Average Sound Transmission Loss of Steel Stud Partitions

James Heddle

James Heddle Acoustical Consultants, Brisbane, Australia

ABSTRACT

For the assessment of speech privacy and security, a uniformly weighted 1/3-octave-band signal-to-noise ratio, clipped to -32 dB, has been found to be a good indicator of speech intelligibility, cadence and audibility. A parameter required in the determination of the ratio for a listener in an adjoining room to the speech source is the average sound transmission loss of the separating construction. An estimation model for the average sound transmission loss of steel stud partitions has been developed and will be discussed.

1. INTRODUCTION

For the evaluation of acoustic privacy in enclosed rooms, the general scenario to be considered is sound from an external source, such as speech, with contributions from the source room acoustics (reflected sound energy) being transmitted through a separating construction to the receiving room where it will reach the listener along with contributions from the receiving room acoustics, generated in response to the transmitted sound, and the ambient noise in the room.

A thorough series of investigations were conducted by John Bradley and colleagues at the NRC Institute for Research in Construction (IRC), Canada, looking in particular at speech privacy and the sound transmission to a listener via a separating wall (Gover,2004; Bradley, 2006; Park, 2007a; Park, 2007b; Bradley, 2008; Bradley, 2011).

A number of different measures for the prediction of speech intelligibility, threshold of intelligibility and threshold of audibility for speech transmitted through walls were evaluated. These investigations found that the uniformly weighted signal-to-noise ratio (SNR_{UNI32}) was an objective, well-correlated (R^2= 0.853) index for the prediction of the speech intelligibility and the audibility and intelligibility thresholds.

The SNR_{UNI32} is determined from the average of the differences, for each of the one third octave bands from 160 Hz to 5000 Hz, between the transmitted speech level and the ambient noise in the listening space. The differences are in each band are given uniform (equal) weighting and are constrained to be not less than -32 dB.

In contrast, the investigations found that the sound transmission loss index Rw was a very poor guide to the speech privacy that could be expected from a given wall construction. Figure 1 is a graph of the mean speech intelligibility score versus Rw rating for 20 simulated walls.

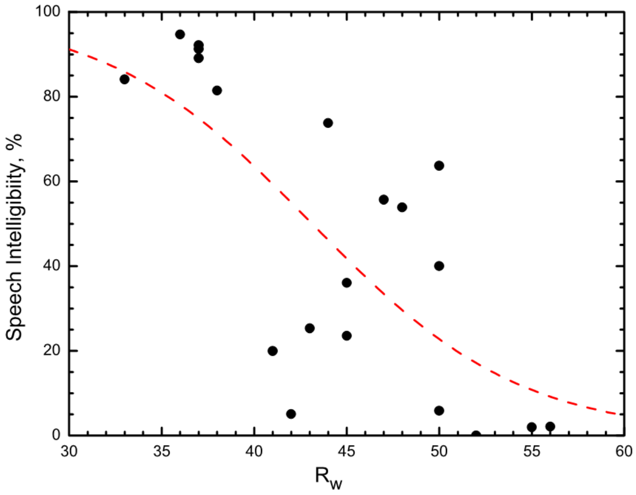

Figure 1: Speech intelligibility scores versus Rw ratings of 20 simulated walls (Park, 2007b)
Neutral spectrum 35 dBA ambient noise in the receiving room. (R^2= 0.542)

The investigations concluded that the SNR_{UNI32} ratio could be expressed approximately as,

$$SNR_{UNI32} \cong [L_{sp}(avg) - LD(avg)] - L_n(avg) \cong [L_{sp}(avg) - (TL(avg) + k)] - L_n(avg) \tag{1}$$

Where:

$[L_{sp}(avg) - LD(avg)]$	=	average speech level transmitted to the listener
$L_n(avg)$	=	the ambient noise average at the listener
$L_{sp}(avg)$	=	source room average speech level
LD(avg)	=	The average level difference from a source room average to the level at a listener position
	=	TL(avg) + k

Here, TL(avg) is the average sound transmission loss and k, is an empirical factor introduced to correct for the influence of the receiving room reverberant sound field.

The averages are taken over the 16 one third octave bands with centres frequencies from 160 Hz to 5000 Hz.

Figure 2 shows a transmitted speech spectrum (dotted curve) for an example source room speech spectrum and separating wall sound transmission loss.

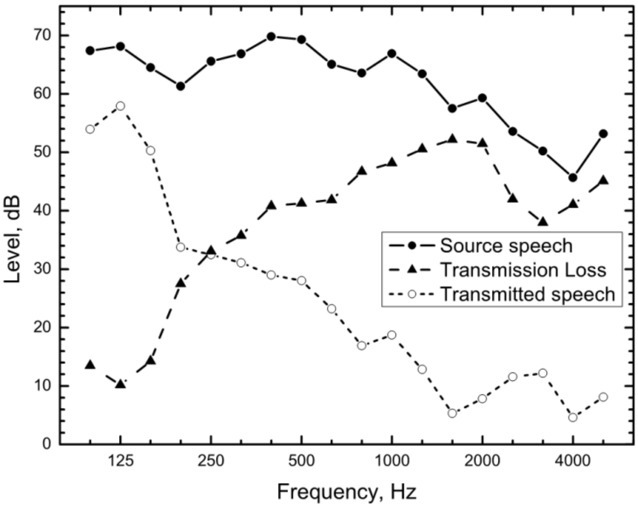

Figure 2: Example transmitted speech spectrum for given transmission loss and source speech spectrum (Park, 2007b)

In the development of the method, the receiver location was chosen to be close to the wall (0.25 m) because this represented a more sensitive position for eavesdroppers without being too sensitive to errors in the microphone position, allowed the detection of weak points in the sound isolation and did not require the receiving space to have diffuse field behavior. The adjustment k is a correction for the reverberant sound field level in the receiving room, relating the average transmission loss values, TL(avg), to the level difference, LD(avg). In general, k is small and adding absorption to the rooms decreases its magnitude to be close to zero.

2. AVERAGE SOUND TRANSMISSION LOSS DEPENDENCIES AND MODEL

The approach taken to develop a predictor for TLavg(160-5kHz) was guided by previous analysis and modelling by Warnock (Warnock, 1995) and was limited to wall constructions with steel studs at spacings of 600mm, typically used. Analyses were made on the factors: total panel density (M, kg/m^2); cavity depth (d, mm) and airflow resistance (R, MKS Rayls) of the cavity infill. These had previously been found to be the most relevant in a regression analysis of wall sound transmission loss. 1/3rd octave band test data on 186 steel studs walls with stud spacing at 600mm (Halliwell, 1998) and genetic algorithm optimization were used to refine the model. This found,

$$TLavg(160 - 5kHz) = \ 18.78\ Log(M) + 37.29\ \left(Log(d)\right)^{0.22} + 1.34\ Log(R) - 19.77\ dB \qquad (2)$$

Figure 3 shows the predicted relative to measured TLavg(160-5kHz) results based on this formula. Standard steel studs are indicated in the figure by the dark blue diamonds with the standard steel studs trend line shown as a bold light blue line. The other types (separate stud, studs with resilient channels) are indicated by orange triangles. The overall trend, all steel stud types, is indicated by the aqua line.

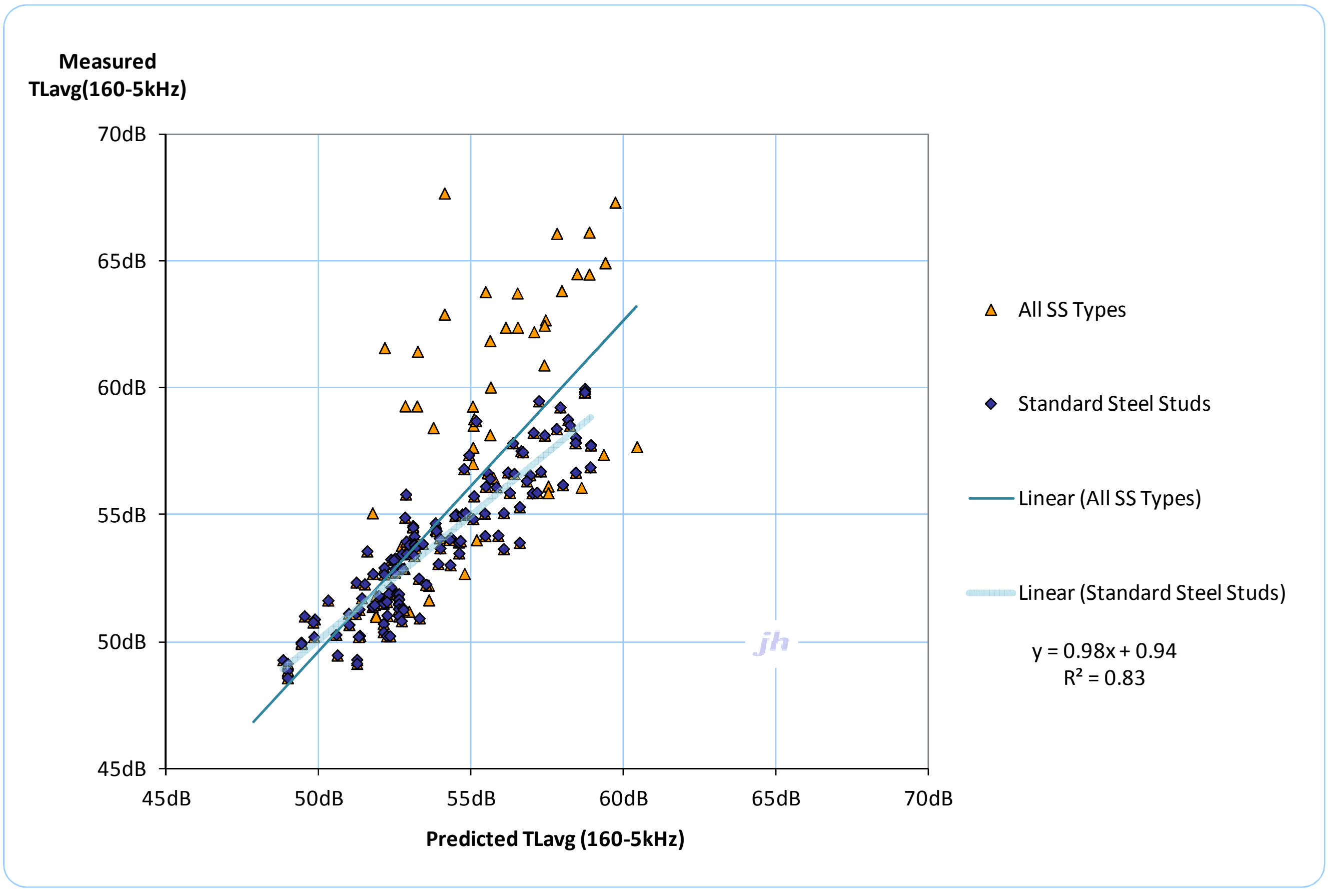

Figure 3: Initial TLavg(160-5kHz) estimation model, IRC data (Halliwell, 1998)

Given that the correlation of the prediction to the measurements for the standard steel stud walls was reasonable but poor for the other types, an adjustment for the types of stud type was pursued. Of the various options a simple offset for each stud type was trialled. After optimization the following was found to best fit the data.

$$TLavg(160 - 5kHz) = \ 18.78\ Log(M) + 37.29\ \left(Log(d)\right)^{0.22} + 1.34\ Log(R) - 19.77 + C \pm 1.39\ dB \qquad (3)$$

where C = -5.26 for standard studs and no absorptive infill in cavity
= 0 for standard studs with absorptive infill
= 3.13 for absorptive infill and resilient channels
= 7.52 for absorptive infill and separate studs

The estimation formula with adjustments for stud type had a mean error of zero, a squared Pearson correlation coefficient of 0.91 and standard deviation of the estimation error relative to the measured values of 1.39 dB.

Figure 4 shows the predicted relative to measured TLavg(160-5kHz) results based on this modified formula.

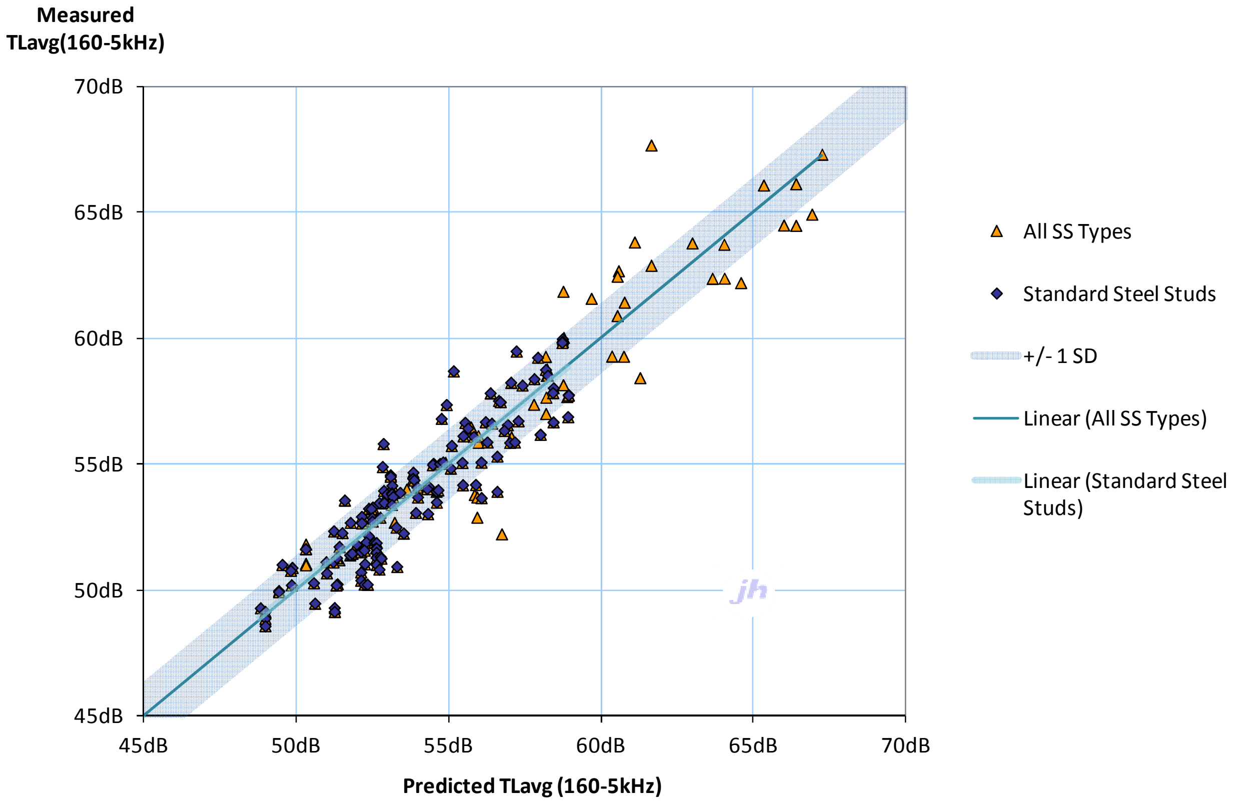

Figure 4: Modified TLavg(160-5kHz) estimation model, IRC data (Halliwell, 1998)

3. REPRODUCIBILITY

The estimation scheme developed was used to predict the TLavg(160-5kHz) values for comparison to values derived from some Australian test facility 1/3 octave band data (RMIT, EBS). This found significant differences with a mean over-estimation of 6.18 dB. In reviewing the possible causes for this difference, a literature search found a study of inter-laboratory reproducibility (Fausti, 1999) indicating that differences of this order between testing laboratories could be expected. The reproducibility, R value, is defined as the value below which the absolute difference between two single results from different laboratories may be expected to lie with a probability of 95%.

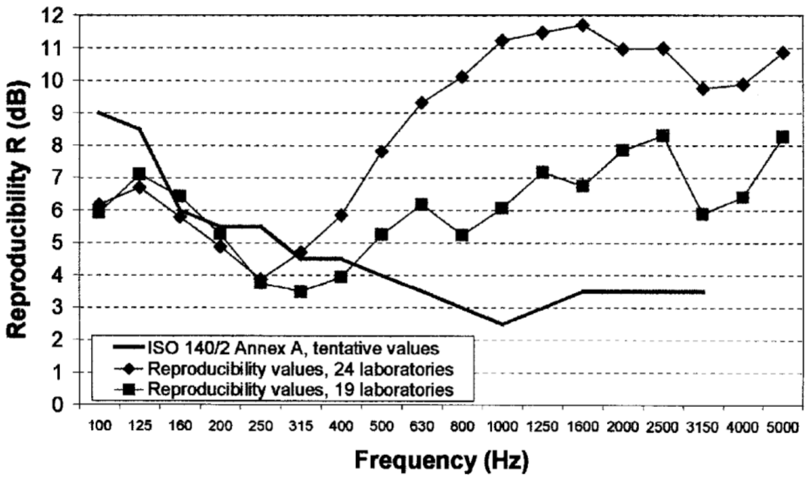

Figure 5: Inter-Laboratory Reproducibility, European Inter-Laboratory Test (ILT) program (Fausti, 1999)

4. DISCUSSION

A few points are worth noting in relation to the use of TLavg(160-5kHz) estimation for design and assessment purposes:

- The estimation scheme, described by equation (3), only applies to steel stud wall constructions with 600mm stud spacings.
- As Figure 6 shows for speech audibility, the change in SNR_{UNI32} between inaudibility and audibility is non-linear and occurs in a relatively narrow range, the response of listeners is more akin to a soft or biological switch. The response characteristic is similar for speech intelligibility (Bradley, 2006; ~8dB for a change from 10% to 90% responding for audibility and ~10dB for speech intelligibility). This means that estimations and performance/design outcomes are quite sensitive to input error, a relatively rapid change occurring in audibility or intelligibility in the switch zones for a small change in SNR_{UNI32}. That is, in the range of values where the switching occurs there is high sensitivity to input error in the TLavg(160-5kHz) estimate, the assumed ambient noise level, the assumed speech level and to k.

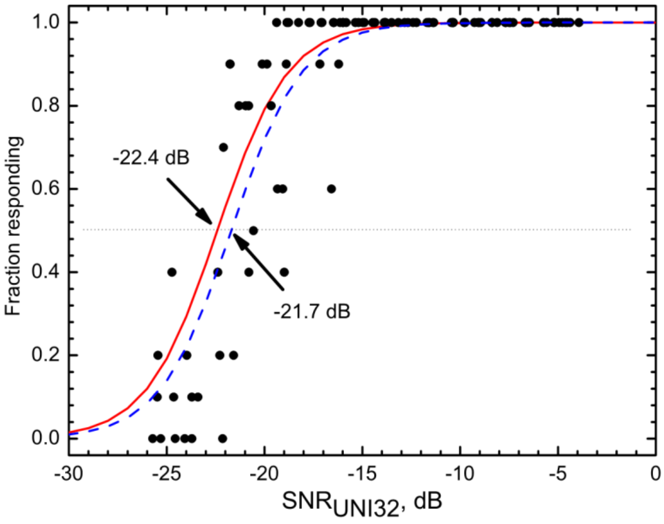

Figure 6: Fraction of listeners indicating that they heard some speech sounds for each test sentence (Bradley, 2006)

- Inter-lab transmission loss test result variability is also potentially problematic for the accuracy of predictions of audibility or intelligibility. Calibration to individual test laboratories is advisable. For this estimation scheme the correction for IRC test data is 0 dB, Australian test data assessed required an adjustment to the estimation result in the order of -6.2 dB.
- Adding infill to a wall cavity causes a marked improvement in TLavg(160-5kHz).
- Using separate studs with cavity infill causes a marked improvement in the TLavg(160-5kHz) compared to single studs with cavity infill.
- The estimation scheme may be of most use in comparing the relative merit of construction options in relation to design for speech privacy.

5. CONCLUSION

Compared to other single number transmission loss indices, such as Rw, a superior prediction of speech privacy and audibility for a separating wall is enabled using the average transmission loss of the construction, TLavg(160-5kHz). An estimation scheme for the average transmission loss of steel stud partitions with good predictive power has been developed. Some cautions relating to its use due to inter-laboratory test result variability have been given. Future work will look further into the differences in results between different testing laboratories.

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