3pNSb5. Compliance and vegetated-barrier acoustical testing in a purpose-built sound-transmission suite

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Random-incidence transmission losses and absorption coefficients of a vegetated noise barrier of Criblock® construction were measured without and with plants in a sound-transmission suite built specifically for the purpose, constructed from concrete noise barriers, with the vegetated barrier separating source and receiver rooms. The suite was tested for compliance with ASTM E90-09, and found to be substantially but not completely in compliance with respect to uniformity of steady-state levels and surface absorption. It was found that the transmission loss of the vegetated barrier ranged from 42 dB at low frequencies to 66 dB at 1000 Hz; above 1000 Hz only a lower limit of the TL could be determined -- values of 57-62 dB were found. These values are at least 25 dB higher than recommended by BC Ministry of Transportation guidelines. The absorption coefficients of the unplanted and planted barriers were measured; the plants decreased the absorption slightly, from NRC 0.42 to 0.37.

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INTRODUCTION

This report discusses the results of measurements of random-incidence transmission loss and absorption coefficient of a vegetated barrier, made to determine if the barrier would be a suitable roadside noise barrier for use in British Columbia (B.C.), Canada. A sound-transmission suite was built by Retaining Walls Northwest, Inc. at the Cascade Concrete Industries, Inc. plant in Burlington, Washington, USA for the sole purpose of these measurements. The suite was designed and tested for compliance with ASTM E90-09 [1], the standard test method for laboratory measurement of the airborne sound-transmission loss (TL) of building partitions and elements. Once done, the random-incidence absorption coefficients and transmission losses of the barrier, when unplanted and planted with unestablished, wilted grasses, were measured. The results were compared with design criteria used by the B.C. Ministry of Transportation and Infrastructure (BCMoTI) [2]; these specify the minimum TL a barrier must have to be effective, and the minimum sound absorption a barrier must have to be considered an absorptive barrier.

![FIGURE 1. The purpose-built sound-transmission suite.](image1)

SOUND-TRANSMISSION SUITE AND VEGETATED BARRIER

The sound-transmission suite, comprising source and receiver rooms separated by the test barrier, was built out of existing concrete panels on a concrete ground surface (see Figure 1). The suite was built such that the vegetated noise barrier formed the entire partition separating the two rooms. The source room was 5.80-m long, 4.70-m wide and 3.10-m high; the receiver room had the same width and height, and was 6.20-m long.

The vegetated barrier was of Criblock™ construction [3], comprising a framework of concrete members (see Figure 2) filled with compacted, wet sand; this concept has been used by Retaining Walls Northwest, Inc. to construct retaining walls for many years [4]. It is typically 1.4-m thick and, in this case, was 3.1-m high and 4.7-m wide. The barrier can either be unplanted (Figure 3a) or planted. In the planted case tested here (Figure 3b), one side of the barrier was planted with variegated Japanese sedge (Carex morrowii ‘Aurea-variegata’). The roots of plants grown in pots were inserted in the soil and the barrier was tested before the plants had any opportunity to become established.

![FIGURE 2. Illustration of the structure of the Criblock™ noise barrier.](image2)
The tests were performed using WinMLS, installed on an Acer laptop. WinMLS outputs maximum length sequences and processes measured responses to obtain, after filtering, frequency-varying room impulse responses, from which sound-decay curves and reverberation times are determined. An Electro-Voice S-122 monitor loudspeaker was connected to the output of the laptop through a Bryston amplifier. For the reverberation-time measurements, a Rion NA-28 sound-level meter used as the receiver was connected to the input of the laptop to acquire the signal. For the sound-level measurements, WinMLS was again used to provide the sound signal to the loudspeaker; the Rion was used to record levels. Measurements were made in third-octave frequency bands from 100 to 8000 Hz. Temperature and humidity were measured with a Psychro-Dyne psychrometer.

COMPLIANCE TESTING

The transmission-loss standard, ASTM E90-09, was the basis for the design of the sound-transmission suite and of the transmission-loss tests. Thus, compliance with the standard was tested. Below are several important requirements of the standard that were addressed in the design and testing of the facility for compliance with the standard.

Room Volume

In the standard, for measurement down to 100 Hz, the specified minimum requirement for the source- and receiver-room volumes is 80 m$^3$. Given the dimensions stated above, the volumes of the source and receiver rooms were 84.5 m$^3$ and 90.3 m$^3$, respectively.

Temperature

The standard states that, unless otherwise specified, the average temperature in each room during measurements should be in the range 22 ± 5°C. This is understood to be intended to ensure that test specimens usually used inside buildings are tested at room temperature. The sound-transmission suite was an unheated concrete structure located outdoors, and testing took place in November. The temperature during testing was 6 ± 1°C; however, as the type of vegetated barriers being tested here will be located outdoors year-round, this is a more realistic temperature at which to test their performance, consistent with the intent of the standard.
Room Absorption

In the standard, the maximum receiver-room sound-absorption area is specified as a function of the room volume. For a room with a volume of 90 m$^3$, the maximum absorption is 6.7 m$^2$. Since the vegetated barrier comprised the whole partition between the rooms, and had a sound-absorptive surface, this condition could not be met when the barrier was uncovered. Measurements were therefore made with the barrier uncovered, and then repeated with the barrier covered with 25-mm-thick plywood panels, as shown in Figure 4. With the barrier covered with plywood panels, the absorption was in compliance with the standard, except at frequencies above 2000 Hz. The lack of compliance would be expected to have a negligible effect on the measured performance.

Confidence Interval for Transmission-Loss Measurements

To ensure a sufficiently diffuse sound field in each room, maximum allowable confidence intervals for the measured transmission loss are specified in the standard. The total confidence interval is the sum of three contributions: those of the sound levels in the source and receiver rooms, and that of the receiver-room absorption. It was assumed \textit{a priori} that the confidence interval of the absorption of the receiver room was negligible in the calculation of the TL confidence interval. Therefore, assuming that the confidence intervals of the sound levels in the source and receiver rooms were the same, the maximum allowable confidence interval of the sound level in one room ($\Delta L$) would be the TL confidence interval ($\Delta TL$) divided by $\sqrt{2} = 0.71$. These confidence intervals are given in Table 1.

Sound-level measurements were made at nine receiver positions (Figure 5), following the guidelines in the standard for the minimum distances between receiver positions, walls and the sound source. Preliminary tests with the uncovered, unplanted barrier showed the facility to be slightly out of compliance in several bands. Thus several 25-mm-thick plywood panels, leaning against the walls and hung from the ceiling, were introduced as diffusers. With the barrier not covered with plywood panels, eight of twenty third-octave bands were slightly out of compliance (by up to 0.5 dB); the presence of the large absorptive barrier surface inevitably reduced the diffuseness of the sound field. With the vegetated barrier covered with plywood panels, the sound-level confidence intervals decreased, and were in compliance in all but one (315 Hz) of the twenty third-octave bands. This indicated that there was a highly diffuse sound field in the room when the room absorption was minimized. The lack of compliance would be expected to have a negligible effect on the measured performance.

\begin{table}
\centering
\begin{tabular}{|c|c|c|}
\hline
Third-Octave-Band Frequency (Hz) & $\Delta TL$ (dB) & $\Delta L$ (dB) \\
\hline
80 & 6 & 4.2 \\
100 & 4 & 2.8 \\
125, 160 & 3 & 2.1 \\
200, 250 & 2 & 1.4 \\
315 – 4000 & 1 & 0.7 \\
\hline
\end{tabular}
\caption{Third-octave-band maximum confidence intervals specified in Ref. 1 for the transmission loss ($\Delta TL$), and assumed for the sound level ($\Delta L$).}
\end{table}
The confidence intervals for the calculated transmission loss did not meet the standard’s recommendations in half of the third-octave bands. Because of the very high TL of the barrier, the receiver-room noise levels that were measured were mostly those of background noise due to nearby road traffic, which was quite variable, increasing the overall confidence intervals. The increase was not due to non-diffuseness of the sound field in the source or receiver room. How the excessive noise levels were dealt with, and their effect on the measurement results, are discussed in the next section.

TRANSMISSION-LOSS MEASUREMENT

The barrier’s transmission loss and the receiver-room background-noise levels were measured for three configurations: receiver side covered with plywood, both sides of the barrier uncovered and unplanted, and receiver side planted. Due to the high transmission loss of the vegetated barrier, background noise was a limiting factor in measuring the receiver-room noise levels at high frequencies; above 1000 Hz, signal-to-noise levels were essentially zero. Due to the variable background-noise levels at frequencies above 1000 Hz, a minimum background-noise level of 30 dB was assumed in the calculation of the transmission loss. Calculating the transmission loss using this value gave an estimate of the lower limit of the TL; therefore, at frequencies above 1000 Hz, the TL’s presented here are lower limits and may, in fact, be higher.

FIGURE 5. Plan sketch of the sound-transmission suite showing the receiver positions in the source and receiver rooms. The number in the brackets at each position indicates the height of the microphone.

FIGURE 6. Measured third-octave-band transmission loss of the vegetated barrier, when covered with plywood, unplanted and planted. Also shown is the minimum-TL criterion for a highway noise barrier in B.C. [2].
FIGURE 7. Measured third-octave-band random-incidence absorption coefficient of the unplanted and planted vegetated barriers.

Figure 6 shows the transmission losses of the barrier in the three configurations, as well as the minimum TL used by the BCMoTI [2]. The transmission loss of the vegetated barrier was found to increase from 42 dB at 100 Hz, to 66 dB at 1000 Hz. Above 2000 Hz, the lower limit of the TL varied from 57-62 dB. Covering the receiver side of the barrier with sheets of plywood increased the TL by up to 3 dB at higher frequencies. Planting the receiver side of the barrier decreased TL by up to 2 dB at higher frequencies. However, it was raining on the day of testing of the planted barrier, there was water on the floor of the facility and the background noise had increased; this may have led to a slightly decreased measured TL. In any case, and most importantly, all three configurations had TL’s that exceeded the minimum TL criterion by more than 25 dB.

ABSORPTION MEASUREMENT

Barrier absorption was calculated in accordance with ASTM C423-07a [5]. Reverberation times in one room of the sound-transmission suite were measured for three barrier configurations: barrier covered in plywood (representing the ‘no-sample’ case), barrier uncovered and unplanted, and barrier planted with grass. The random-incident absorption coefficients of the unplanted and planted barriers were determined from the changes in reverberation time relative to the ‘no-sample’ case, and are shown in Figure 7. The negative absorption coefficients found at low frequencies were likely caused by the added absorption of the plywood panels at low frequencies due to panel vibration. The NRC values – the average of the absorption coefficients at 250, 500, 1000 and 2000 Hz – of the unplanted and planted barriers were 0.42 and 0.37, respectively. These values of absorption coefficient, and the small decrease in absorption with planting, are consistent with recent results for vegetated roofs, which also showed that the sound absorption of substrates increases with the amount of organic matter and decreases with increased compaction and moisture content [6]. The minimum-NRC criterion for a barrier to be considered absorptive by the BCMoTI is 0.75; therefore this barrier would not be considered a highly absorptive barrier according to this criterion, which clearly never anticipated the advent of vegetated barriers, though it does provide significant absorption. It certainly absorbs significantly more sound than a typical reflective noise barrier. However, it is apparently not as absorbent as commercially-available absorbent conventional barriers [7].

CONCLUSION

The random-incidence transmission loss and absorption coefficient of a Criblock™ vegetated noise barrier were measured in a sound-transmission suite built specifically for the purpose of the measurements. The suite was tested for compliance with the ASTM E90-09 standard, and found to be substantially, but not perfectly, in compliance. The lack of compliance would not be expected to negatively affect the apparent barrier performance. It was found that the transmission loss of the vegetated barrier ranged from 42 dB at 100 Hz, to 66 dB at 1000 Hz. Above 1000 Hz, only a lower limit for the TL could be determined; values of 57-62 dB were found. These values are at least 25 dB higher than the minimum-TL criterion for a noise barrier used by the BCMoTI. The absorption coefficient was
measured for the planted and unplanted barriers; the plants decreased the absorption slightly, giving an NRC value of 0.37, as compared to 0.42. The plants had not become established and were wilted, so the results are only indicative of the absorption of a real, established vegetated-barrier configuration which could have lower or higher absorption. The measured values indicate that, while the Criblock™ vegetated barrier would not be considered an absorptive barrier by the BCMoTI criterion [2], which certainly never anticipated the advent of vegetated barriers, it absorbs significantly more sound than a typical reflective barrier. It is possible that higher absorption could be obtained using a substrate with a higher proportion of organic matter, or using different plants [6].

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REFERENCES