laboratory transmission loss data into in-situ values as shown in Equation 19 of ISO 15712-1. Therefore, the direct sound transmission loss of the unlined separating CLT wall or floor as well as the in-situ sound transmission loss for each unlined CLT flanking surface is taken as equal to the laboratory sound transmission loss determined according to ASTM E90.
2. For flanking transmission, Section 4.2.2 in ISO 15712-1 notes that only resonant sound transmission should be included. This requires a correction below the critical frequency of the sound transmission loss measured in the laboratory. For bare concrete and masonry assemblies, the critical frequency is below 125 Hz and therefore no correction to remove the non-resonant sound transmission is needed. For the CLT78(3) assembly, the critical frequency is about 500 Hz which is in the frequency range of interest when calculating the ASTC rating. Corrections to the laboratory sound transmission loss are therefore recommended at the lower frequencies. Unfortunately, the current version of ISO 15712-1 does not specify a method for determining the resonant sound transmission loss from the measured sound transmission loss. Hence, in the procedure below and in the worked examples, the uncorrected laboratory sound transmission loss is used as the input data. This should lead to conservative results, especially for the flanking sound transmission loss of the CLT78(3) assemblies.
3. The effect of adding linings to the surfaces of the CLT wall and floor assemblies can be treated with an additive correction as is done for concrete and masonry assemblies (see discussion in Section 2.3 of Guide RR-331). Care must be taken to use the Base CLT data for CLT flanking surfaces. Data on the improvements due to linings for several common types of CLT assemblies are provided in Section 2.1.2 of this Report.

4. The connections provided by angle brackets at CLT junctions are not consistent with the symmetric rigid junction assumptions of Annex E of ISO 15712-1 (which are suitable for mortar-bonded junctions of concrete and masonry). Therefore, the junction attenuation for a range of cases needs to be determined using measurements of junction transmission following the appropriate parts of ISO 10848. Chapter 3 of this Report provides vibration reduction index data for a variety of floor/wall and wall-wall CLT junctions.
5. Since the frequency averaged internal losses of CLT assemblies are greater than 0.03, the equivalent absorption length a_{situ} is set numerically equal to the surface area of the CLT assembly when calculating the velocity level difference from measured K_{ij} values using Equation 21 of ISO 15712-1, following Section 4.2.2 of ISO 15712-1.

The input data required for the calculations include both laboratory sound transmission loss data measured according to ASTM E90 and junction attenuation data measured according to ISO 10848.

The calculation process follows the steps illustrated in Figure 4.2.1, and explained in detail below.

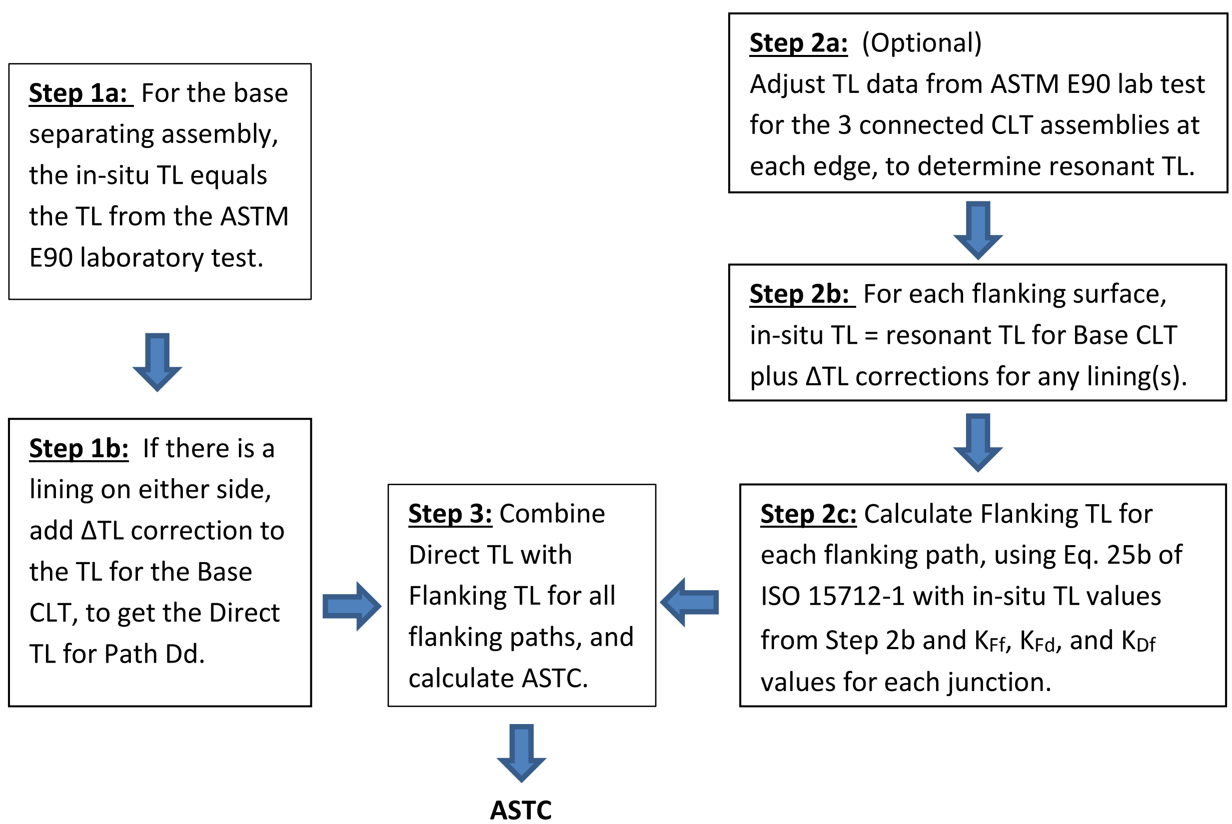


Figure 4.2.1: Steps to calculate the ASTC rating using the Detailed Method.

Step 1: Determine the sound transmission loss of the separating assembly (direct transmission loss):

(a) For the base separating assembly, the in-situ sound transmission loss for each frequency is equal to the sound transmission loss measured in the laboratory without linings according to the standard, ASTM E90.

(b) Add ΔTL corrections obtained following the procedures of ASTM E90 for changes due to added lining(s) on the source room and/or receiving room side of the separating assembly (surfaces D and d) to obtain the direct transmission loss.

Step 2: Determine the sound transmission loss of the flanking assemblies (Flanking TL):

(a) For each flanking surface, use the laboratory measured sound transmission loss determined according to ASTM E90 as a conservative estimate of the resonant sound transmission loss. A correction to calculate the resonant sound transmission loss is recommended, but not defined in ISO 15712-1 and therefore a correction is not used in this Report. Set the equivalent absorption length for each surface numerically equal to the area of the CLT assembly, as required in Section 4.2.2 of ISO 15712-1.

(b) Add ΔTL corrections obtained in accordance with ASTM E90 for changes due to adding a lining on a matching CLT assembly, to calculate the in-situ sound transmission loss values.

(c) For each flanking path, combine the values of the vibration reduction index K_{Ff}, K_{Fd}, and K_{Df} (measured following the procedures of ISO 10848 as presented in Chapter 3) with in-situ sound transmission loss values (including the change due to linings from Step 2b) using Eq. 25b of ISO 15712-1 to obtain the Flanking TL values.

Step 3: Calculate the Apparent TL by combining Direct TL and Flanking TL:

Combine the sound transmission via the direct path and the flanking paths, using Equation 1.1 in Chapter 1 of this Report (equivalent to Eq. 26 in Section 4.4 of ISO 15712-1) to obtain the combined Sound Transmission Loss at each frequency. The combined values are used to calculate the ASTC using the procedure of ASTM E413.

EXAMPLE 4.2-H1: (DETAILED METHOD)

- **Rooms side-by-side**
- **Bare CLT Floors and CLT Walls**

Separating wall assembly (loadbearing) with:

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, oriented so that face ply strands are vertical
- No added linings on either side

Junction 1: Bottom Junction (separating wall / floor) with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added topping or flooring

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added linings

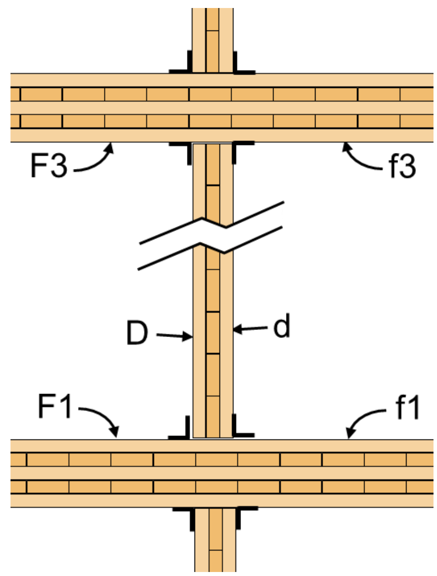
Junction 3: Top Junction (separating wall / ceiling) with:

- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added ceiling lining

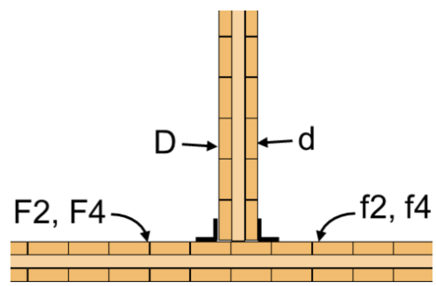
Acoustical Parameters:

Separating wall area (m^2) =	12.5		Sep. wall internal loss, η_i =	>0.03
Floor/sep. wall junction (m) =	5.0		Floor internal loss, η_i =	>0.03
Wall/sep. wall junction (m) =	2.5		Flanking wall int. loss, η_i =	>0.03
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3:				
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01
For Junctions 2 and 4:				
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	No lining	0	0	0	0	0	0	
ΔTL change by Lining on d	ΔR_d	No lining	0	0	0	0	0	0	
If airborne flanking or bare CLT		RR-335, TL(Bare CLT78) - TL(Base CLT78)	-1	-3	-3	-3	-4	-1	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**25**	**25**	**28**	**34**	**42**	**49**	**33**
Junction 1: Separating Wall/Floor									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f1	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-WF-Xa-01	1.1	1.1	1.1	1.1	1.1	1.1	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**35**	**44**	**48**	**57**	**54**	**47**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	36	34	42	47	56	53	46
Junction 2: Separating Wall/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
ΔTL change by Lining on F	ΔR_F2	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f2	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-WW-Tb-01	3.5	3.5	3.5	3.5	3.5	3.5	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**39**	**42**	**48**	**57**	**61**	**47**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	33	35	38	44	53	57	43
Junction 3: Separating Wall/Ceiling									
All values the same as for Junction 1									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**35**	**44**	**48**	**57**	**54**	**47**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**44**	**44**	**50**	**55**	**64**	**64**	**54**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	36	34	42	47	56	53	46
Junction 4: Separating Wall/Wall									
All values the same as for Junction 2									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**37**	**39**	**42**	**48**	**57**	**61**	**47**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**39**	**41**	**44**	**50**	**59**	**63**	**49**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	33	35	38	44	53	57	43
Total Flanking (for all 4 junctions)		Subset of Eq. 1.1	28	29	34	39	48	49	38
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**23**	**23**	**27**	**33**	**41**	**46**	**32**

EXAMPLE 4.2-H2: (DETAILED METHOD)

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  (Same as example 4.2-H1, plus linings)

Separating wall assembly (loadbearing) with:

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

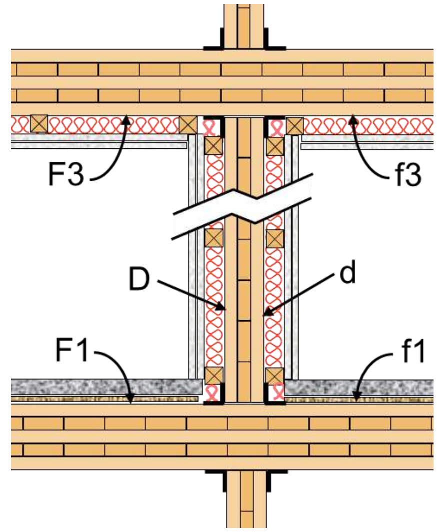
Junction 3: Top Junction (separating wall / ceiling) with:

- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

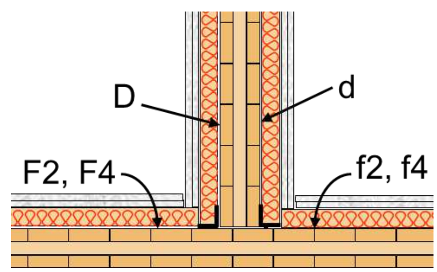
Acoustical Parameters:

Separating wall area (m^2) =	12.5			Sep. wall internal loss, η_i =	>0.03
Floor/sep. wall junction (m) =	5.0			Floor internal loss, η_i =	>0.03
Wall/sep. wall junction (m) =	2.5			Flanking wall int. loss, η_i =	>0.03
	Path Ff	Path Fd	Path Df	Reference	
For Junctions 1 and 3:					
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01	
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01	
For Junctions 2 and 4:					
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01	
10*log(Sep. Area/Junction) =	7.0				

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
ΔTL change by Lining on d	ΔR_d	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
If airborne flanking or bare CLT		N/A	0	0	0	0	0	0	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**34**	**42**	**49**	**61**	**66**	**70**	**52**
Junction 1: Separating Wall/Floor									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	RR-335, ΔTL-CLT-F03	4	11	8	21	29	32	
ΔTL change by Lining on f	ΔR_f1	RR-335, ΔTL-CLT-F03	4	11	8	21	29	32	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-WF-Xa-01	1.1	1.1	1.1	1.1	1.1	1.1	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**57**	**60**	**90**	**90**	**90**	**67**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**52**	**62**	**67**	**88**	**90**	**90**	**73**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**52**	**62**	**67**	**88**	**90**	**90**	**73**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	44	55	59	84	85	85	65
Junction 2: Separating Wall/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
ΔTL change by Lining on F	ΔR_F2	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
ΔTL change by Lining on f	ΔR_f2	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-WW-Tb-01	3.5	3.5	3.5	3.5	3.5	3.5	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**53**	**60**	**72**	**77**	**81**	**63**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**47**	**55**	**62**	**74**	**79**	**83**	**65**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**47**	**55**	**62**	**74**	**79**	**83**	**65**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	41	49	56	68	73	77	59
Junction 3: Separating Wall/Ceiling									
All values the same as for Junction 1, except linings									
ΔTL change by Lining on F	ΔR_F3	RR-335, ΔTL-CLT-C01	2	11	5	12	11	11	
ΔTL change by Lining on f	ΔR_f3	RR-335, ΔTL-CLT-C01	2	11	5	12	11	11	
Flanking Transmission Loss									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**41**	**57**	**54**	**72**	**79**	**76**	**62**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**50**	**62**	**64**	**79**	**85**	**85**	**70**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**50**	**62**	**64**	**79**	**85**	**85**	**70**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	40	55	53	71	77	75	60
Junction 4: Separating Wall/Wall									
All values the same as for Junction 2									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**53**	**60**	**72**	**77**	**81**	**63**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**47**	**55**	**62**	**74**	**79**	**83**	**65**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**47**	**55**	**62**	**74**	**79**	**83**	**65**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	41	49	56	68	73	77	59
Total Flanking (for all 4 junctions)			35	45	50	64	70	72	55
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**32**	**40**	**46**	**59**	**64**	**68**	**50**

EXAMPLE 4.2-H3: (DETAILED METHOD)

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  (Same as example 4.2-H2, except enhanced linings)

Separating wall assembly (loadbearing) with:
- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[2] on resilient metal channels[3] spaced 600 mm o.c., on 38 x 38 mm wood furring spaced 400 mm o.c. with absorptive material[6] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:
- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:
- CLT78(3) wall assembly with mass per unit area 42.4 kg/m^2, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

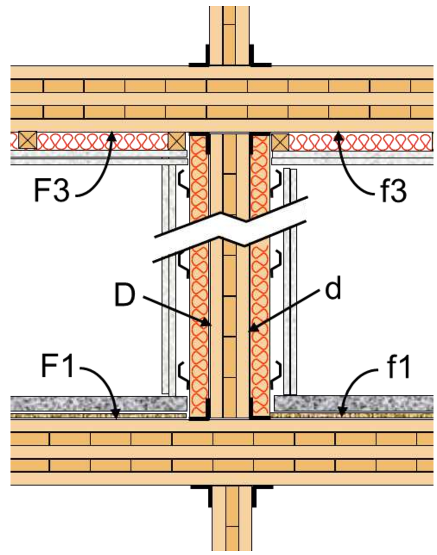
Junction 3: Top Junction (separating wall / ceiling) with:
- CLT175(5) ceiling assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

Acoustical Parameters:

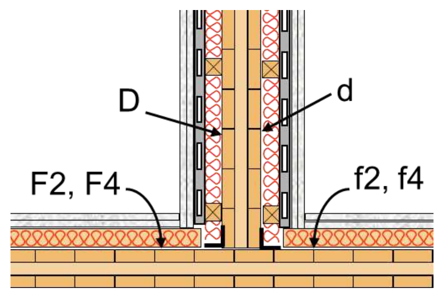
Separating wall area (m^2) =	12.5	Sep. wall internal loss, η_i =	>0.03
Floor/sep. wall junction (m) =	5.0	Floor internal loss, η_i =	>0.03
Wall/sep. wall junction (m) =	2.5	Flanking wall int. loss, η_i =	>0.03

	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3:				
Kij [dB] =	1.1	10.5	10.5	RR-335, CLT-WF-Xa-01
10*log(Sep. Area/Junction) =	4.0			or CLT-WC-Xa-01
For Junctions 2 and 4:				
Kij [dB] =	3.5	5.7	5.7	RR-335, CLT-WW-Tb-01
10*log(Sep. Area/Junction) =	7.0			

Illustration for this case



Cross-junctions of a CLT78(3) wall assembly with CLT175(5) floor and ceiling assemblies.
(Side view of Junctions 1 and 3)



T-junction of separating wall with side wall, both of CLT78(3) assemblies.
(Plan view of Junctions 2 and 4)

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	RR-335, ΔTL-CLT-W04	6	17	20	24	20	22	
ΔTL change by Lining on d	ΔR_d	RR-335, ΔTL-CLT-W04	6	17	20	24	20	22	
If airborne flanking or bare CLT		N/A	0	0	0	0	0	0	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**38**	**62**	**71**	**85**	**86**	**90**	**62**
Junction 1: Separating Wall/Floor									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	RR-335, ΔTL-CLT-F03	4	11	8	21	29	32	
ΔTL change by Lining on f	ΔR_f1	RR-335, ΔTL-CLT-F03	4	11	8	21	29	32	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-WF-Xa-01	1.1	1.1	1.1	1.1	1.1	1.1	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-WF-Xa-01	10.5	10.5	10.5	10.5	10.5	10.5	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**57**	**60**	**90**	**90**	**90**	**67**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**54**	**72**	**78**	**90**	**90**	**90**	**78**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**54**	**72**	**78**	**90**	**90**	**90**	**78**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	44	57	60	85	85	85	67
Junction 2: Separating Wall/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT78(3)	26	28	31	37	46	50	36
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	26	28	31	37	46	50	36
ΔTL change by Lining on F	ΔR_F2	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
ΔTL change by Lining on f	ΔR_f2	RR-335, ΔTL-CLT(3-ply)-W03	4	7	9	12	10	10	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-WW-Tb-01	3.5	3.5	3.5	3.5	3.5	3.5	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-WW-Tb-01	5.7	5.7	5.7	5.7	5.7	5.7	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**53**	**60**	**72**	**77**	**81**	**63**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**49**	**65**	**73**	**86**	**89**	**90**	**73**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**49**	**65**	**73**	**86**	**89**	**90**	**73**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	42	52	60	72	76	80	63
Junction 3: Separating Wall/Ceiling									
All values the same as for Junction 1, except linings									
ΔTL change by Lining on F	ΔR_F3	RR-335, ΔTL-CLT-C01	2	11	5	12	11	11	
ΔTL change by Lining on f	ΔR_f3	RR-335, ΔTL-CLT-C01	2	11	5	12	11	11	
Flanking Transmission Loss									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**41**	**57**	**54**	**72**	**79**	**76**	**62**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**52**	**72**	**75**	**90**	**90**	**90**	**76**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**52**	**72**	**75**	**90**	**90**	**90**	**76**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	40	57	54	72	78	76	61
Junction 4: Separating Wall/Wall									
All values the same as for Junction 2									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**45**	**53**	**60**	**72**	**77**	**81**	**63**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**49**	**65**	**73**	**86**	**89**	**90**	**73**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**49**	**65**	**73**	**86**	**89**	**90**	**73**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	42	52	60	72	76	80	63
Total Flanking (for all 4 junctions)			36	48	51	67	72	73	57
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**34**	**48**	**51**	**67**	**72**	**73**	**57**

EXAMPLE 4.2-V1: (DETAILED METHOD)

- **Rooms one-above-the-other**
- **Bare CLT Floors and CLT Walls**

Separating floor assembly with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- No added linings (floor topping or ceiling)

Junction 1, 3 or 4: Separating floor / walls with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- No added lining on walls

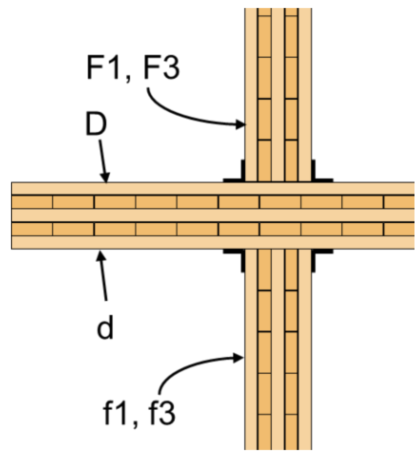
Junction 2: Separating floor / walls with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- No added lining on walls

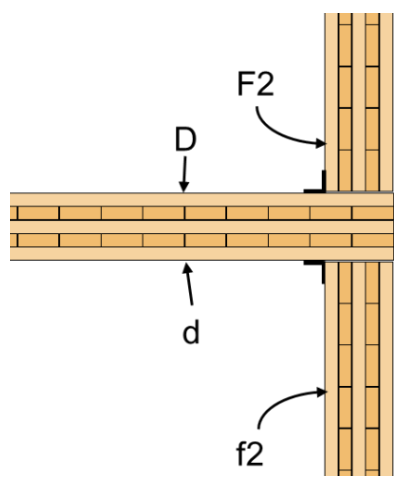
Acoustical Parameters:

Separating floor area (m^2) =	20.0		Floor internal loss, η_i =	>0.03
oor/wall junctions 1 and 3 (m) =	5.0		Wall internal loss, η_i =	>0.03
oor/wall junctions 2 and 4 (m) =	4.0		Wall internal loss, η_i =	>0.03
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3 and 4:				
Kij [dB] =	17.6	10.2	10.2	RR-335, CLT-FW-Xa-05
10*log(Sep. Area/Junction) =	6.0	For Junctions 1 and 3		
10*log(Sep. Area/Junction) =	7.0	For Junction 4		
For Junction 2:				
Kij [dB] =	12.9	6.8	6.8	RR-335, CLT-FW-Ta-05
10*log(Sep. Area/Junction) =	7.0	For Junction 2		

Illustration for this case



Cross-junctions of a separating floor of CLT175(5) with CLT175(5) wall assemblies above and below. (Side view of Junctions 1, 3 and 4, except the orientation of the floor assemblies differs for Junction 4)



T-junction of a CLT175(5) floor with CLT175(5) wall assemblies above and below. (Side view of Junction 2)

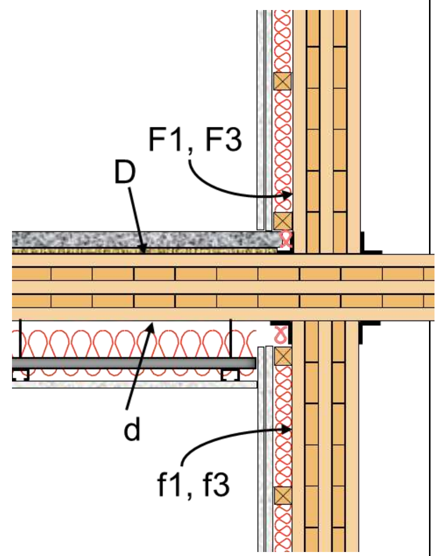
For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	No lining	0	0	0	0	0	0	
ΔTL change by Lining on d	ΔR_d	No lining	0	0	0	0	0	0	
If airborne flanking or bare CLT		RR-335, TL(Bare CLT175) - TL(Base CLT175)	0	-1	-3	1	-1	-3	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**32**	**29**	**36**	**44**	**51**	**46**	**40**
Junction 1: Separating Floor/Wall									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f1	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-FW-Xa-05	17.6	17.6	17.6	17.6	17.6	17.6	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-FW-Xa-05	10.2	10.2	10.2	10.2	10.2	10.2	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-FW-Xa-05	10.2	10.2	10.2	10.2	10.2	10.2	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**56**	**54**	**63**	**67**	**76**	**73**	**66**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**48**	**46**	**55**	**59**	**68**	**65**	**58**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**48**	**46**	**55**	**59**	**68**	**65**	**58**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	45	43	52	56	65	62	55
Junction 2: Separating Floor/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F2	No lining	0	0	0	0	0	0	
ΔTL change by Lining on f	ΔR_f2	No lining	0	0	0	0	0	0	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-FW-Ta-05	12.9	12.9	12.9	12.9	12.9	12.9	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-FW-Ta-05	6.8	6.8	6.8	6.8	6.8	6.8	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-FW-Ta-05	6.8	6.8	6.8	6.8	6.8	6.8	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**52**	**50**	**59**	**63**	**72**	**69**	**62**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**46**	**44**	**53**	**57**	**66**	**63**	**56**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**46**	**44**	**53**	**57**	**66**	**63**	**56**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	42	40	49	53	62	59	52
Junction 3: Separating Floor/Wall									
All values the same as for Junction 1									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**56**	**54**	**63**	**67**	**76**	**73**	**66**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**48**	**46**	**55**	**59**	**68**	**65**	**58**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**48**	**46**	**55**	**59**	**68**	**65**	**58**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	45	43	52	56	65	62	55
Junction 4: Separating Floor/Wall									
Transmission loss values of flanking elements are the same as for Junction 2, but Kij values are the same as for Junction 1 and 3 (cross-junction).									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**57**	**55**	**64**	**68**	**77**	**74**	**67**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**49**	**47**	**56**	**60**	**69**	**66**	**59**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**49**	**47**	**56**	**60**	**69**	**66**	**59**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	46	44	53	57	66	63	56
Total Flanking (for all 4 junctions)			38	36	45	49	58	55	48
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**31**	**28**	**36**	**43**	**50**	**46**	**40**

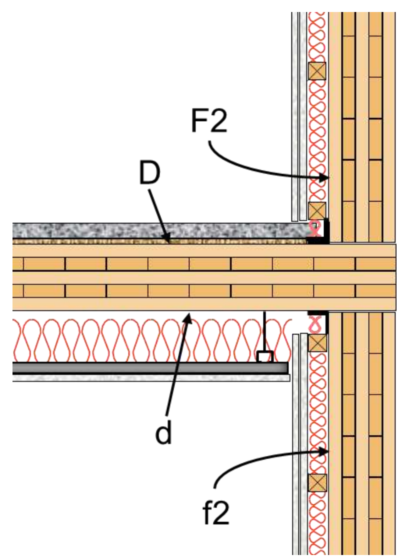
EXAMPLE 4.2-V2: **(DETAILED METHOD)**

- **Rooms one-above-the-other**
- **CLT Floors and CLT Walls**
  (Same as example 4.2-V1, plus linings)

Illustration for this case



Cross-junctions of a separating floor of CLT175(5) with CLT175(5) wall assemblies above and below. (Side view of Junctions 1, 3 and 4, except the orientation of the floor assemblies differs for Junction 4)



T-junction of a CLT175(5) floor with CLT175(5) wall assemblies above and below.
(Side view of Junction 2)

Separating floor assembly with:

- CLT175(5) floor assembly with mass per unit area 91.4 kg/m^2, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board
- Ceiling lining of 15.9 mm gypsum board[2] fastened to hat-channels supported on cross-channels hung on wires, cavity of 150 mm between CLT and ceiling, with 140 mm absorptive material[6]

Junction 1, 3 or 4: (separating floor / flanking walls) with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

Junction 2: Each Side (separating floor / flanking walls) with:

- CLT175(5) wall assembly with mass per unit area 91.4 kg/m^2, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- Two layers of 12.7 mm gypsum board[2] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[6] in cavities

Acoustical Parameters:

Separating floor area (m^2) =	20.0		Floor internal loss, η_i =	>0.03
oor/wall junctions 1 and 3 (m) =	5.0		Wall internal loss, η_i =	>0.03
oor/wall junctions 2 and 4 (m) =	4.0		Wall internal loss, η_i =	>0.03
	Path Ff	Path Fd	Path Df	Reference
For Junctions 1 and 3 and 4:				
Kij [dB] =	17.6	10.2	10.2	RR-335, CLT-FW-Xa-05
10*log(Sep. Area/Junction) =	6.0	For Junctions 1 and 3		
10*log(Sep. Area/Junction) =	7.0	For Junction 4		
For Junction 2:				
Kij [dB] =	12.9	6.8	6.8	RR-335, CLT-FW-Ta-05
10*log(Sep. Area/Junction) =	7.0	For Junction 2		

For the notes in this table please see the corresponding endnotes.

	ISO Symbol	Reference	125	250	500	1000	2000	4000	STC or ASTC
Separating Partition									
Laboratory Transmission Loss	R_D,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission		N/A	0	0	0	0	0	0	
ΔTL change by Lining on D	ΔR_D	RR-335, ΔTL-CLT-F03	4	11	8	21	29	32	
ΔTL change by Lining on d	ΔR_d	RR-335, ΔTL-CLT-C03	15	25	30	36	34	30	
If airborne flanking or bare CLT		N/A	0	0	0	0	0	0	
Direct TL in-situ	R_D,situ	ISO 15712-1, Eq. 24	**51**	**66**	**77**	**90**	**90**	**90**	**75**
Junction 1: Separating Floor/Wall									
Transmission Loss of Flanking Elements									
TL of element F1, laboratory	R_F1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f1, laboratory	R_f1,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F1		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f1		N/A	0	0	0	0	0	0	
TL of element F1, in-situ	R_F1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f1, in-situ	R_f1,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F1	RR-335, ΔTL-CLT(5-ply)-W03	3	8	5	11	10	11	
ΔTL change by Lining on f	ΔR_f1	RR-335, ΔTL-CLT(5-ply)-W03	3	8	5	11	10	11	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,1	RR-335, CLT-FW-Xa-05	17.6	17.6	17.6	17.6	17.6	17.6	
Vibration Reduction Index for Fd	K_Fd,1	RR-335, CLT-FW-Xa-05	10.2	10.2	10.2	10.2	10.2	10.2	
Vibration Reduction Index for Df	K_Df,1	RR-335, CLT-FW-Xa-05	10.2	10.2	10.2	10.2	10.2	10.2	
Flanking Transmission Loss									
Flanking TL for path Ff_1	R_ Ff	ISO 15712-1, Eq. 25b	**62**	**70**	**73**	**89**	**90**	**90**	**81**
Flanking TL for path Fd_1	R_ Fd	ISO 15712-1, Eq. 25b	**66**	**79**	**90**	**90**	**90**	**90**	**88**
Flanking TL for path Df_1	R_ Df	ISO 15712-1, Eq. 25b	**55**	**65**	**68**	**90**	**90**	**90**	**76**
Junction 1: Flanking TL for all paths		Subset of Eq. 1.1	54	64	67	85	85	85	75
Junction 2: Separating Floor/Wall									
Transmission Loss of Flanking Elements									
TL of element F2, laboratory	R_F2,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
TL of element f2, laboratory	R_f2,lab	RR-335, Base CLT175(5)	32	30	39	43	52	49	42
Correction Resonant Transmission F2		N/A	0	0	0	0	0	0	
Correction Resonant Transmission f2		N/A	0	0	0	0	0	0	
TL of element F2, in-situ	R_F2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
TL of element f2, in-situ	R_f2,situ	ISO 15712-1, Eq. 19, T_s,situ = T_s,lab	32	30	39	43	52	49	42
ΔTL change by Lining on F	ΔR_F2	RR-335, ΔTL-CLT(5-ply)-W03	3	8	5	11	10	11	
ΔTL change by Lining on f	ΔR_f2	RR-335, ΔTL-CLT(5-ply)-W03	3	8	5	11	10	11	
Junction Coupling									
Vibration Reduction Index for Ff	K_Ff,2	RR-335, CLT-FW-Ta-05	12.9	12.9	12.9	12.9	12.9	12.9	
Vibration Reduction Index for Fd	K_Fd,2	RR-335, CLT-FW-Ta-05	6.8	6.8	6.8	6.8	6.8	6.8	
Vibration Reduction Index for Df	K_Df,2	RR-335, CLT-FW-Ta-05	6.8	6.8	6.8	6.8	6.8	6.8	
Flanking Transmission Loss									
Flanking TL for path Ff_2	R_ Ff	ISO 15712-1, Eq. 25b	**58**	**66**	**69**	**85**	**90**	**90**	**77**
Flanking TL for path Fd_2	R_ Fd	ISO 15712-1, Eq. 25b	**64**	**77**	**88**	**90**	**90**	**90**	**87**
Flanking TL for path Df_2	R_ Df	ISO 15712-1, Eq. 25b	**53**	**63**	**66**	**89**	**90**	**90**	**74**
Junction 2: Flanking TL for all paths		Subset of Eq. 1.1	52	61	64	83	85	85	72
Junction 3: Separating Floor/Wall									
All values the same as for Junction 1									
Flanking TL for path Ff_3	R_ Ff	ISO 15712-1, Eq. 25b	**62**	**70**	**73**	**89**	**90**	**90**	**81**
Flanking TL for path Fd_3	R_ Fd	ISO 15712-1, Eq. 25b	**66**	**79**	**90**	**90**	**90**	**90**	**88**
Flanking TL for path Df_3	R_ Df	ISO 15712-1, Eq. 25b	**55**	**65**	**68**	**90**	**90**	**90**	**76**
Junction 3: Flanking TL for all paths		Subset of Eq. 1.1	54	64	67	85	85	85	75
Junction 4: Separating Floor/Wall									
Transmission loss values of flanking elements are the same as for Junction 2, but Kij values are the same as for Junction 1 or 3 (cross-junction).									
Flanking TL for path Ff_4	R_ Ff	ISO 15712-1, Eq. 25b	**63**	**71**	**74**	**90**	**90**	**90**	**82**
Flanking TL for path Fd_4	R_ Fd	ISO 15712-1, Eq. 25b	**67**	**80**	**90**	**90**	**90**	**90**	**88**
Flanking TL for path Df_4	R_ Df	ISO 15712-1, Eq. 25b	**56**	**66**	**69**	**90**	**90**	**90**	**77**
Junction 4: Flanking TL for all paths		Subset of Eq. 1.1	55	65	68	85	85	85	76
Total Flanking (for all 4 junctions)			47	57	60	78	79	79	68
ASTC due to Direct plus Flanking Paths		RR-335, Eq. 1.1	**46**	**57**	**60**	**78**	**79**	**79**	**67**

Summary for Section 4.2: Calculation Examples using the Detailed Method

The worked examples (4.2-H1 to H3 and 4.2-V1 to V2) illustrate the use of the Detailed Method for calculating the sound transmission between rooms in a building with CLT floor and wall assemblies, with or without linings added to some or all of the walls and floors.

The examples present the calculations for the same set of scenarios used to illustrate the Simplified Method in Section 3.1.

- For the cases without linings (4.2-H1 and 4.2-V1), the detailed calculations result in the same ASTC ratings as the simplified calculations. This agreement (aside from possible rounding errors of ±1) is to be expected since the methods deal with the same data in slightly different ways.
- However, for the cases with linings, the differences between the calculation methods are larger, because the Simplified Method treats the improvement due to linings using a deliberately conservative approximation for the ΔSTC rating. In the Detailed Method, the ΔTL value for the two linings in each transmission path are simply added to the sound transmission loss values for the base assemblies, which tends to give higher predicted values of the ASTC rating.
- In each of the cases with linings shown in these examples, the Detailed Method gives a result that is higher by 2 to 5 ASTC points than the Simplified Method. For linings with higher ΔSTC ratings, there would be a greater difference between the two calculations methods.

5 Appendices of Sound Transmission Data

This Appendix presents one-third octave band sound transmission loss data. The data includes:

- The sound transmission loss values for the Bare and the Base mass timber assemblies measured according to the standard, ASTM E90. The details of the test facilities and the measurement procedures are given in Chapter 2 and Chapter 3.
- The ΔTL data for the change in sound transmission loss due to the addition of linings to the Base mass timber assemblies in one-third octave bands. The process for determining the ΔTL values is described in Chapter 2.
- The structural reverberation times for the tested unlined mass timber assemblies
- The bending wavenumbers for the mass timber assemblies

The transmission loss and ΔTL values in one-third octave bands presented in this Appendix may be used for calculations according to the Detailed Method of ISO 15712-1, as described in Section 4.3.

This Appendix also presents the comparable single number ratings:

- The ΔSTC rating for the change in sound transmission loss due to the addition of linings to the Base mass timber assemblies. The procedure for calculating the ΔSTC rating is presented in Appendix A2.

The single-number STC and ΔSTC ratings presented in this Appendix may be used for calculations according to the Simplified Method of ISO 15712-1, as described in Section 4.1.

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Appendix A1.1:
Sound Transmission Data for CLT Wall and Floor Assemblies

This section of Appendix A1 includes data for the sound transmission loss of Cross Laminated Timber (CLT) assemblies:

A1.1.1 Airborne sound transmission loss for the ***Bare*** CLT assemblies (See Section 2.1.1)

A1.1.2 Airborne sound transmission loss for the ***Base*** CLT assemblies (See Section 2.1.1)

A1.1.3 Structural reverberation times for the tested unlined CLT assemblies (See Section 2.1.4)

A1.1.4 One-third octave band ΔTL values for the ***change*** in sound transmission loss (ΔTL) due to linings on single-leaf CLT assemblies (See Section 2.1.2)

A1.1.5 One-third octave band ΔTL values for the ***change*** in sound transmission loss (ΔTL) due to linings on double-leaf CLT78(3) wall assemblies (See Section 2.1.3)

A1.1.6 One-third octave band values for the wavenumbers of the CLT assemblies (See Section 2.1.5)

Details of the test facilities and the measurement procedures are given in Chapter 2.

Table A1.1.1: Sound transmission loss data for **Bare CLT** assemblies. Note that the results are compromised by leakage, as explained in Section 2.1.1.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Bare CLT78(3)	One leaf of 3-ply CLT, 42.4 kg/m^2 78 mm thick	**33**	24	24	22	24	25	25	25	25	25
Bare CLT175(5) (mean)	One leaf of 5-ply CLT, 91.4 kg/m^2 175 mm thick	**41**	28	30	25	29	32	31	29	30	29
Bare CLT245(7)	One leaf of 7-ply CLT, 130 kg/m^2 245 mm thick	**44**	30	28	32	30	33	32	31	32	36
Bare CLT292(9)	One leaf of 9-ply CLT, 157 kg/m^2 292 mm thick	**45**	34	33	34	31	32	33	31	32	35
Bare 2-leaf CLT78(3)	Two leafs of 3-ply CLT, total 89.6 kg/m^2, 181 mm thick	**47**	25	19	20	28	34	34	39	35	36

Table A1.1.2: Sound transmission loss data for **Base CLT** assemblies. Note that the data has been corrected to eliminate sound transmission due to leakage, as explained in Section 2.1.1.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Base CLT78(3)	One leaf of 3-ply CLT, 42.4 kg/m^2 78 mm thick	**36**	26	25	22	26	26	26	27	28	28
Base CLT175(5) (mean)	One leaf of 5-ply CLT, 91.4 kg/m^2 175 mm thick	**42**	28	29	27	28	32	32	30	30	30
Base CLT245(7)	One leaf of 7-ply CLT, 130 kg/m^2 245 mm thick	**45**	31	30	33	31	34	31	32	33	37
Base CLT292(9)	One leaf of 9-ply CLT, 157 kg/m^2 292 mm thick	**45**	34	32	34	32	33	30	31	32	36
Base 2-leaf CLT78(3)	Two leafs of 3-ply CLT, total 89.6 kg/m^2, 181 mm thick	**50**	28	16	21	28	36	37	41	36	39

Table A1.1.3: Structural reverberation times for the tested CLT assemblies

Specimen Code	Description		63 Hz			125 Hz			250 Hz		
CLT78(3)	One leaf of 3-ply CLT, 42.4 kg/m^2 78 mm thick					.321	.230	.205	.151	.170	.134
CLT175(5)-Wall	One leaf of 5-ply CLT, 91.4 kg/m^2 175 mm thick					.217	.229	.225	.185	.194	.187
CLT175(5)-Floor	One leaf of 5-ply CLT, 91.4 kg/m^2 175 mm thick					.462	.496	.258	.242	.142	.148
CLT245(7)	One leaf of 7-ply CLT, 130 kg/m^2 245 mm thick										
CLT292(9)	One leaf of 9-ply CLT, 157 kg/m^2 292 mm thick										

(**Continuation of Table A1.1.1 from opposite page**):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
26	28	29	30	34	37	40	42	45	47	49	48	TLA-12-197,223
34	36	39	42	44	47	49	52	50	45	46	50	TLA-12-170:171
38	40	42	44	47	49	52	53	51	51	53	54	TLF-13-025
38	40	44	47	49	51	51	50	49	49	48	48	TLA-19-046
38	42	46	49	56	62	68	74	80	84	85	84	TLA-12-222

(Continuation of Table A1.1.2 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
28	31	33	34	37	39	42	46	46	50	50	48	TLA-12-197:199,223
37	39	41	44	43	46	48	52	51	50	49	50	TLA-12-170:176
39	41	43	43	46	48	52	51	51	53	56	60	TLF-13-023:025
39	41	44	47	49	51	51	49	48	49	49	49	TLA-19-057
43	46	48	52	59	63	67	75	82	86	87	83	TLA-12-218:222

(Continuation of Table A1.1.3 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
.120	.103	.092	.075	.063	.045	.039	.040	.027	.027	.026	.020	
.123	.094	.069	.064	.052	.041	.035	.028	.024	.020	.023	.019	
.104	.078	.082	.078	.062	.052	.045	.041	.035	.029	.022	.020	

Table A1.1.4: Change in sound transmission loss (ΔTL) due to linings on single-leaf CLT assemblies

Lining Code	Lining Description	ΔSTC	63 Hz			125 Hz			250 Hz		
Wall Linings											
ΔTL-CLT78(3)-W01	2G13	**2**	2	2	2	2	3	3	2	2	1
ΔTL-CLT175(5)-W01	2G13	**0**	1	1	1	2	1	0	1	0	1
ΔTL-CLT78(3)-W02	2G13_WFUR38(400)_GFB38	**4**	1	-1	-2	0	1	-3	1	11	8
ΔTL-CLT175(5)-W02	2G13_WFUR38(400)_GFB38	**-5**	1	1	-1	-3	-6	-8	2	8	6
ΔTL-CLT78(3)-W03	2G13_WFUR38(600)_GFB38	**9**	1	-1	-2	-5	4	6	10	7	6
ΔTL-CLT175(5)-W03	2G13_WFUR38(600)_GFB38	**8**	-1	-5	-6	-4	3	7	10	8	8
ΔTL-CLT-W04	2G13_RC13(600)_ WFUR38(400)_GFB38	**15**	-4	-8	-4	2	6	11	13	17	18
ΔTL-CLT-W05	2G13_WFUR64(600)_GFB65	**6**	-1	-6	-6	1	7	6	11	6	7
ΔTL-CLT-W06	2G13_WS64(600)_GFB65 _AIR13	**16**	-4	1	7	10	13	14	13	17	19
Ceiling Linings											
ΔTL-CLT-C01	2G13_WFUR38(600)_GFB38	**7**	1	-4	-2	-2	2	2	9	11	9
ΔTL-CLT-C02	2G13_UC22(600)_ CC38(1200)_GFB140	**25**	-3	3	5	10	14	17	23	24	28
ΔTL-CLT-C03	G16_UC22(600)_CC38(1200) GFB140_2G13	**25**	0	7	8	11	15	18	22	25	27
Floor Linings											
ΔTL-CLT-F01	CON38(no bond)	**7**	9	3	9	4	5	5	7	9	11
ΔTL-CLT-F02	CON38_FOAM09	**11**	6	4	10	6	6	4	8	10	15
ΔTL-CLT-F03	CON38_WFB13	**10**	6	7	9	5	4	6	10	11	13
ΔTL-CLT-F04	CON38_FELT19	**15**	6	7	2	1	6	8	13	17	21
ΔTL-CLT-F05	CON38_RESL13	**9**	8	5	8	3	1	4	8	12	16
ΔTL-CLT-F06	CON38_RESL08	**9**	7	6	10	6	4	5	9	11	13
ΔTL-CLT-F07	CON38_RESL17	**11**	6	7	9	5	4	5	9	12	15
ΔTL-CLT-F08	2CEMBRD12_WFB13	**4**	4	-4	1	-2	-2	-1	3	5	8
ΔTL-CLT-F09	GCON38_FOAM09	**7**	9	-3	9	4	2	3	5	5	9

(**Continuation of Table A1.1.4 from opposite page**)

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
1	0	1	2	3	5	5	2	1	0	3	6	TLA-12-197:203 vs.Base03
-2	-1	1	2	5	5	6	3	1	2	5	8	TLA-12-170:177 vs.Base05
8	9	10	11	11	11	10	9	5	5	8	11	TLA-12-201:202 vs.Base03
6	7	9	8	10	9	10	7	4	6	10	13	TLA-12-172:178 vs.Base05
10	9	10	11	12	12	12	10	7	6	10	14	TLA-12-197:203 vs.Base03
6	5	9	9	11	11	12	10	6	7	11	15	TLA-12-181:184 vs.Base05
19	20	21	22	24	23	23	20	16	18	22	24	TLA-12-177:180 vs.Base05
4	5	8	7	9	9	10	8	6	8	12	16	TLA-12-181:184 vs.Base05
17	17	17	17	21	22	24	22	21	24	27	30	TLA-12-185 vs.Base05
7	5	8	8	12	12	14	11	5	7	11	14	TLF-13-014 vs. Base05F
29	33	36	35	38	38	36	29	28	30	35	38	TLF-13-012 vs. Base05F
27	30	32	31	36	36	37	34	28	28	30	33	TLF-13-016:21 vs. Base05F
6	5	6	6	10	11	14	16	20	22	26	31	TLF-13-010 vs. Base05F
13	12	15	17	22	23	26	27	30	30	32	35	TLF-12-048 vs. Base05F
10	8	11	15	21	23	27	29	28	28	32	36	TLF-12-049 vs. Base05F
21	19	21	22	25	25	28	31	32	33	38	44	TLF-12-044 vs. Base05F
13	12	16	19	25	28	32	34	30	31	38	43	TLF-13-009 vs. Base05F
10	8	10	12	17	19	22	24	28	30	35	38	TLF-12-052, 13-001 vs. Base05F
13	12	16	18	24	26	29	32	34	36	39	42	TLF-13-004 vs. Base05F
7	8	11	12	17	19	21	17	15	16	20	25	TLF-13-017:018 vs.Base05F
9	9	11	12	15	17	20	21	24	24	25	23	TLF-13-020:021 vs. Base05F

Table A1.1.5: Change in sound transmission loss (ΔTL) due to linings on double-leaf CLT78(3) wall assemblies

Lining Code	Lining Description	ΔSTC	63 Hz			125 Hz			250 Hz		
ΔTL-2xCLT78(3)-W01	2G13	**3**	-3	4	3	3	2	3	1	4	2
ΔTL-2xCLT78(3)-W03	2G13_WFUR38(600)_GFB38	**6**	-7	2	0	-1	2	7	8	8	5

Table A1.1.6: Measured bending wavenumbers in rad/m for the CLT assemblies

Specimen Code	Description	Dir.	63 Hz	125 Hz			250 Hz		
Bare CLT175(5)	One leaf of 5-ply CLT, 91.4 kg/m^2 175 mm thick	**Hor.**		.36	1.08	5.45	1.75	1.68	3.49
		Vert.		.07	1.19	4.26	.01	.66	4.75
Bare CLT245(7)	One leaf of 7-ply CLT, 130 kg/m^2 245 mm thick	**Hor.**		1.11	1.37	1.61	4.01	4.59	2.58
		Vert.		1.01	4.44	2.67	3.46	2.33	5.24
Bare CLT292(9)	One leaf of 9-ply CLT, 158 kg/m^2 292 mm thick	**Hor.**		.87	1.23	1.63	1.26	3.19	4.23
		Vert.		.27	2.14	3.04	3.27	5.40	.17

(**Continuation of Table A1.1.5 from opposite page**):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
2	3	6	7	6	6	7	6	3	2	1	1	TLA-12-220,221 vs. Base 2xCLT78(3)
7	9	12	11	9	10	11	9	5	4	2	2	TLA-12-218 vs. Base 2xCLT78(3)

(**Continuation of Table A1.1.6 from opposite page**):

500 Hz			1000 Hz			2000 Hz			4000 Hz		Reference
4.26	4.26	6.54	7.92	10.02	13.3	13.95	17.89	21.2	23.86	24.9	
7.60	5.67	9.84	10.58	12.71	13.62	21.2	22.9	26.03	40.92	27.27	
2.28	5.29	7.12	8.26	10.02	11.91	14.3	13.95	19.08	23.86	28.64	
6.94	4.40	8.03	9.36	11.2	14.3	18.46	19.74	14.3	26.03	44.07	
2.66	3.53	6.94	6.04	6.54	8.14	10.39	15.89	10.78	14.67	15.06	
3.56	6.31	7.4	10.39	13.3	16.35	19.08	22.02	14.67	52.08	38.19	

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Appendix A1.2:
Sound Transmission Data for NLT Wall and Floor Assemblies

This section of Appendix A1 includes data for the sound transmission loss of Nail Laminated Timber (NLT) assemblies:

A1.2.1 Airborne sound transmission loss for the Base NLT assemblies including a 19 mm plywood shear membrane attached on 1 side of the sealed NLT assembly (See Section 2.2.1)

A1.2.2 One-third octave band ΔTL values for the change in sound transmission loss due to the addition of linings to the Base NLT assemblies (See Section 2.2.2)

A1.2.3 Airborne sound transmission loss data for NLT89 specimens, tested according to standard ASTM E90

A1.2.4 Airborne sound transmission loss data for NLT140 specimens, tested according to standard ASTM E90

A1.2.5 Airborne sound transmission loss data for NLT191 specimens, tested according to standard ASTM E90

A1.2.6 Airborne sound transmission loss data for NLT242 specimens, tested according to standard ASTM E90

A1.2.7 Airborne sound transmission loss data for NLT293 specimens, tested according to standard ASTM E90

A1.2.8 Structural reverberation times for the tested NLT assemblies

A1.2.9 One-third octave band values for the wavenumbers of the NLT assemblies (See Section 2.2.4)

Details of the test facilities and the measurement procedures are given in Chapter 2.

Table A1.2.1: Sound transmission loss data for **Base NLT** assemblies which have a shear membrane of 19 mm plywood attached on one side of the sealed NLT assembly. Attaching a shear membrane to the NLT assembly is normal practice to provide structural rigidity in typical applications, as explained in Section 2.1.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Base NLT89	NLT89_PLY19	**34**	26	25	26	25	29	27	25	24	25
Base NLT140	NLT140_PLY19	**36**	31	30	30	29	32	28	29	25	30
Base NLT184	NLT184_PLY19	**38**	31	31	30	28	33	26	25	35	28
Base NLT235	NLT235_PLY19	**41**	30	33	31	30	35	33	27	36	34
Base NLT286	NLT286_PLY19	**43**	30	35	35	29	32	35	35	33	38

Note 1: ΔPLY19 is estimated from TLA-18-048 vs. 036, TLA-18-046 vs. 047, TLA-18-060 vs. 061
Note 2: For a NLT assembly thicknesses not listed, use the nearest entry.

Table A1.2.2: Change in sound transmission loss (ΔTL) due to linings on NLT wall assemblies

Lining Code	Lining Description	ΔSTC	63 Hz			125 Hz			250 Hz		
ΔTL-NLT140-W02	2G13_WFUR38(400)_GFB38	**1**	-2	0	-1	-4	-6	-5	-1	10	7
ΔTL-NLT184-W02	2G13_WFUR38(400)_GFB38	**-3**	-1	1	1	0	-9	-4	3	1	10
ΔTL-NLT235-W02	2G13_WFUR38(400)_GFB38	**-3**	0	0	0	-4	-10	-8	4	5	5
ΔTL-NLT286-W02	2G13_WFUR38(400)_GFB38	**-7**	-1	-2	-2	0	-6	-11	2	11	3
ΔTL-NLT140-W06	2G13_WS64(600)_GFB65_AIR13	**23**	-2	4	8	13	11	14	17	22	21
ΔTL-NLT184-W06	2G13_WS64(600)_GFB65_AIR13	**19**	0	6	9	14	9	14	18	13	23
ΔTL-NLT235-W06	2G13_WS64(600)_GFB65_AIR13	**19**	1	2	5	8	10	14	20	15	20
ΔTL-NLT286-W06	2G13_WS64(600)_GFB65_AIR13	**20**	1	-1	3	11	11	15	20	21	17
Mean ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	**21**	0	3	6	11	10	14	19	18	20
ΔTL-NLT286-F01	CON38(no bond)	**8**	7	3	-1	6	6	1	3	7	9
ΔTL-NLT286-F02	CON38_FOAM09	**12**	7	0	1	6	4	3	7	10	14
ΔTL-NLT286-F03	CON38_WFB13	**13**	7	0	0	8	10	7	9	11	14

(**Continuation of Table A1.2.1** from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
27	29	30	32	35	39	42	44	47	49	51	53	TLA-17-152, ΔPLY19[1]
30	31	33	35	37	40	42	43	45	47	51	54	TLA-18-048
35	32	35	36	40	42	44	43	45	48	51	54	TLA-18-022, ΔPLY19[1]
37	36	39	39	41	42	43	46	48	51	54	57	TLA-18-046
37	40	41	42	43	43	45	48	50	53	56	59	TLA-18-060

(Continuation of Table A1.2.2 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
10	13	13	13	13	13	12	12	7	7	7	9	TLA-18-029,035,048
7	11	10	11	10	11	12	12	8	7	9	10	TLA-18-013,020,022+
4	9	8	11	13	14	15	12	8	8	9	11	TLA-18-040,043,046
7	8	9	12	13	15	14	11	8	9	10	11	TLA-18-052,057,060
25	28	28	29	29	29	28	29	26	27	27	27	TLA-18-031,033,048
20	25	24	26	25	26	27	30	28	28	29	28	TLA-18-014,019,022+
19	22	20	21	24	27	30	29	27	27	29	26	TLA-18-029,041,045
19	19	20	22	23	27	29	27	25	26	28	25	TLA-18-053,059,060
21	23	23	25	25	27	29	29	26	27	28	27	
12	10	7	11	14	16	19	21	23	24	24	25	TLF-18-023,035
16	13	10	14	18	23	28	32	36	37	35	33	TLF-18-026,035
17	14	12	16	19	20	23	26	28	29	31	30	TLF-18-029,035

Table A1.2.3: Measured Sound transmission loss data for **NLT89 assemblies** with or without a lining.

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT89	**24**	18	16	15	14	17	16	16	18	18
PLY19_NLT89	**29**	27	25	28	29	27	23	22	21	23
PLY19_NLT89_PLY19	**33**	26	26	27	26	30	29	28	25	25
NLT89_OSB19	**30**	28	27	28	29	31	24	22	21	23
NLT89_WF38(400)_GFB38_2G13	**40**	29	26	23	19	21	19	25	33	36
NLT89_AIR13_WS64(600)_GFB65_2G13	**52**	23	19	18	22	28	31	36	41	45
PLSTR_NLT89	**34**	25	25	25	25	28	27	25	23	27
PLSTR_NLT89_PLSTR	**34**	26	25	26	25	29	28	27	22	27

Table A1.2.4 Measured Sound transmission loss data for **NLT140 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT140	**22**	19	18	16	15	18	17	19	19	21
PLY19_NLT140	**31**	32	33	34	29	27	23	24	22	24
NLT140_OSB19	**32**	32	34	32	27	24	23	23	22	25
PLSTR_NLT140	**38**	31	31	30	28	31	29	30	25	33
NLT140_PLY19_WF38(400)_GFB38_2G13	**44**	30	31	31	28	26	23	28	35	37
PLY19_NLT140_WF38(400)_GFB38_2G13	**45**	29	30	29	25	26	24	31	37	40
NLT140_PLY19_AIR13_WS64(600)_GFB65_2G13	**60**	29	34	38	42	43	42	46	47	51
PLY19_NLT140_AIR13_WS64(600)_GFB65_2G13	**62**	32	34	38	44	48	45	46	47	52
PLSTR_NLT140_PLY19	**36**	31	30	30	29	32	28	29	25	30

(Continuation of Table A1.2.3 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
21	22	24	25	26	25	23	23	26	26	25	25	TLA-17-142
25	25	26	27	29	31	32	34	36	38	40	42	TLA-17-143
26	27	28	30	33	36	38	41	43	46	49	52	TLA-17-144
25	25	26	28	31	33	33	35	37	40	43	46	TLA-17-147
37	41	44	46	48	50	52	51	50	52	55	58	TLA-17-148
50	54	57	60	62	64	64	62	61	64	67	71	TLA-17-151
27	30	31	33	35	38	40	41	42	42	43	42	TLA-17-152
26	29	30	32	35	37	39	41	43	43	43	44	TLA-17-153

(Continuation of Table A1.2.4 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
22	24	25	24	23	21	22	23	21	23	22	22	TLA-18-023
25	26	28	30	31	33	34	35	36	38	40	42	TLA-18-027
26	28	30	32	33	34	35	36	38	40	43	47	TLA-18-032
29	33	36	38	40	41	42	42	41	41	43	44	TLA-18-036
40	44	46	48	50	53	54	55	52	54	58	63	TLA-18-029
41	45	46	49	52	56	59	57	55	58	63	68	TLA-18-035
55	59	61	64	66	69	70	72	71	74	78	81	TLA-18-031
56	60	62	65	68	72	74	74	72	75	81	83	TLA-18-033
30	31	33	35	37	40	42	43	45	47	51	54	TLA-18-048

Table A1.2.5 Measured Sound transmission loss data for **NLT184 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT184	**24**	19	19	17	15	19	18	18	20	21
PLY19_NLT184	**31**	35	36	33	28	29	21	22	25	26
PLY19_NLT184_PLY19	**35**	31	32	31	31	35	23	26	28	27
NLT184_OSB119	**32**	33	35	34	30	28	21	22	24	25
NLT184_WF38(400)_GFB38_2G13	**41**	31	29	25	21	23	20	25	37	38
NLT184_AIR13_WS64(600)_GFB65_2G13	**55**	19	18	20	26	32	36	39	45	49
PLSTR_NLT184	**38**	31	31	30	28	33	27	26	34	30
NLT184_PLY19_WF38(400)_GFB38_2G13	**43**	32	32	32	30	24	22	29	36	38
PLY19_NLT184_WF38(400)_GFB38_2G13	**45**	30	32	31	28	28	24	28	38	38
NLT184_PLY19_ AIR13_WS64(600)_GFB65_2G13	**59**	31	37	39	42	42	40	43	48	51
PLY19_NLT184_ AIR13_WS64(600)_GFB65_2G13	**60**	33	37	39	45	47	41	44	49	53

Table A1.2.6 Measured Sound transmission loss data for **NLT235 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT235	**29**	25	26	23	21	25	25	23	25	25
PLY19_NLT235	**36**	34	35	30	27	31	30	27	29	29
NLT235_OSB119	**37**	34	34	30	27	31	30	26	29	30
PLSTR_NLT235	**39**	33	33	31	29	35	35	26	35	34
NLT235_PLY19_WF38(400)_GFB38_2G13	**47**	32	34	31	26	25	26	34	43	43
PLY19_NLT235_WF38(400)_GFB38_2G13	**46**	30	33	32	28	28	25	31	41	39
NLT235_PLY19_ AIR13_WS64(600)_GFB65_2G13	**64**	31	35	36	39	46	49	48	54	56
PLY19_NLT235_ AIR13_WS64(600)_GFB65_2G13	**61**	33	36	37	38	45	47	47	51	54
PLSTR_NLT235_PLY19	**41**	30	33	31	30	35	33	27	36	34

(Continuation of Table A1.2.5 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
23	24	23	21	22	24	24	24	25	25	26	26	TLA-18-003
26	26	28	29	31	33	34	35	37	40	42	45	TLA-18-004
28	29	31	34	37	39	41	43	46	49	53	56	TLA-18-005
26	27	29	31	32	34	36	37	39	42	45	48	TLA-18-012
43	46	47	48	51	53	55	54	51	53	56	60	TLA-18-021
52	55	57	57	60	64	66	65	62	65	68	71	TLA-18-016
35	33	36	37	40	41	42	40	41	42	43	44	TLA-18-022
42	43	45	47	50	53	56	55	53	55	60	64	TLA-18-013
42	44	45	47	52	54	56	57	56	59	64	68	TLA-18-020
55	57	59	62	65	68	71	73	73	76	80	82	TLA-18-014
56	58	59	62	66	71	74	75	74	77	82	83	TLA-18-019

(Continuation of Table A1.2.6 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
26	27	28	29	30	30	30	31	31	32	32	32	TLA-18-037
30	31	34	35	37	39	39	40	41	44	46	49	TLA-18-038
31	32	35	37	39	40	40	42	44	46	50	53	TLA-18-042
36	36	38	39	40	39	39	41	42	43	44	45	TLA-18-047
45	48	50	52	55	57	58	58	56	59	63	68	TLA-18-040
41	45	47	50	54	56	58	58	57	62	68	74	TLA-18-043
59	62	64	66	70	73	76	76	75	78	83	83	TLA-18-041
56	58	59	60	65	69	73	75	75	80	85	84	TLA-18-045
37	36	39	39	41	42	43	46	48	51	54	57	TLA-18-046

Table A1.2.7 Measured Sound transmission loss data for **NL286 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT286	**39**	28	32	32	28	30	32	34	32	36
PLY19_NLT286	**41**	30	34	33	29	31	33	34	33	36
NLT286_OSB119	**41**	32	33	34	28	32	34	35	31	38
PLSTR_NLT286	**42**	32	35	35	30	34	37	37	30	41
NLT286_PLY19_WF38(400)_GFB38_2G13	**48**	33	34	33	29	28	27	38	45	48
PLY19_NLT286_WF38(400)_GFB38_2G13	**47**	36	35	33	30	29	26	37	42	42
NLT286_PLY19_ AIR13_WS64(600)_GFB65_2G13	**68**	35	35	38	40	46	53	57	54	63
PLY19_NLT286_ AIR13_WS64(600)_GFB65_2G13	**63**	35	38	40	41	45	52	55	52	56
PLSTR_NLT286_PLY19	**43**	34	36	35	29	34	37	35	31	39
SEAL_NLT286_PLY19	**43**	34	36	35	29	34	37	35	31	39
CON38(no bond)_NLT286	**53**	34	38	34	35	36	34	38	43	47
CON38_FOAM09_NLT286	**56**	34	35	36	35	34	36	42	46	52

Table A1.2.8: Structural reverberation times for the tested NLT assemblies

Specimen Code	63 Hz	125 Hz			250 Hz		
NLT89_PLY19		0.262	0.193	0.143	0.123	0.125	0.200
NLT140_PLY19		0.262	0.223	0.222	0.153	0.129	0.137
NLT184_PLY19		0.252	0.174	0.152	0.141	0.160	0.242
NLT235_PLY19		0.263	0.241	0.226	0.203	0.152	0.132
NLT286_PLY19		0.232	0.264	0.169	0.188	0.144	0.144

(Continuation of Table A1.2.7 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
36	36	36	38	40	39	40	41	42	43	44	44	TLA-18-050
36	37	38	39	41	42	43	44	46	49	51	54	TLA-18-051
36	37	38	40	42	42	43	45	48	51	53	56	TLA-18-055
37	40	40	41	42	42	43	45	47	49	50	51	TLA-18-061
47	52	53	54	57	59	60	59	58	62	66	70	TLA-18-052
43	48	49	53	56	58	59	59	58	63	69	74	TLA-18-057
63	65	67	69	70	73	77	77	77	81	84	84	TLA-18-053
55	59	60	63	66	70	74	75	75	79	85	84	TLA-18-059
36	40	40	41	43	43	45	48	50	53	56	59	TLA-18-060
50	50	49	53	57	60	64	69	73	77	80	84	TLF-18-023
54	53	52	56	61	67	73	80	86	90	91	92	TLF-18-026
55	54	54	58	62	64	68	74	78	82	87	89	TLF-18-029

(Continuation of Table A1.2.8 from opposite page**):**

500 Hz			1000 Hz			2000 Hz			4000 Hz	
0.087	0.081	0.067	0.057	0.057	0.061	0.046	0.032	0.027	0.025	0.027
0.134	0.060	0.059	0.056	0.061	0.057	0.069	0.034	0.030	0.022	0.026
0.086	0.064	0.065	0.064	0.049	0.055	0.062	0.039	0.028	0.028	0.030
0.073	0.049	0.055	0.055	0.051	0.043	0.055	0.027	0.022	0.024	0.022
0.087	0.061	0.053	0.043	0.051	0.062	0.101	0.038	0.025	0.024	0.026

Table A1.2.9: Measured bending wavenumbers in rad/m for the NLT assemblies

Specimen Code	Description	Dir.	63 Hz	125 Hz	250 Hz
Bare NLT89	NLT89_PLY19	**Hor.**		1.63 3.10 3.66	2.00 2.36 3.35
		Vert.		8.78 10.99 13.30	19.74 23.86 22.02
Bare NLT184	NLT184_PLY19	**Hor.**		1.05 1.90 2.18	2.00 2.51 5.73
		Vert.		10.02 8.51 11.43	13.95 17.34 28.64

(**Continuation of Table A1.2.9 from opposite page**):

500 Hz			1000 Hz			2000 Hz			4000 Hz		Reference
6.39	6.11	6.69	5.79	6.85	9.36	11.91	15.06	18.46	22.9	27.27	
26.03	44.07	47.74	33.69	57.29	28.64	35.80	44.07	38.19	81.85	35.80	
2.63	2.87	4.10	5.50	5.34	7.30	9.84	9.06	10.20	13.30	17.89	
35.80	38.19	52.08	38.19	27.27	26.03	35.80	40.92	57.29	63.66	57.29	

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Appendix A1.3:
Sound Transmission Data for DLT Wall and Floor Assemblies

This section of Appendix A1 includes data for the sound transmission loss through Dowel Laminated Timber (DLT) assemblies:

A1.3.1 Airborne sound transmission loss for the Base DLT assemblies including a 13 mm plywood shear membrane attached on 1 side of the sealed DLT assembly (See Section 2.3.1)

A1.3.2 One-third octave band ΔTL values for the change in sound transmission loss due to the addition of linings to the Base DLT assemblies (See Section 2.3.2)

A1.3.3 Airborne sound transmission loss data for DLT89 specimens, tested according to standard ASTM E90

A1.3.4 Airborne sound transmission loss data for DLT140 specimens, tested according to standard ASTM E90

A1.3.5 Airborne sound transmission loss data for DLT186 specimens, tested according to standard ASTM E90

A1.3.6 Structural reverberation times for the tested DLT assemblies

A1.3.7 One-third octave band values for the wavenumbers of the DLT assemblies (See Section 2.3.4)

Details of the test facilities and the measurement procedures are given in Chapter 2.

Table A1.3.1: Sound transmission loss data for **Base DLT** assemblies which had a shear membrane of 13 mm plywood attached on one side and the other side of the assembly was sealed. Attaching a shear membrane to the DLT assembly is normal practice to provide structural rigidity in typical applications, as explained in Section 2.1.3.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Base DLT89	PLSTR_DLT89_PLY13	36	26	27	29	29	30	29	29	24	26
Base DLT140	PLSTR_DLT140_PLY13	38	34	31	31	30	32	30	28	24	31
Base DLT186	PLSTR_DLT186_PLY13	40	35	33	32	33	35	25	29	34	29

Note 1: For DLT assembly thicknesses not listed, use the nearest entry.

Table A1.3.2: Change in sound transmission loss (ΔTL) due to linings on DLT wall assemblies

Lining Code	Lining Description	ΔSTC	63 Hz			125 Hz			250 Hz		
ΔTL-DLT89-W01	2G13	2	2	1	0	0	2	1	1	3	2
ΔTL-DLT140-W01	2G13	-1	-3	0	0	1	1	1	-1	4	-2
ΔTL-DLT186-W01	2G13	1	-2	-1	1	0	1	1	2	-2	2
Mean ΔTL-DLT-W01	2G13	2	-1	0	1	1	1	1	1	2	1
ΔTL-DLT89-W02	2G13_WFUR38(400)_GFB38	0	1	0	-3	-4	-7	-6	3	10	8
ΔTL-DLT140-W02	2G13_WFUR38(400)_GFB38	-1	-2	-2	-2	-4	-8	-6	7	11	9
ΔTL-DLT186-W02	2G13_WFUR38(400)_GFB38	-2	-2	-2	-1	-5	-9	1	5	8	8
Mean ΔTL-DLT-W02	2G13_WFUR38(400)_GFB38	-1	-1	-1	-2	-4	-8	-4	5	10	8
ΔTL-DLT89-W06	2G13_WS64(600)_GFB65_AIR13	23	-6	-2	1	7	13	16	19	23	27
ΔTL-DLT140-W06	2G13_WS64(600)_GFB65_AIR13	25	-10	-2	2	8	13	18	23	25	26
ΔTL-DLT186-W06	2G13_WS64(600)_GFB65_AIR13	26	-6	1	5	9	14	21	20	24	26
Mean ΔTL-DLT-W06	2G13_WS64(600)_GFB65_AIR13	25	-7	-1	3	8	13	18	21	24	26

Note: The ΔTL and ΔSTC ratings for ΔTL-DLT140-W01 were based in part on estimate for PLY13_DLT140_2G13. See note on Table A1.3.4.

(**Continuation of Table A1.3.1** from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
28	30	33	35	38	40	43	44	46	46	47	49	TLA-18-105
30	33	35	37	40	42	44	45	47	47	49	51	TLA-18-075
35	34	37	39	42	43	44	45	46	48	50	53	TLA-18-076

(Continuation of Table A1.3.2 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
3	2	1	1	2	4	3	2	0	2	4	6	TLA-18-088, 104, 105
2	0	0	3	4	4	4	3	2	3	4	7	TLA-18-074, 75, estimate from (88,104,78,83,74)
0	2	1	3	2	4	5	4	2	3	4	6	TLA-18-078, 83, 84
2	2	1	3	3	5	5	4	2	3	5	7	
10	12	11	11	11	12	12	12	8	9	12	11	TLA-18-090, 100, 105
11	14	12	12	12	13	14	13	9	10	12	14	TLA-18-070, 72, 75
8	13	10	11	10	11	13	13	9	8	11	13	TLA-18-079, 81, 84
10	13	11	11	11	12	13	13	9	9	12	13	
28	28	24	24	22	22	21	21	21	25	28	27	TLA-18-097, 103, 105
26	26	26	26	26	27	29	30	27	29	31	31	TLA-18-071, 73, 75
27	29	29	27	28	31	34	34	31	33	34	34	TLA-18-080, 82, 84
27	28	26	26	25	27	28	28	26	29	31	31	

Table A1.3.3: Measured Sound transmission loss data for **DLT89 assemblies** with or without a lining.

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
PLY13_DLT89	34	27	28	27	27	29	27	27	21	26
DLT89_PLY13_2G13	40	28	29	30	29	32	30	30	29	30
PLY13_DLT89_2G13	38	28	28	29	30	32	30	30	27	28
DLT89_PLY13_WF38(400)_GFB38_2G13	46	27	28	27	25	24	25	34	35	36
PLY13_DLT89_WF38(400)_GFB38_2G13	44	28	27	26	26	23	23	32	34	34
DLT89_PLY13_AIR13_WS64(600)_GFB65_2G13	62	21	28	32	36	44	47	50	49	55
PLY13_DLT89_AIR13_WS64(600)_GFB65_2G13	60	20	25	30	38	43	45	48	47	53
PLSTR_DLT89	36	26	27	29	29	30	29	29	24	26

Table A1.3.4 Measured Sound transmission loss data for **DLT140 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
PLY13_DLT140	38	28	29	29	29	31	30	29	23	32
DLT140_PLY13_2G13	43	32	31	31	31	33	33	28	30	33
PLY13_DLT140_2G13	39	31	31	31	32	33	31	27	28	29
DLT140_PLY13_WF38(400)_GFB38_2G13	45	33	31	30	26	26	24	35	37	41
PLY13_DLT140_WF38(400)_GFB38_2G13	46	32	29	29	28	24	25	36	35	40
DLT140_PLY13_AIR13_WS64(600)_GFB65_2G13	64	26	32	33	38	45	48	53	49	59
PLY13_DLT140_AIR13_WS64(600)_GFB65_2G13	63	24	29	33	41	45	48	51	49	57
PLSTR_DLT140_PLY13	38	34	31	31	30	32	30	28	24	31

NOTE: Values for PLY13_DLT140_2G13 were not measured. Estimates listed were calculated by correcting DLT140_PLY13_2G13 with average of corresponding differences due to plywood location for DLT89 and DLT186 specimens with 2G13 lining. See discussion in Section 2.3.2.

(Continuation of Table A1.3.3 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
27	29	32	33	36	38	40	41	42	43	44	46	TLA-18-085
32	34	37	40	44	47	50	50	49	51	54	56	TLA-18-088
31	32	34	36	40	44	46	46	46	48	51	55	TLA-18-104
40	45	48	50	53	55	57	58	55	57	59	60	TLA-18-090
38	42	44	46	49	52	55	56	54	55	60	64	TLA-18-100
57	61	60	63	67	70	73	74	73	75	79	82	TLA-18-097
56	58	57	59	60	62	64	65	67	71	75	76	TLA-18-103
28	30	33	35	38	40	43	44	46	46	47	49	TLA-18-105

(Continuation of Table A1.3.4 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
29	33	36	38	40	42	43	44	45	46	47	49	TLA-18-069
35	38	42	45	49	51	53	53	52	53	56	60	TLA-18-074
32	33	35	40	44	46	48	48	49	50	53	58	Estimated (See Note)
43	50	50	53	54	58	61	61	58	59	62	66	TLA-18-070
41	47	47	49	52	55	58	58	56	57	61	65	TLA-18-072
59	63	63	66	70	73	76	78	77	78	82	85	TLA-18-071
56	59	61	63	66	69	73	75	74	76	80	82	TLA-18-073
30	33	35	37	40	42	44	45	47	47	49	51	TLA-18-075

Table A1.3.5: Measured Sound transmission loss data for **DLT186 assemblies** with or without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
PLY13_DLT186	40	32	31	31	32	35	26	28	35	29
DLT186_PLY13_2G13	45	33	32	33	33	36	27	32	33	35
PLY13_DLT186_2G13	41	35	35	33	34	36	26	31	32	31
DLT186_PLY13_WF38(400)_GFB38_2G13	48	33	31	31	28	26	27	35	42	40
PLY13_DLT186_WF38(400)_GFB38_2G13	47	35	32	31	30	27	26	34	42	37
DLT186_PLY13_AIR13_WS64(600)_GFB65_2G13	67	30	35	38	42	49	46	49	61	57
PLY13_DLT186_AIR13_WS64(600)_GFB65_2G13	66	29	34	37	43	49	46	49	58	55
PLSTR_DLT186_PLY13	40	35	33	32	33	35	25	29	34	29

Table A1.3.6: Structural reverberation times for the tested DLT assemblies

Specimen Code	63 Hz	125 Hz			250 Hz		
PLY13_DLT89		.083	.057	.066	.041	.056	.039
PLY13_DLT140		.075	.064	.054	.051	.048	.043
PLY13_DLT186		.089	.082	.070	.052	.051	.028

Table A1.3.7: Measured bending wavenumbers in rad/m for the DLT assemblies

Specimen Code	Description	Dir.	63 Hz	125 Hz			250 Hz		
Bare PLY13_DLT89	PLY13_DLT89	**Hor.**		1.10	3.68	0.21	0.76	1.43	3.33
		Vert.		7.12	8.39	3.23	9.51	13.0	13.3
Bare PLY13_DLT140	PLY13_DLT140	**Hor.**		0.41	0.58	0.73	0.00	4.92	0.08
		Vert.		4.37	5.91	9.36	8.26	7.21	13.0
Bare PLY13_DLT186	PLY13_DLT186	**Hor.**		0.51	0.10	0.69	0.50	3.11	6.24
		Vert.		4.30	6.17	6.85	10.99	13.3	2.13

(Continuation of Table A1.3.5 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
36	35	38	40	40	42	44	44	44	46	48	51	TLA-18-076
38	41	45	47	49	51	54	54	51	53	57	60	TLA-18-078
35	36	38	42	44	47	49	49	48	51	54	59	TLA-18-083
47	51	51	54	56	59	62	62	58	59	64	68	TLA-18-079
43	47	47	50	52	54	57	58	55	56	61	66	TLA-18-081
66	66	69	71	75	79	82	83	81	83	87	88	TLA-18-080
62	63	66	66	70	74	78	79	77	81	84	87	TLA-18-082
35	34	37	39	42	43	44	45	46	48	50	53	TLA-18-084

(Continuation of Table A1.3.6 from opposite page**):**

500 Hz			1000 Hz			2000 Hz			4000 Hz		
.058	.061	.056	.080	.056	.036	.021	.047	.056	.056	.027	.058
.055	.069	.065	.096	.083	.046	.030	.033	.020	.022	.019	.055
.046	.050	.057	.062	.044	.028	.019	.012	.008	.006	.007	.046

(**Continuation of Table A1.3.7 from opposite page**):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
5.85	1.30	5.91	5.56	6.46	8.39	13.62	11.2	12.16	17.34	7.12		
18.46	20.45	38.19	31.82	35.8	44.07	40.92	35.8	44.07	52.08	52.08		
0.47	0.09	1.68	3.44	4.92	8.64	12.43	8.64	3.38	15.89	4.37		
17.89	16.83	27.27	26.03	40.92	47.74	35.8	35.8	47.74	38.19	30.14		
0.25	0.08	1.21	2.19	0.78	6.61	6.39	24.9	10.2	12.43	17.89		
7.70	20.45	16.35	9.51	33.69	31.82	23.86	40.92	44.07	63.66	31.82		

Appendix A2:
Calculating the ΔSTC Rating for Linings on Laminated-Timber Assemblies

To characterize the change in sound transmission loss due to adding a specific lining to a heavy base wall or floor (a CLT or NLT or DLT assembly in this case) a single-number rating called ΔSTC is introduced.

Key issues concerning the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 as discussed in Section 4.1.
- The ΔSTC ratings calculated from the experimental data in this Report are presented in Table 2.3.2 at the end of Section 2.1.2.2. Readers of this Report can simply use the tabulated ΔSTC ratings without the need to perform the calculations procedure outlined in this Appendix.
- The procedure for calculating the ΔSTC rating is presented here for completeness. It is a subset of a more general set of procedures presented in NRC Research Report RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings".

ASTM does not define a ΔSTC rating, but there is a counterpart in the ISO standards called ΔR_W. The procedure presented in this Appendix is modified from its ISO counterpart in several ways:

1. The calculation of the STC rating according to ASTM E413 is substituted for the ISO calculation of R_W, plus additional Steps 4 and 5 are included, as explained in Figure A2.4 and the adjacent text.
2. A reference curve to represent the Base assembly is required for the calculation. The ISO standards provide a set of three reference curves: one for heavy concrete floors and two for wall assemblies. The reference curves for the ISO procedure to calculate ΔR_W are smoothed average sound transmission loss curves for some constructions common in Europe: a homogeneous concrete floor (140 mm thick with mass per unit area of 300 kg/m^2), a heavy masonry wall with low coincidence frequency (mass per unit area of 350 kg/m^2) and a lighter masonry wall of gypsum blocks (mass per unit area of 70 kg/m^2) described as a "wall with medium-high coincidence frequency." They may be used for other constructions which have a transmission loss curve that exhibits a similar dependence on frequency.

In selecting the appropriate reference curve for the calculation of the ΔSTC rating, the mass or thickness of the unlined base wall or floor assembly is irrelevant. What matters is the frequency dependence of its sound transmission loss curve, especially around the frequency where the curve transitions from a comparatively flat plateau at low frequencies to a slope rising at about 2 dB per one-third octave band.

To establish the best reference curve for a given base wall or floor assembly, the reference curve was shifted up or down to match the transmission loss of the tested assembly in the "plateau region" below the frequency where the curve bends up. The reference curve can be shifted up or down (changing the sound transmission loss at all frequency bands by the same amount) without altering the calculation of the ΔSTC rating because, as explained in the calculation procedure below, the ΔSTC rating is the *difference* between the STC rating for the reference curve and the STC rating calculated for the curve obtained by adding the ΔTL values at each frequency to the reference curve.

Reference Curves for CLT Assemblies

The measured sound transmission loss data for the CLT245(7), CLT175(5) and CLT78(3) base assemblies are compared with the shifted ISO reference curves in Figures A2.1, A2.2, and A2.3 respectively.

Figure A2.1:
The sound transmission loss for the Base CLT245(7) assembly is compared to the proposed reference curve which has been shifted to match the STC rating of the Base CLT245(7) assembly.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.0 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.3 dB.

This reference curve is used for the calculation of the ΔSTC ratings for linings installed on CLT245(7) in Section 2.1.2.

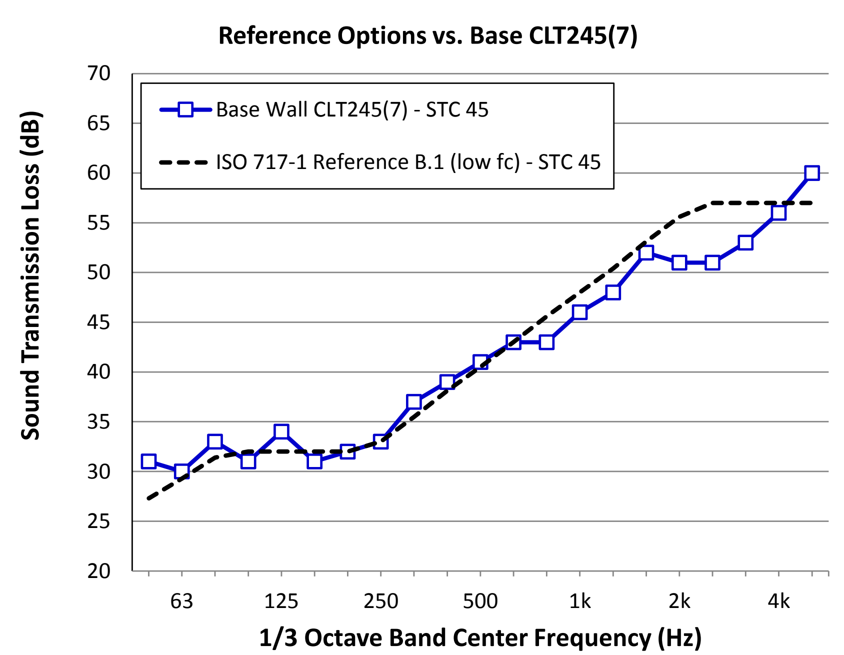
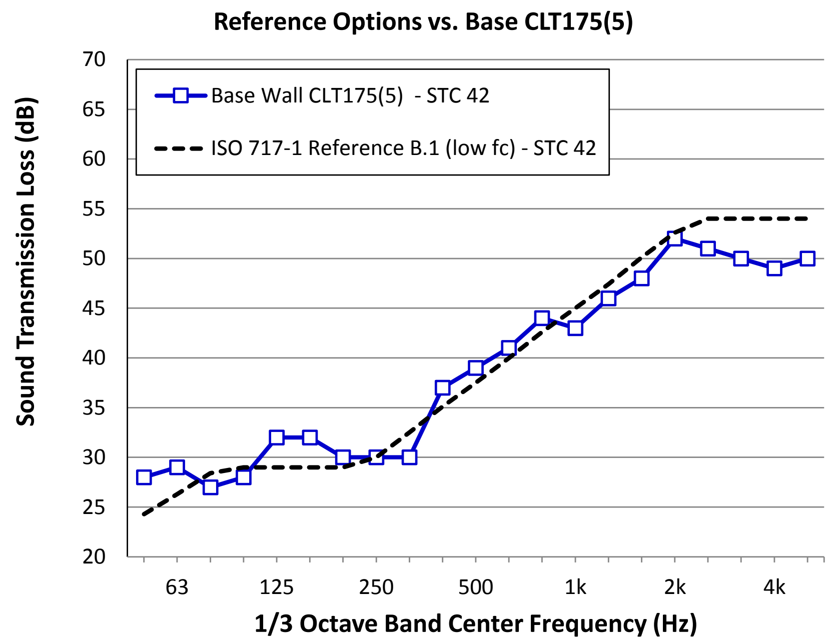


Figure A2.2:
The sound transmission loss for the Base CLT175(5) assembly is compared to the proposed reference curve which has been shifted to match the STC rating of the Base CLT175(5) assembly.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 1.2 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.2 dB.

This reference curve is used for the calculation of the ΔSTC ratings for linings installed on CLT175(5) in Section 2.1.2.



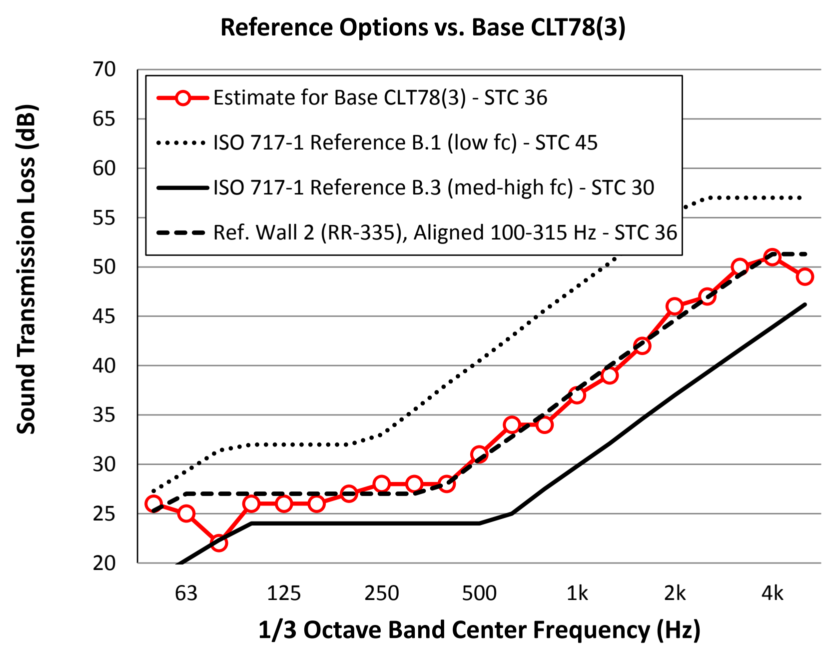
Figures A2.1 and A2.2. show the good fit between the proposed reference curve and the sound transmission loss curves for the Base CLT245(7) and the Base CLT175(5) assemblies. This reference curve (noted as B.1 in the ISO standards and Reference Wall 1 in NRC Research Report RR-331) was therefore used in Section 2.1.2 for the calculation of the ΔSTC ratings for linings applied to CLT245(7) and CLT175(5) assemblies.

Figure A2.3 compares the sound transmission loss curves for the Base CLT78(3) assembly to two reference curves from ISO 717-1. It is evident from the figure that the fit between the measured sound transmission loss curve for the Base CLT78(3) and the ISO reference curves B.1 or B.3 is less satisfactory than the fit shown in Figures A2.1 and A2.2. The frequency for transition from the plateau to the rising curve is at too low a frequency for Reference Curve B.1 and at too high a frequency for ISO Reference Curve B.3. In order to calculate the ΔSTC ratings for linings on CLT78(3) assemblies, it was therefore necessary to introduce a third reference curve as shown in Figure A2.3. This curve for Reference Wall 2 was obtained by shifting the ISO Reference Curve B.3 to lower frequencies by two one-third octave bands, placing it approximately midway between ISO Reference Curves B.1 and B.3 as evident in Figure A2.3.

Figure A2.3:
The sound transmission loss for the Base CLT78(3) assembly is compared to the proposed Reference Wall 2 curve (dashed line) shifted to match the STC rating of the CLT78(3) assembly.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.4 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.3 dB.

The Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on CLT78(3) in Section 2.1.2.



The good fit between the Reference Wall 2 Curve and the sound transmission loss data for the Base CLT78(3) assembly is evident in Figure A2.3. **Reference Wall 2 was used in Section 2.1.2 for calculating ΔSTC ratings for the linings applied to CLT78(3) assemblies.**

Reference Curves for NLT Assemblies

The measured sound transmission loss data for the NLT89_Ply, NLT140_Ply, NLT184_Ply, NLT235_Ply and NLT286_PLY19 base assemblies are compared with pertinent reference curves in Figures A2.4, A2.5, A2.6, A2.7 and A2.8, respectively.

A good fit between the Reference Wall 2 curve and the sound transmission loss data for the NLT89-PLY19 assembly can be seen in Figure A2.4. Not only did this Curve give a low mean deviation for the rising segment, but also the intersection of the two sections of the reference curve (around 300 to 400 Hz) is consistent with the trend of the data. This reference curve was therefore used in Section 2.2.2 for the calculation of the ΔSTC ratings for linings applied to NLT89-PLY19 assemblies.

Figure A2.4:
The sound transmission loss for the NLT89_PLY19 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 1.1 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.2 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on NLT89_PLY19 in Section 2.2.2.

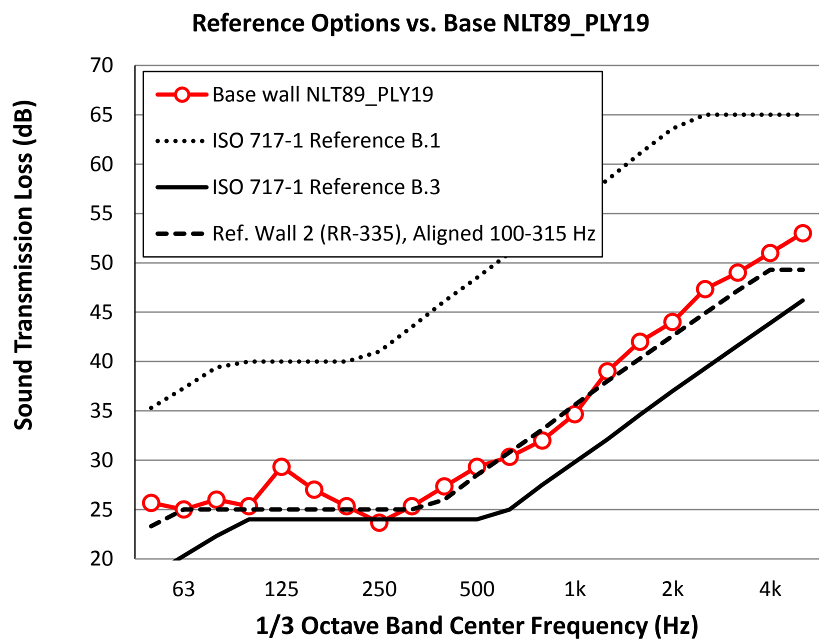


Figure A2.5:
The sound transmission loss for the NLT140_PLY19 assembly is compared to the possible reference curves.

In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 1.5 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.4 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on NLT140_PLY19 in Section 2.2.2.

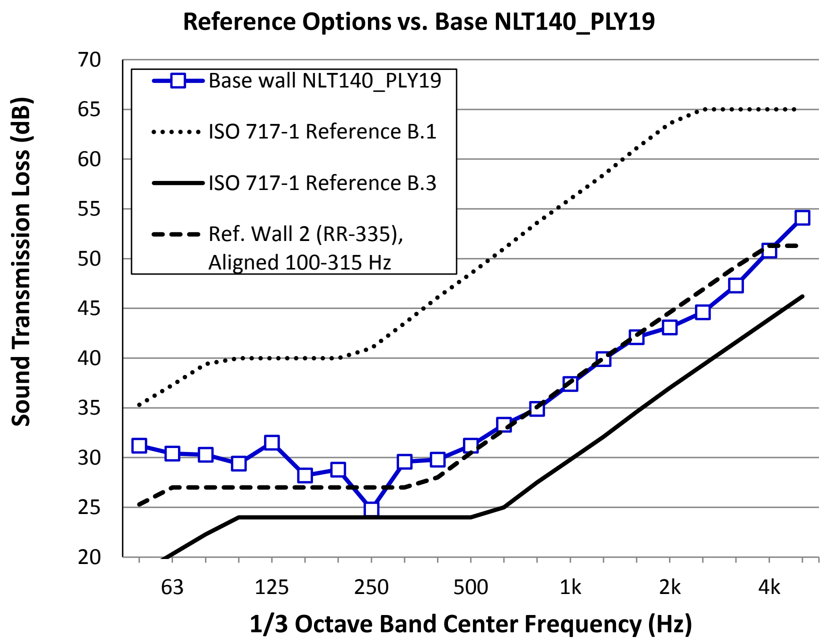


Figure A2.6:
The sound transmission loss for the NLT184_PLY19 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.4 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 1.3 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on NLT184_PLY19 in Section 2.2.2.

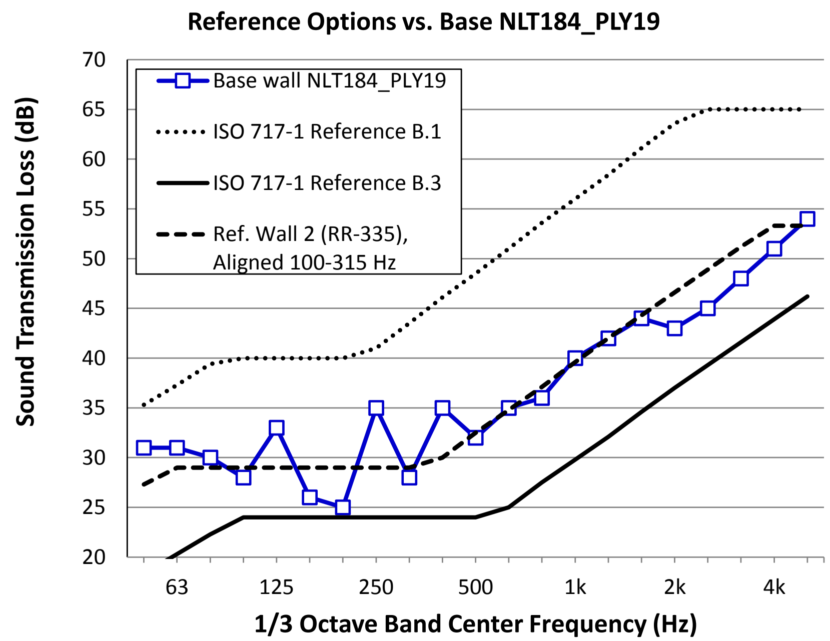


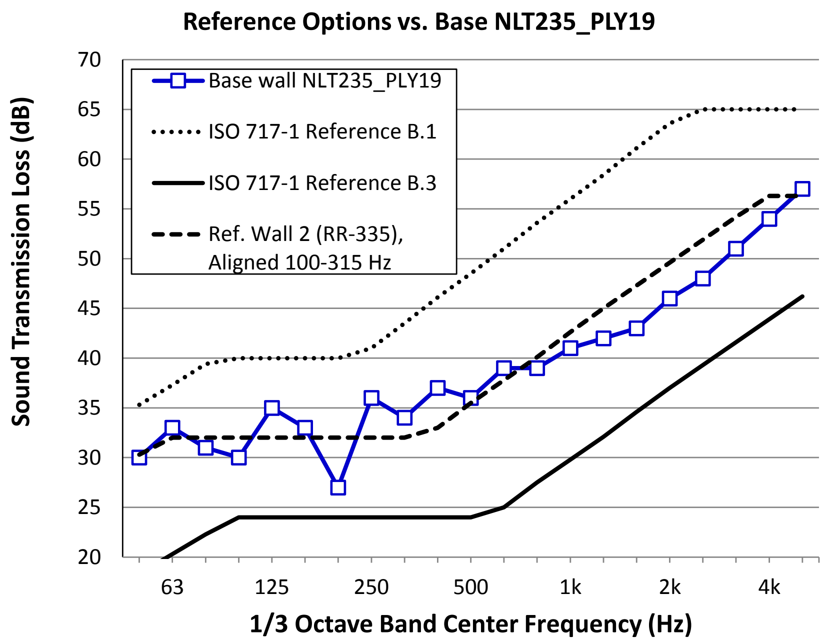
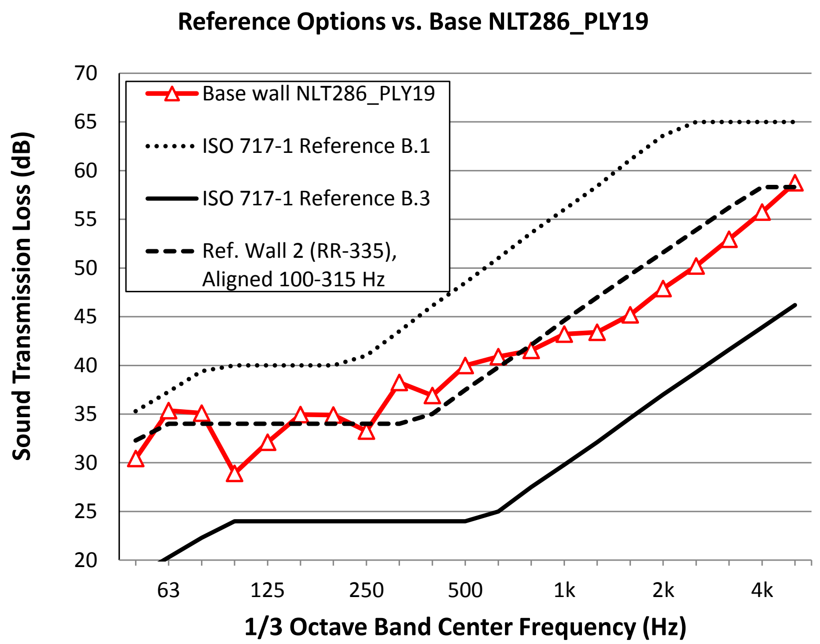
Figure A2.7: The sound transmission loss for the NLT235_PLY19 assembly is compared to the possible reference curves. There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.2 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 1.3 dB. Reference Wall 2 Curve was the best fit for the data. Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on NLT184_PLY19 in Section 2.2.2.	

Figure A2.8:
The sound transmission loss for the NLT286_PLY19 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 1.2 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 1.0 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on NLT286_PLY19 in Section 2.2.2.



The fit between the Reference Wall 2 Curve and NLT184_PLY19 and NLT286_PLY19 was not as good as the fit for NLT89-PLY19. However, Reference Wall 2 Curve was still the best fit of the options available. for practical purposes, the STC rating of the Base assembly and STC rating of the Base assembly with linings W02 to W06 is determined by a limited set of frequency bands from 125 Hz to 1.25 kHz. When the analysis is restricted to the significant frequency range, it becomes clear that the curve for Reference Wall 2 is a significantly better fit than the ISO reference curves B.1 or B.3. The obvious deviations above 1.25 kHz are irrelevant in this analysis. The frequency for transition from the plateau to the rising curve is at too low a frequency for Reference Curve B.1 and at too high a frequency for ISO Reference Curve B.3. Hence the curve for Reference Wall2 is most suitable for all the NLT specimens.

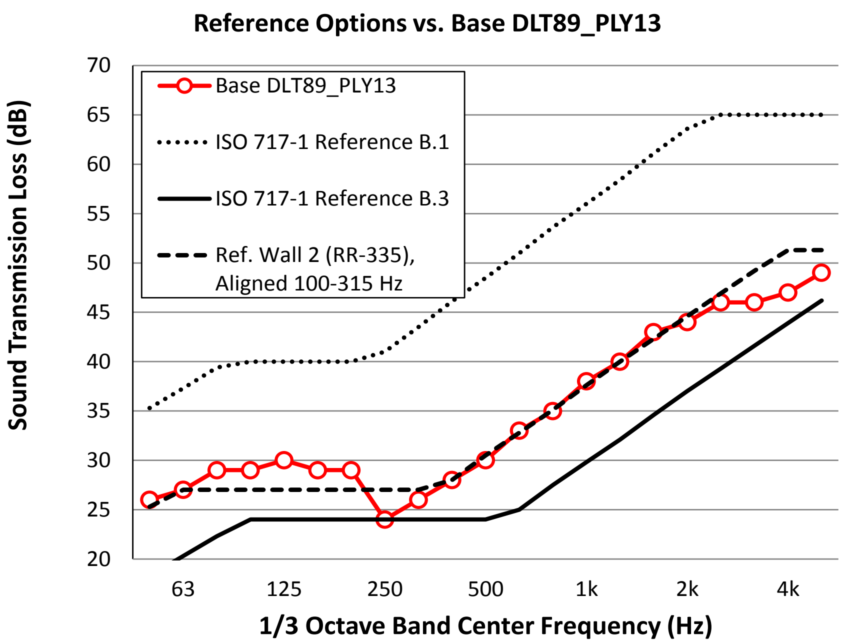
Reference Curves for DLT Assemblies

The measured sound transmission loss data for the DLT89_PLY13, DLT140_PLY13, and DLT186_PLY13 base assemblies are compared with pertinent reference curves in Figures A2.9, A2.10, and A2.11 respectively.

Figure A2.9:
The sound transmission loss for the DLT89_PLY13 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 1.1 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.2 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on DLT89_PLY13 in Section 2.2.2.



The good fit between the Reference Wall 2 Curve and the sound transmission loss data for the DLT89_PLY13 assembly is visually apparent in Figure A2.9. Not only did this match give a low mean deviation for the rising segment, but also the intersection of the two sections of the reference curve (around 300 to 400 Hz) is consistent with the obvious trend of the data. Reference Wall 2 Curve was therefore used in Section 2.3.2 for the calculation of the ΔSTC ratings for linings applied to DLT89_PLY13 assemblies.

It is evident in Figures A2.10 and A2.11 that the overall fit between Reference Wall 2 Curve and the measured sound transmission loss curves for Base DLT140_PLY13 or DLT186_PLY13 does not appear as good as the fit for the DLT89 specimen, especially above 2kHz.

Figure A2.10:
The sound transmission loss for the DLT140_PLY13 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.2 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.3 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on DLT140_PLY13 in Section 2.2.2.

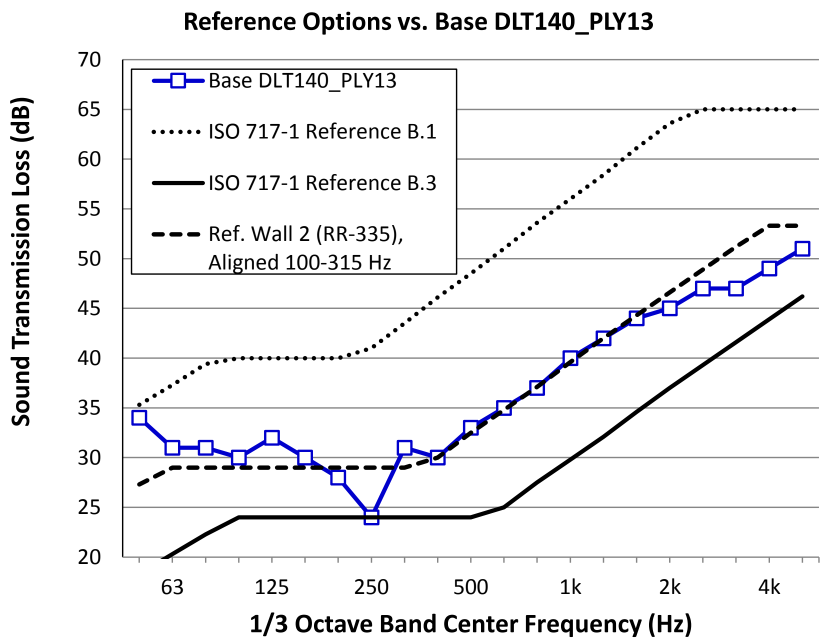
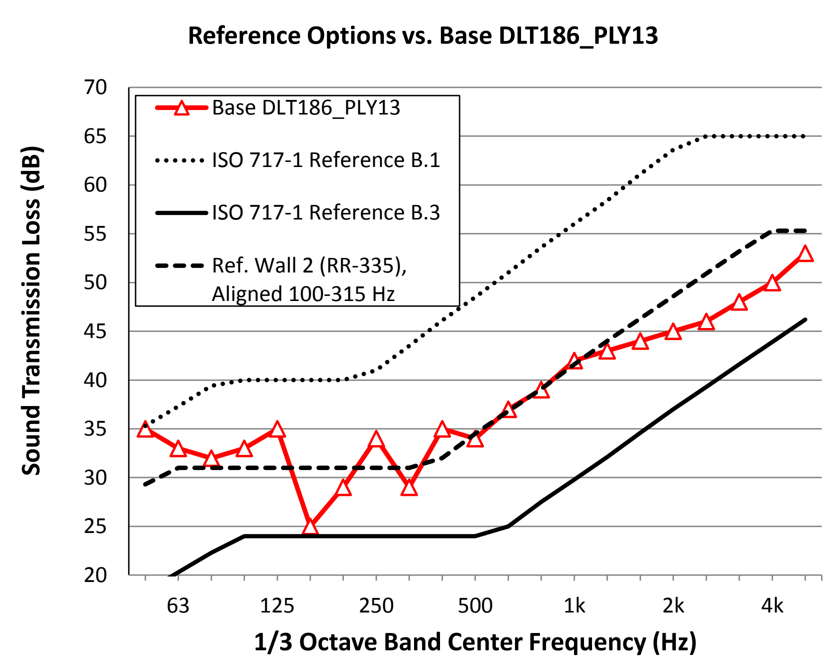


Figure A2.11:
The sound transmission loss for the DLT186_PLY13 assembly is compared to the possible reference curves.

There is good agreement between the curves. In the low frequency plateau region (100 Hz to 200 Hz) the mean deviation is 0.2 dB. In the upward sloping section (250 Hz to 1 kHz) the mean deviation is 0.6 dB. Reference Wall 2 Curve was the best fit for the data.

Reference Wall 2 Curve is used for the calculation of the ΔSTC ratings for linings on DLT186_PLY13 in Section 2.2.2.



However, for practical purposes, the STC rating of the Base assembly and STC rating of the Base assembly with linings W02 to W06 is determined by a limited set of frequency bands from 125 Hz to 1.25 kHz. When the analysis is restricted to the significant frequency range, it becomes clear that the curve for Reference Wall 2 is a significantly better fit than the ISO reference curves B.1 or B.3. The obvious deviations above 1.6 kHz are irrelevant in this analysis. The frequency for transition from the plateau to the rising curve is at too low a frequency for Reference Curve B.1 and at too high a frequency for ISO Reference Curve B.3. Hence the c Reference Wall 2 Curve is most suitable for all the NLT specimens.

Procedure for Calculating ΔSTC Ratings

The procedure to determine the change in sound transmission loss ΔTL due to adding linings is presented in Chapter 2. The procedure presented in this section uses the ΔTL values in one-third octave bands for each lining to calculate the corresponding single-number ΔSTC ratings.

The steps in the procedure are detailed here and shown schematically in Figure A2.4:

Step 1. The change in sound transmission loss (ΔTL) due to adding the lining is calculated from the laboratory test results according to ASTM E90 (for the Base assembly without any added lining and for that assembly with lining(s) added) for each frequency band, including at least 125 Hz to 4 kHz. This may involve averaging results from several pairs of assemblies as explained in Section 2.2.

Step 2. (a) Calculate the sum of the sound transmission loss for the chosen reference curve (from Table A2.1) plus ΔTL for each frequency band. The STC rating for this case is $STC_{1\text{-Side}}$.
(b) Calculate the sum of the sound transmission loss for the Reference curve (from Table A2.1) plus 2 x ΔTL for each frequency band. The STC rating for this case is $STC_{2\text{-Sides}}$.
(c) Calculate the STC rating for the reference curve (STC_{REF}).

Step 3. Subtract the STC rating of the reference curve (STC_{REF}) from $STC_{1\text{-side}}$ to obtain $\Delta STC_{1\text{-Side}}$.

Step 4. Subtract the STC rating of the reference curve (STC_{REF}) from $STC_{2\text{-sides}}$ to obtain $\Delta STC_{2\text{-Sides}}$.

Step 5. Calculate the ΔSTC rating: ΔSTC is the smaller of $\Delta STC_{1\text{-Side}}$ and $\Delta STC_{2\text{-Sides}}/1.5$, rounded to integers (e.g. 20/1.5 ⇨ 13).

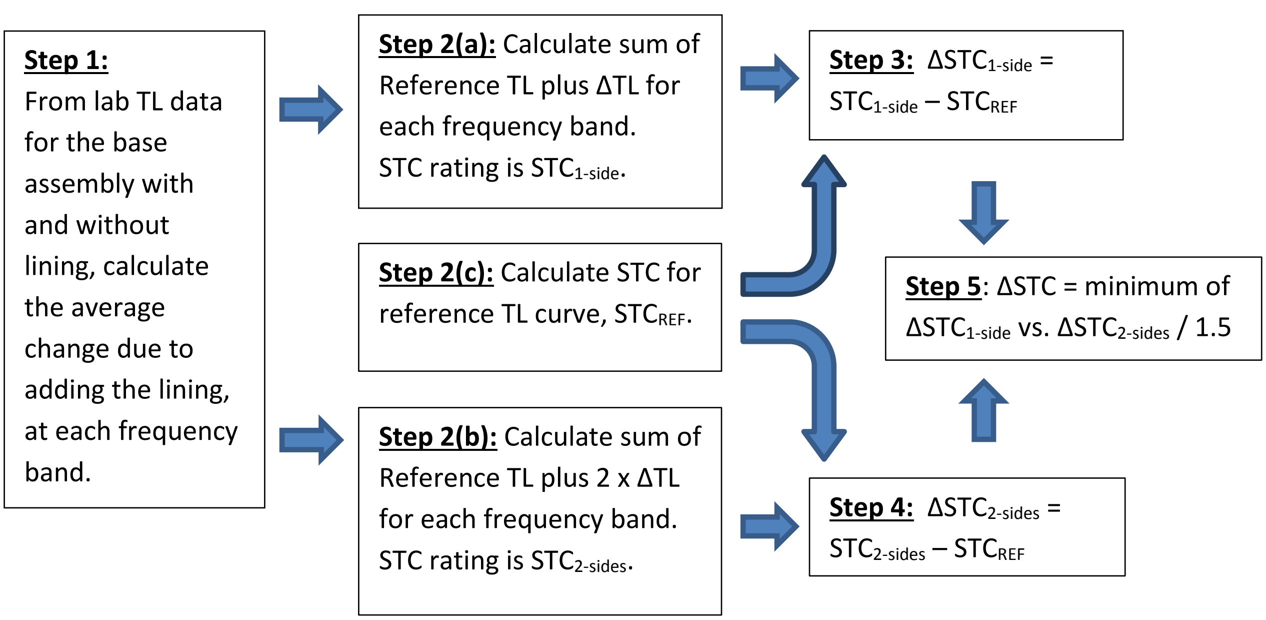


Figure A2.4: Steps to calculate the single-number rating ΔSTC for added linings (as detailed above).

The calculation of the change in the STC rating when there is a lining on both sides of the wall (Step 4) and dividing $\Delta STC_{2\text{-sides}}$ by 1.5 (Step 5) can be understood by considering the use of the ΔSTC ratings in Eq. 4.1.1 and 4.1.2 and in the worked examples in Section 4.2.

The selection of the more conservative value of $\Delta STC_{1\text{-side}}$ or $\Delta STC_{2\text{-sides}}$ in Step 5 is required to avoid a misleading (overly-optimistic) ΔSTC rating in the calculation procedure of the Simplified Method.

The data in one-third octave bands for the two reference curves used for the calculations are presented in Table A2.1.

Table A2.1:

Reference Curves for the calculation of the ΔSTC rating for linings applied to specific base wall or floor assemblies. These curves are based on the set of reference curves for calculating ΔR_W in the relevant ISO standards.

The comparison process for selection of the most suitable reference curve for each type of base CLT assembly (3-ply, 5-ply, or 7-ply CLT) is shown in Figures A2.1 to A2.3.

Frequency (Hz)	**Reference Curve for calculating the ΔSTC rating for linings applied to the 3-ply CLT**	**Reference Curve for calculating the ΔSTC rating for linings applied to 5-ply or 7-ply CLT**
50 Hz	25.3	35.3
63 Hz	27.0	37.3
80 Hz	27.0	39.4
100 Hz	27.0	40.0
125 Hz	27.0	40.0
160 Hz	27.0	40.0
200 Hz	27.0	40.0
250 Hz	27.0	41.0
315 Hz	27.0	43.5
400 Hz	28.0	46.1
500 Hz	30.5	48.5
630 Hz	32.8	51.0
800 Hz	35.1	53.6
1000 Hz	37.6	56.0
1250 Hz	40.0	58.4
1600 Hz	42.3	61.1
2000 Hz	44.6	63.6
2500 Hz	46.9	65.0
3150 Hz	49.2	65.0
4000 Hz	51.3	65.0
5000 Hz	51.3	65.0
STC	**36**	**53**
Source:	Reference Wall 2 in App. A1 of RR-331 (aka Reference Curve B.3 in Annex B of ISO 140-16, shifted two one-third octaves)	Reference Wall 1 in App. A1 of RR-331 (aka Reference Curve B.1 in Annex B of ISO 140-16)

References and Endnotes

Technical Standards

1. ASTM E90-09, “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements”, ASTM International, West Conshohocken, PA, USA.
2. ASTM E336-10, “Standard Test Method for Measurement of Airborne Sound Insulation in Buildings”, ASTM International, West Conshohocken, PA, USA.
3. Other ASTM standards referenced and used in ASTM E90 and E336 include: ASTM E413-10, “Classification for Rating Sound Insulation” and ASTM E2235-04 “Standard Test Method for Determination of Decay Rates for Use in Sound Insulation Test Methods”, ASTM International, West Conshohocken, PA, USA.
4. ISO 717:2013, “Acoustics—Rating of sound insulation in buildings and of building elements—Part 1: Airborne Sound Insulation, Part 2: Impact Sound Insulation” International Organization for Standardization, Geneva.
5. ISO 10140:2011, Parts 1 to 5, “Laboratory measurement of sound insulation of building elements”, International Organization for Standardization, Geneva. Note: In 2011 the ISO 10140 series replaced ISO 140 Parts 1, 3, 6, 8, 10, 11 and 16. In 2014, ISO 140-4 was replaced by ISO 16283-1, “Field measurement of sound insulation in buildings and of building elements.”
6. ISO 10848:2006, Parts 1 to 4, “Laboratory measurement of flanking transmission of airborne and impact sound between adjoining rooms”, International Organization for Standardization, Geneva.
7. ISO 15712:2005, Part 1, “Estimation of acoustic performance of buildings from the performance of elements”, International Organization for Standardization, Geneva.

Other Technical References

8. L. Cremer and M. Heckl, “Structure-borne sound”, edited by E.E. Ungar, Springer-Verlag, New York (original edition 1973, 2nd edition 1996).
9. E. Gerretsen, “Calculation of the sound transmission between dwellings by partitions and flanking structures”, Applied Acoustics, Vol. 12, pp 413-433 (1979), and “Calculation of airborne and impact sound insulation between dwellings”, Applied Acoustics, Vol. 19, pp 245-264 (1986).
10. R.J.M. Craik, “Sound transmission through buildings: Using statistical energy analysis”, Gower Publishing (1996).
11. D.B. Pedersen, “Evaluation of EN 12354 part 1 and 2 for Nordic Dwelling Houses”, Applied Acoustics, Vol. pp 259-268 (2000), (Validation and background studies for the ISO 15712 procedures).
12. Nightingale, T. R. T., Halliwell, R. E., & Pernica, G. (2004). Estimating in-situ Material Properties of a Wood Joist Floor: Part 1—Measurements of the Real Part of Bending Wavenumber. Building Acoustics, 11(3), 175-196.

Sources for Sound Transmission Data

Source references for sound transmission data (both collections of conventional laboratory test results for wall and floor assemblies according to ASTM E90, and flanking sound transmission tests according to ISO 10848) including many NRC Construction reports in the RR- and IR- series are available from the Publications Archive of the National Research Council Canada at http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?lang=en.

13. The software application *soundPATHS* is accessible online at the website of the National Research Council Canada. The calculations are based on experimental studies in the laboratories of the NRC: http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/soundpaths/index.html
14. Technical details concerning the measurement protocol (consistent with ISO 10848) and discussion of the findings of the experimental studies are presented in a series of NRC reports:
    - 14.1. Report A1-100035-02.1, "Report to Research Consortium for Wood and Wood-Hybrid Mid-Rise Buildings, Acoustics – Sound Insulation in Mid-Rise Buildings" (2013)
    - 14.2. IR-754, "Flanking Transmission at Joints in Multi-Family Dwellings. Phase 1: Effects of Fire Stops at Floor/Wall Intersections", T.R.T. Nightingale and R.E. Halliwell, (1997)
    - 14.3. RR-103, "Flanking Transmission in Multi-Family Dwellings Phase II: Effects of Continuous Structural Elements at Wall/Floor Junctions", T.R.T. Nightingale, R.E. Halliwell, and J.D. Quirt (2002)
    - 14.4. RR-168, "Flanking Transmission at the Wall/Floor Junction in Multifamily Dwellings - Quantification and Methods of Suppression", T.R.T. Nightingale, R.E. Halliwell, J.D. Quirt and F. King (2005)
    - 14.5. RR-218, "Flanking Transmission in Multi-Family Dwellings Phase IV", T.R.T. Nightingale, J.D. Quirt, F. King and R.E. Halliwell, (2006)
    - 14.6. RR-219, "Guide for Sound Insulation in Wood Frame Construction", J.D. Quirt, T.R.T. Nightingale, and F. King (2006). See also NRC Construction Technology Update 66, "Airborne Sound Insulation in Multi-Family Buildings", J.D. Quirt and T.R.T. Nightingale (2008)
    - 14.7. J. K. Richardson, J. D. Quirt, R. Hlady, "Best Practice Guide on Fire Stops and Fire Blocks and their Impact on Sound Transmission", NRCC #49677 (2007)
    - 14.8. IR-832, "Sound Insulation of Load-Bearing Shear-Resistant Wood and Steel Stud Walls", T.R.T. Nightingale, R.E. Halliwell, J.D. Quirt and J.A. Birta (2002)
    - 14.9. RR-169, "Summary Report for Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission and Impact Insulation Data", A.C.C. Warnock (2005)
15. RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings" (5th Edition, 2019) is a companion to this Report, which presents both the "Detailed Method" and the "Simplified Method" of ISO 15712-1 for calculating sound transmission in buildings.

16. The databases of flanking sound transmission data used in Guide RR-331 and in *soundPATHS* will be consolidated in a series of NRC publications presenting data from recent studies:
    16.1. RR-333 Apparent Sound Insulation in Precast Concrete Buildings (2019)
    16.2. RR-334 Apparent Sound Insulation in Concrete Block Buildings (2nd Edition, 2019)
    16.3. RR-335 Apparent Sound Insulation in Mass Timber Buildings (2nd Edition, 2020)
    16.4. RR-336 Apparent Sound Insulation in Wood-Framed Buildings (2017)
    16.5. RR-337 Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings (2017)

Endnotes

1 Cross-Laminated Timber (CLT) assemblies are structural panels fabricated by bonding wood elements together in layers with alternating perpendicular orientation of the timber elements. The CLT assemblies evaluated in this study had adhesive bonding between the faces of timber elements in adjacent layers, but no adhesive bonding the adjacent timber elements within a given layer. There were noticeable gaps between the timber elements comprising each layer of the CLT assembly. These CLT assemblies could be called "Face-laminated CLT Panels" but are simply referred to as CLT assemblies in the body of this Report. For the 3-ply panels considered in this Report, each layer or ply has a thickness of 26 mm and is comprised of parallel wood boards whose cross section is 26 x 89 mm. For the 5-ply and 7-ply panels, the ply thickness increases from 26 mm to 35 mm. The physical properties of the tested bare laminated panels are:

- 3-ply panels: 78 mm thick, 42.4 kg/m^2
- 5-ply panels: 175mm thick, 91.4 kg/m^2
- 7-ply panels: 245 mm thick, 130 kg/m^2

2 Gypsum board panels commonly form the exposed surface on lightweight framed wall or floor assemblies and on linings for heavy homogeneous structural wall or floor assemblies of concrete, concrete block or CLT. The gypsum board in this study had nominal thickness of 12.7 mm (1/2 inch) or 15.9 mm (5/8 inch) denoted in specimen codes as 13 mm and 16 mm respectively.

"Fire-rated gypsum board" is typically heavier than non-fire-rated gypsum board. The higher mass of the fire-rated gypsum board gives improved resistance to sound transmission through the assembly. The descriptor "fire-rated" is used in this Report to denote gypsum board with proven fire-resistant properties, with mass per unit area of at least 8.7 kg/m^2 for 12.7 mm thickness, or 10.7 kg/m^2 for 15.9 mm thickness. Gypsum board panels are installed with framing, fasteners and fastener spacing conforming to installation details required by CSA A82.31 M or ASTM C754. The sound transmission results should only be used where the actual construction details correspond to the details of the test assemblies on which the ratings are based.

3 Resilient metal channels are formed from steel with a maximum thickness of 0.46 mm (25 gauge), with a profile essentially as shown in Figure 6.1, with slits or holes in the single "leg" between the faces fastened to the framing and to the gypsum board. Installation of the resilient channels must conform to ASTM C754.

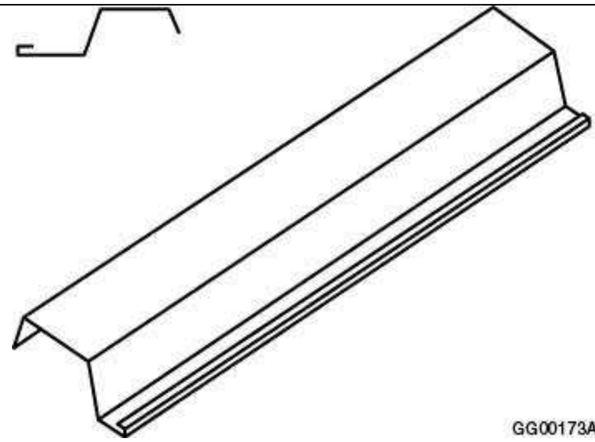


Figure 6.1: Drawing to illustrate the typical profile of resilient metal channels; approximate dimensions in cross-section are 13 mm x 60 mm (not precisely to scale).

(Copied from Figure A-9.10.3.1 of the National Building Code of Canada, used with permission)

4 Nail-Laminated Timber (NLT) assemblies are structural panels fabricated from timber elements that are nailed together to form a panel with aligned timber elements. Although the adjacent timbers were fastened tightly together, there were noticeable cracks between the timber elements comprising each bare NLT assembly. The NLT panels in this study included:

- NLT89 panel fabricated from nominal 2x4 lumber (38 x 89 mm cross-section),
- NLT140 panel fabricated from nominal 2x6 lumber (38 x 140 mm cross-section),
- NLT184 panel fabricated from nominal 2x8 lumber (38 x 184 mm cross-section),
- NLT235 panel fabricated from nominal 2x10 lumber (38 x 235 mm cross-section),
- NLT286 panel fabricated from nominal 2x12 lumber (38 x 286 mm cross-section),

Each timber element in a NLT panel is attached to adjacent timbers by rows of 100 mm nails, with the rows spaced 300 mm on center. The actual physical properties of the tested bare NLT panels are:

- 89 mm thick panel of 2x4 timbers attached with 2 nails per row, weight 39.5 kg/m^2,
- 138 mm thick panel of 2x6 timbers attached with 3 nails per row, weight 65.8 kg/m^2,
- 183 mm thick panel of 2x8 timbers attached with 3 nails per row, weight 81.6 kg/m^2,
- 234 mm thick panel of 2x10 timbers attached with 4 nails per row, weight 89.5 kg/m^2,
- 285 mm thick panel of 2x12 timbers attached with 4 nails per row, weight 136.8 kg/m^2.

In typical application, the Base NLT assembly includes a layer of plywood or OSB sheets mechanically attached to one face of the NLT panel to provide shear bracing.

5 Dowel-Laminated Timber (DLT) assemblies are structural panels fabricated from timber elements that are fastened together with dowels to form a panel with aligned timber elements. The DLT panels in this study included:

- DLT89 panel fabricated from nominal 2x4 lumber (38 x 89 mm cross-section),
- DLT140 panel fabricated from nominal 2x6 lumber (38 x 140 mm cross-section),
- DLT186 panel fabricated from nominal 2x8 lumber (38 x 186 mm cross-section),

Typically, the Base DLT assembly includes a layer of plywood o mechanically attached to one face of the DLT panel to provide shear bracing.

6 Sound absorbing material is porous (closed-cell foam is not included) and readily-compressible, and includes fiber processed from rock, slag, glass or cellulose fiber. Such material provides acoustical benefit for direct transmission through lightweight framed wall or floor assemblies, and for flanking transmission when installed in the cavities between lining surfaces and heavy homogeneous structural elements of concrete, concrete block or CLT. Note that overfilling the cavity could diminish the benefit.