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A case study on the transmission loss suite in the University of Technology Sydney

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ABSTRACT
This paper introduces the newly built sound transmission loss suite at the Centre for Audio, Acoustics and Vibration (CAAV) at the University of Technology Sydney. This report covers vital parameters of the transmission loss suite when testing a typical heavyweight masonry wall, including the background noise, the spatial variations of the sound pressure level, the reverberation time, the absorption coefficients and the transmission loss. The averaged overall background noise level inside the receiving room is 21.3 dB or 15.5 dBA, approaching the test system/equipment's range. The standard deviation of the sound pressure levels in each test room is less than 1.6 dB in one-third-octave bands with centre frequencies between 100 Hz and 5000 Hz. The weighted sound reduction index (R_w) of the test wall is 66 dB with spectrum adaptation terms (C and C_{tr}) being −1 dB and −6 dB for the A-weighted pink noise spectrum and urban traffic noise spectrum, respectively.

1 INTRODUCTION

The acoustic transmission loss of a building element is essential in noise control. For fair assessment and comparison amongst different products, the transmission loss is generally measured in a laboratory set-up within controlled conditions (ISO 10140-5, 2010). However, various laboratory parameters can affect the measured sound transmission loss, such as the size of the source and receiving room (Guy, De Mey, & Sauer, 1985), the presence and depth of a sample niche (Vinokur, 2006), the sample size (Wareing, Davy, & Pearse, 2015), the sample mounting conditions (Nilsson, 1972), and the construction of the sample. Extensive work has been made to refine the design and usage criteria of a transmission loss test suite with special attention made to improve the consistency of the test results amongst laboratories (Martin, 1986; Meier, Schmitz, & Raabe, 1999; Schmitz, Meier, & Raabe, 1999). To promote measurement accuracy, the transmission loss suite in the University of Technology Sydney (UTS) has:

- flanking transmission suppressed by structural isolation between the source and receiving rooms and highly sound reflective surfaces of both rooms,
- sound field diffuseness promoted with non-parallel walls with suspended diffusers, and
- structural decoupling by rooms of distinct geometry, i.e. a flat room as the source room and a tall room as the receiving room.

As a case study, this paper reports the measurement of a typical Type C heavyweight wall in the UTS transmission loss suite, which has a result matching the theoretical expectation.

2 THE TRANSMISSION LOSS SUITE AT UTS

2.1 Dimensions

The transmission loss suite in UTS consists of two adjacent reverberant rooms with a test opening between them, in which the test element is inserted. Each reverberation room comprises an inner shell of concrete walls forming four walls and a roof, all mounted on a designed concrete floating slab floor which in turn is floated on correctly loaded anti-vibration mounts to reduce the inference from surround sound and vibration. The volume of the source room is approximately 147 m^3 with a total surface area of about 176 m^2. The volume of the receiving room is around 232 m^3 with a total surface area of approximately 247 m^2. The test opening is 3.37 m wide and 2.99 m high. The source room has two double-leaf triple seal access doors and the dimensions of the doors are 2.50 m wide and 2.54 m high. The receiving room has two single-leaf triple seal access doors and the dimensions of the doors are 0.98 m wide and 2.54 m high. Figure 1 shows the geometry of the source room and the receiving room, where HT means the height of the wall from floor level and all units are in millimeter. Figure 2 shows two photos inside the source room and Figure 3 shows two photos inside the receiving room. In this measurement, the source room and receiving room suspend three and four transparent perspex plane panels, respectively, as diffusers from the roof of the room. The size of all the panels is 1.50 m × 1.20 m × 0.01 m. The structural opening for measuring the transmission loss is approximately 3.83 m wide and 2.99 m high with a clear opening 3.37 m wide and 2.99 m high. Figure 4 shows three photos of the test opening with and without the test wall.

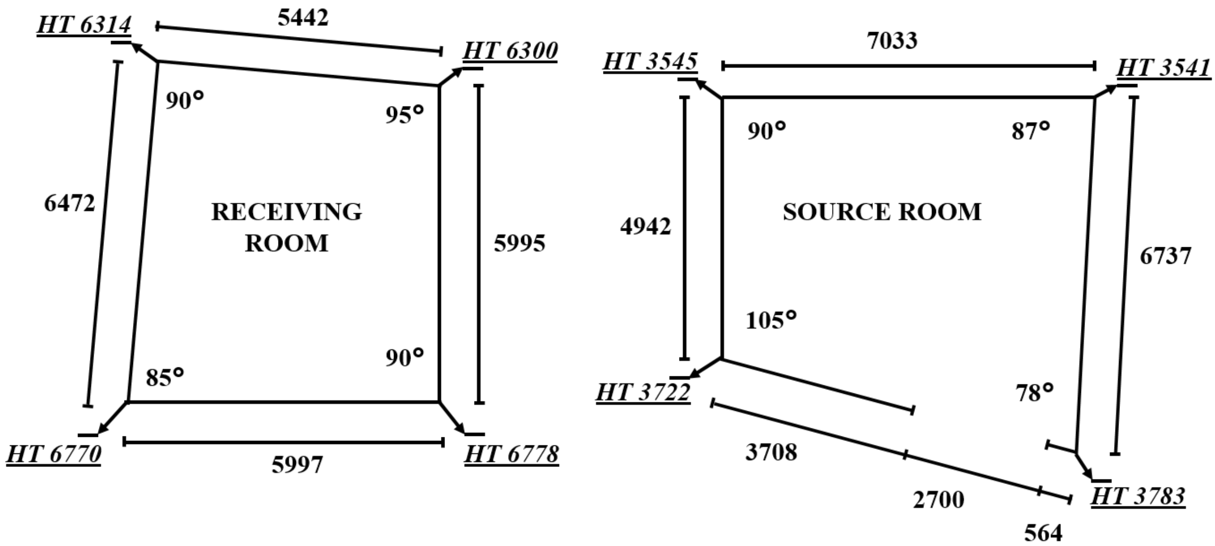


Figure 1: Geometry of the floor of the source room and the receiving room, where HT means the height of the wall from floor level and all units are in millimetre

(a)

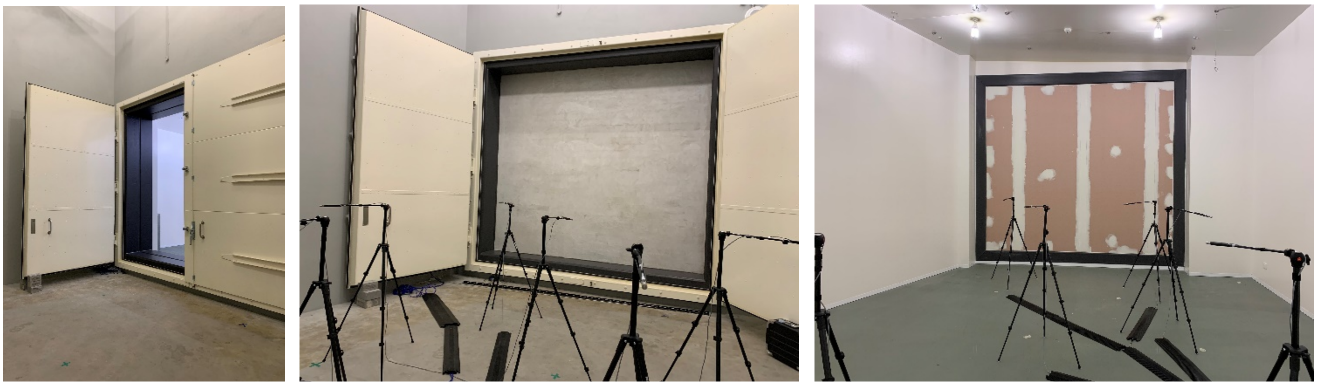
(b)

Figure 2: Photos of the source room at UTS (a) ceiling with transparent diffusers and (b) ground with testing sources and microphones

(a)

(b)

Figure 3: Photos of the receiving room at UTS (a) ceiling with transparent diffusers and (b) ground with testing sources and microphones



(a) (b) (c)

Figure 4: Photos of the test opening (a) empty (b) with test wall viewed from the receiving room (c) with test wall viewed from the source room

2.2 Measurement Setup

The temperature and relative humidity in the room during the measurement are 26.0°C and 66%, respectively. Measurements have been taken in 18 one-third-octave bands with the centre frequencies of 100 Hz, 125 Hz, 160 Hz, 200 Hz, 250 Hz, 315 Hz, 400 Hz, 500 Hz, 630 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1600 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz, and 5000 Hz according to ISO 10140. The microphones are twelve sets of Brüel & Kjær 4942-L-001 1/2'' microphones. The sound source is Brüel & Kjær 4292-L high-power omnidirectional loudspeaker. The equipment names used in the measurements are listed in Table 1.

The position of the microphones and the sound sources used in the measurements are listed in Tables 2 and 3. The origin of the coordinate is separately at the left top corner of the floor of the source room at the right bottom corner of the floor of the receiving room in Figure 1. The sound sources in the source room are for the sound pressure level measurement and the sound sources in the receiving room are for the equivalent absorption area measurement. The sound source positions were qualified following Annex D of ISO 10140-5:2010.

Table 1: The equipment used in the measurements

Equipment Name	Description
Pulse LabShop Software	Brüel & Kjær Version 23
Pulse Measurement System Switch	Brüel & Kjær Type UL-0265 S/N: A043118AR0300041
Pulse Generator Module	Brüel & Kjær Type 3160-A-042 S/N: (1) 3160-106866 (2) 3160-107668
Pulse 6ch. Input Module	Brüel & Kjær Type 3050-A-060 S/N: (1) 3050-112794 (2) 3050-112726
Power Amplifier	Brüel & Kjær Type 2734 S/N: (1) 060006 (2) 088001 (3) 088002
Omnidirectional Loudspeaker	Brüel & Kjær Type 4292-L S/N: (1) 052008 (2) 072008 (3) 072009
Microphone with Preamplifier	Brüel & Kjær Type 4942-L-001 S/N: (1) 2913236 (2) 2913211 (3) 2913210 (4) 2913207 (5) 2742563 (6) 2913212 (7) 2913213 (8) 2913237 (9) 2913235 (10) 2913209 (11) 2913208 (12) 2913214
Digital Thermo-Hygrometer	CEM DT-322 S/N: 131134137

Table 2: The position of the microphones and sound sources in the source room

Items	*x* (m)	*y* (m)	*z* (m)
Microphone 1	2.09	1.26	1.22
Microphone 2	1.38	2.98	1.22
Microphone 3	1.82	4.74	1.22
Microphone 4	3.72	5.42	1.21
Microphone 5	3.10	2.82	1.26
Microphone 6	3.77	1.36	1.27
Source 1	0.32	6.73	0.23
Source 2	6.32	6.54	0.23

Table 3: The position of the microphones and sound sources in the receiving room

Items	*x* (m)	*y* (m)	*z* (m)
Microphone 1	1.58	2.94	1.22
Microphone 2	3.14	2.35	1.23
Microphone 3	4.51	1.10	1.23
Microphone 4	4.97	3.12	1.24
Microphone 5	3.99	4.35	1.24
Microphone 6	2.29	4.32	1.23
Source 1	0.46	5.45	0.23
Source 2	6.01	4.99	0.23

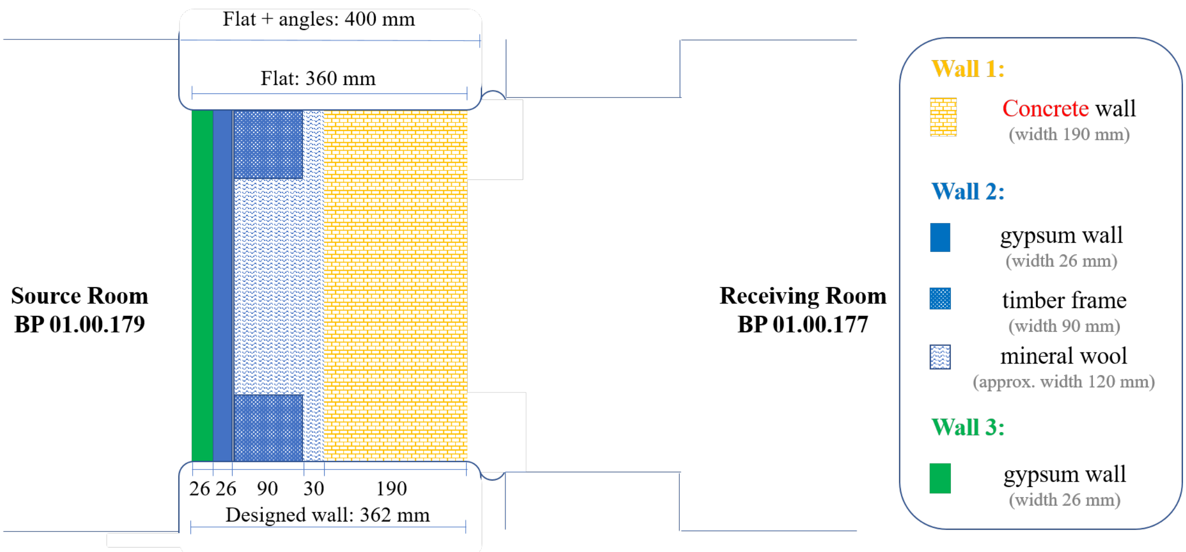


Figure 5: Geometry of the test wall at the test opening, which is composed of three layers

Figure 5 shows the test wall, a typical heavyweight masonry wall following ISO 10140-5, A.2.2.1.3. It consists of a concrete brick wall, having a mass per unit area of approximately 400 kg/m^2. On one side, an independent lining is constructed comprising four layers of 13 mm plasterboard supported on a 90 mm timber frame that is not connected to the wall. The cavity between the wall and the lining is 120 mm wide and contains mineral wool. The 190 mm thick concrete block wall was installed to steel-framed test opening, with a skim coat of render to external face and joints caulked all around. The insulation layer was filled with the 75 mm Fibretech 350 rock wool board with a nominal density of 60 kg/m^3. The plasterboard sheets were staggered 13 mm Fyrchek with joints caulked all around.

3 MEASUREMENT RESULTS

3.1 Background Noise

The background noise was measured at the six microphone positions in the receiving room (shown in Table 3) on 30 January 2020. Following Chapter 4.3 in ISO 10140-4, the measured background noise includes noise from outside the test room and electrical noise in the receiving system. The averaged measured values (arithmetic mean value of the values at the six microphone positions) in the 18 one-third-octave bands and the absolute criteria for background noise specified in Table 2 of ISO 3741 are shown in Figure 6. The measured noise level fully meets the absolute criteria for the background noise. The averaged overall background noise level of the sound pressure level in the whole frequency band is 21.3 dB and 15.5 dBA.

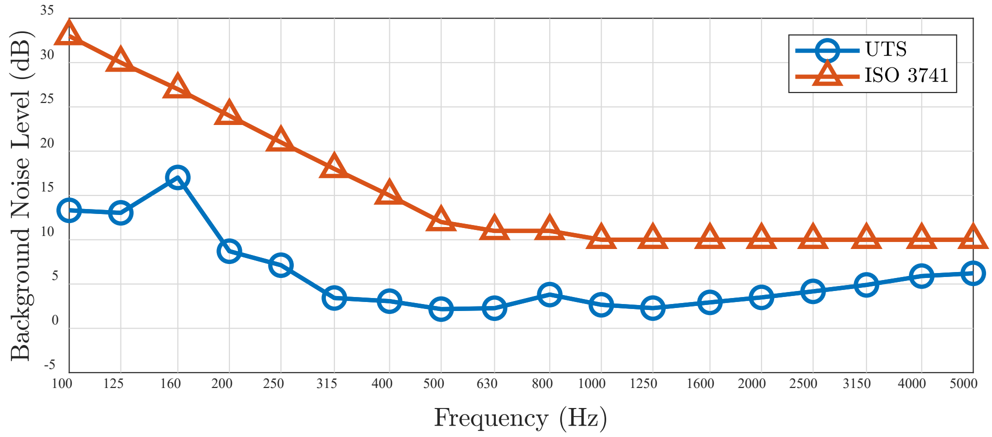


Figure 6: The averaged values of the background noise level of the receiving room measured by Brüel & Kjær 4942 1/2" microphone and the absolute criteria for the background noise specified in Table 2 of ISO 3741

3.2 Spatial Variations of the Reverberant Field

The standard deviation of the sound pressure levels measured at the six microphone positions for a sound source position in a one-third-octave band can be determined from Eq. (1) following Chapter 8.4.1 of ISO 3741,

$$s_{\mathrm{M}} = \sqrt{\sum_{i=1}^{N_{\mathrm{M}}} \frac{(L_i - L_M)^2}{N_{\mathrm{M}}-1}} \tag{1}$$

where L_i is the one-third-octave band time-averaged sound pressure level measured at the ith microphone position, L_{M} is the arithmetic mean value of the one-third-octave band time-averaged sound pressure levels measured at the six initial microphone positions, and $N_{\mathrm{M}} = 6$ is the number of microphone positions. Table 4 lists the averaged standard deviation of the sound pressure levels separately in the source room and receiving room when a steady-state sound field is generated by using two sound sources simultaneously in the source room. The measured value does not exceed 1.6 dB in any one-third-octave band. Small variations of the sound pressure level in each room indicate that no dominating strong standing wave is present in the rooms and the steady-state reverberant field has good diffusion.

3.3 Reverberation Time and Sound Absorption Area

The number of spatially independent measured decay curves shall be at least 12. Six microphone positions and two sound source positions have been used in each control room, and their positions follow the guidelines specified in Chapters 7.1.2 and 7.1.3 of ISO 354 and Chapter 4.6 of ISO 10140-4. The mean reverberation time of each room in each frequency band is expressed by the arithmetic mean of the total number of reverberation time measurements made in the frequency band as specified in Chapter 8.1.1 of ISO 354. Table 4 lists the measured values of the source room and the receiving room from the interrupted noise method as specified in ISO 10140-4. In the measurements, the source room and the receiving room are measured separately with the test wall being inserted at the test opening. The equivalent sound absorption areas listed in Table 4 are calculated with Eq. (5) in ISO 10140-4 by using the mean reverberation time of each room in each frequency band.

Table 4: The parameters of the transmission loss suite at UTS

Frequency (Hz)	Source Room			Receiving Room		
	Averaged standard deviation of the SPL (dB)	Mean RT (s) (interrupted noise method)	Sound absorption area (m^2)	Averaged standard deviation of the SPL (dB)	Mean RT (s) (interrupted noise method)	Sound absorption area (m^2)
100	1.05	3.2	7.2	1.58	10.0	3.7
125	1.08	4.4	5.3	1.21	7.3	5.1
160	1.09	4.8	4.9	0.44	10.1	3.7
200	0.82	4.8	4.9	0.59	9.4	4.0
250	0.37	5.3	4.4	0.58	9.9	3.8
315	0.68	5.3	4.4	0.63	9.2	4.0
400	0.48	5.0	4.7	0.46	8.7	4.3
500	0.66	4.5	5.2	0.33	9.0	4.1
630	0.26	3.8	6.2	0.39	8.7	4.3
800	0.27	3.7	6.4	0.19	8.0	4.7
1000	0.33	3.8	6.2	0.20	7.6	4.9
1250	0.30	3.6	6.5	0.13	6.8	5.4
1600	0.50	3.5	6.7	0.42	6.0	6.2
2000	0.37	3.2	7.2	0.32	5.2	7.1
2500	0.41	3.1	7.6	0.43	4.9	7.6
3150	0.41	3.0	7.8	0.24	4.4	8.5
4000	0.47	3.0	7.7	0.19	3.7	10.0
5000	0.63	2.7	8.5	0.25	3.1	11.9

3.4 Transmission Loss

The transmission loss is calculated using equation (2) in ISO 10140-2,

$$R = L_1 - L_2 + 10\lg\frac{S}{A} \tag{2}$$

where L_1 is the energy average sound pressure level in the source room, L_2 is the energy average sound pressure level in the receiving room, S is the area of the free test opening in which the test element is installed, and A is the equivalent sound absorption area in the receiving room. Their values in the one-third-octave bands are presented in Figure 7, and the corresponding sound reduction index is presented in Figure 8. The background noise level is more than 18 dB below the level of signal and background noise combined at each frequency band, so that the observations in the receiving room are not affected by the background noise. The minimal sound reduction is 47.1 dB in the one-third-octave band centred at 160 Hz, and the maximal sound reduction is 83.9 dB in the one-third-octave band centred at 5000 Hz. The weighted sound reduction index (R_w) of the test wall is 66 dB with spectrum adaptation terms (C and C_{tr}) being –1 dB and –6 dB for the A-weighted pink noise spectrum and urban traffic noise spectrum, respectively. The sound transmission class (STC) of the test wall is also 66 dB.

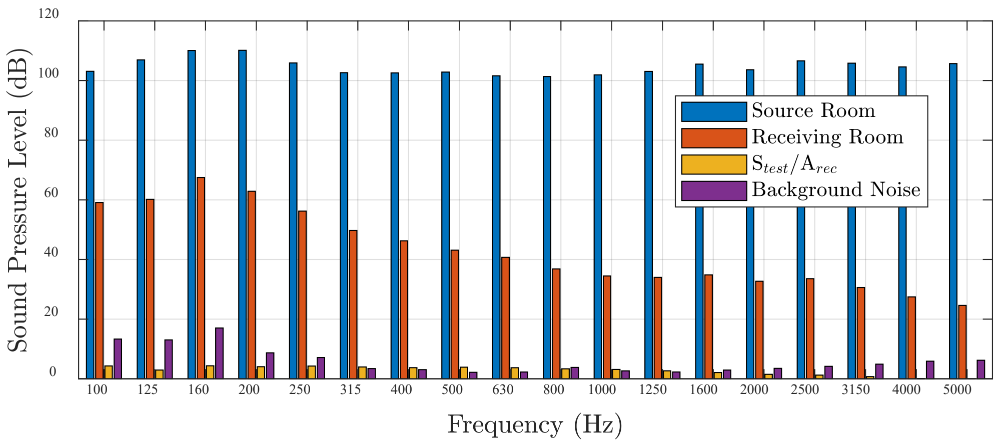


Figure 7: The energy average sound pressure level in the source room and the receiving room, the spatially averaged background noise in the receiving room, and the ratio of area of the test opening and the area of the equivalent sound absorption

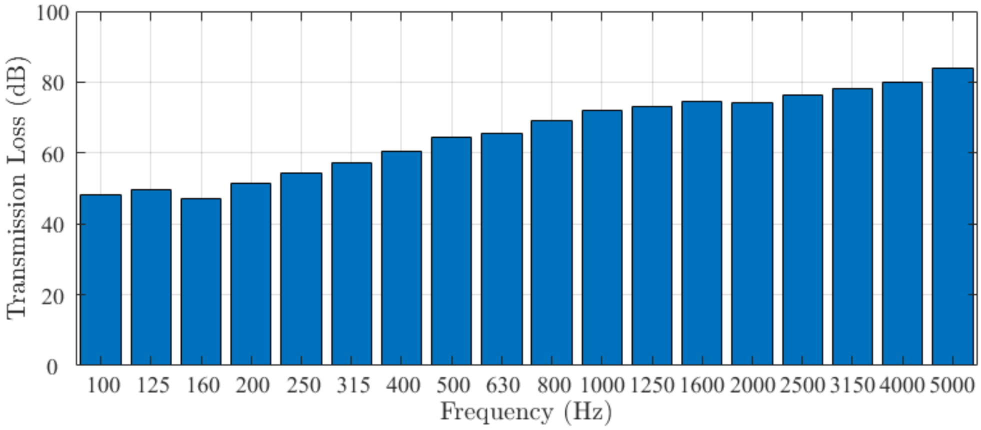


Figure 8: The transmission loss of the test wall versus the frequency

4 DISCUSSION

4.1 Intermedium Results During the Wall Construction

The intermedium results of the transmission loss with different wall setup are presented in Figure 9 with reference to the theoretical estimations calculated using ENC software (ENC, 2010). The rating of the transmission loss is reported in Table 5. The sound transmission loss improves with the increased layers of walls.

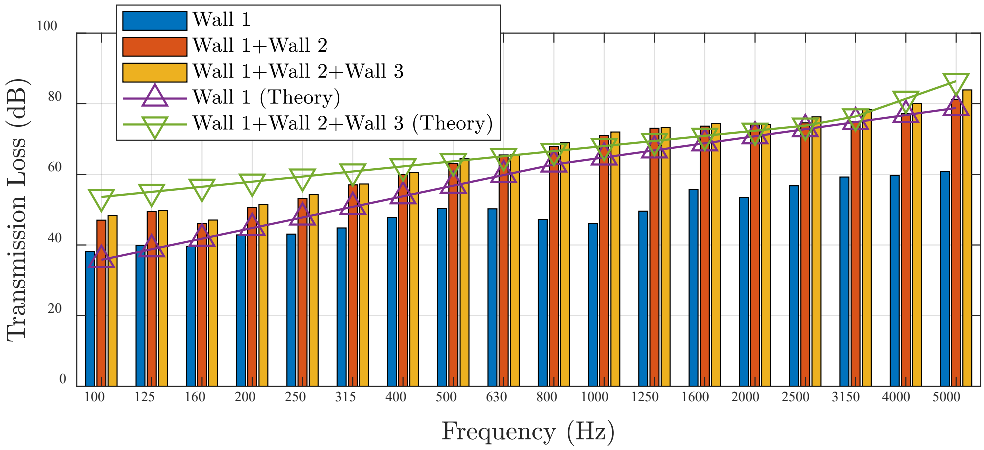


Figure 9: Transmission loss under different test wall conditions, with the theoretical estimations as reference

Table 5: The rating of the transmission loss under different test wall conditions

Test Wall Condition	Sound Transmission Descriptor			
	STC	R_W	C	C_{tr}
Wall 1	51	51	–1	–4
Wall 1+Wall 2	66	65	–2	–6
Wall 1+Wall 2+Wall 3	66	66	–1	–6

4.2 Further Development

Recently, the transmission loss suite has been developed with more diffusers installed to further promote the sound field diffuseness, especially in the receiving room. Besides, it is also equipped with cameras and an audio system with 64 DPA 4060 microphones and Yamaha DAW systems to allow live audio-visual feed for remote observation and monitoring of acoustic testing. Furthermore, as measured sound transmission loss can be affected by the sample mounting conditions and the construction of the sample, Laser Doppler Vibrometry and acoustics camera might be used to assist the onsite debugging of the sample installation.

5 CONCLUSION

The background noise of the transmission loss suite is in compliance with ISO 3741. The standard deviation of the sound pressure levels is less than 1.6 dB in the one-third-octave bands with centre frequencies between 100 Hz and 5000 Hz, indicating good diffusion of the reverberant sound field. The weighted sound reduction index (R_w) of the test wall is 66 dB with spectrum adaptation terms (C and C_{tr}) being −1 dB and −6 dB for the A-weighted pink noise spectrum and urban traffic noise spectrum, respectively. The transmission loss suite at UTS meets all the requirements in ISO 10140 on the laboratory test facilities for airborne sound insulation measurements. The measurement results of the test wall indicates that the laboratory is capable of measuring building elements, such as Type C walls and floors, having values of R_w up to 52 dB. Further measurements should be performed to determine the maximal maximum measurable sound reduction index for other building elements with much increased density, such as walls made of metal.

REFERENCES

Engineering Noise Control Software (ENC) (2010). http://www.causalsystems.com/htm/encoverview.htm

ISO 10140-1:2016 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 1: Application rules for specific products*

ISO 10140-2:2010 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 2: Measurement of airborne sound insulation*

ISO 10140-4:2010 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 4: Measurement procedures and requirements*

ISO 10140-5:2010 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 5: Requirements for test facilities and equipment*

ISO 354:2003 *Acoustics – Measurement of sound absorption in a reverberation room*

ISO 3741:2010 *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for reverberation test rooms*

Guy, R., De Mey, A. and Sauer, P. (1985). The effect of some physical parameters upon the laboratory measurements of sound transmission loss. *Applied Acoustics,* vol. 18(2), pp. 81-98.

Martin, H. J. (1986). Sound transmission rooms: A comparison.

Meier, A., Schmitz, A. and Raabe, G. (1999). Inter-laboratory test of sound insulation measurements on heavy walls: Part II—Results of main test. *Building Acoustics,* vol. 6(3), pp. 171-186.

Nilsson, A. (1972). Reduction index and boundary conditions for a wall between two rectangular rooms. Part I: Theoretical results. *Acta Acustica united with Acustica,* vol. 26(1), pp. 1-18.

Schmitz, A., Meier, A. and Raabe, G. (1999). Inter-laboratory test of sound insulation measurements on heavy walls: Part I—Preliminary test. *Building Acoustics,* vol. 6(3), pp. 159-169.

Vinokur, R. (2006). Mechanism and calculation of the niche effect in airborne sound transmission. *The Journal of the Acoustical Society of America,* vol. 119(4), pp. 2211-2219.

Wareing, R. R., Davy, J. L. and Pearse, J. R. (2015). Variations in measured sound transmission loss due to sample size and construction parameters. *Applied Acoustics*, vol. 89, pp. 166-177.