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noise and vibration control • sound quality • test facility design • instruction

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INTRODUCTION

Nelson Acoustics performed acoustical measurements at CTR's request along I-30 in Dallas TX in order to demonstrate a method for assessing the *in situ* reflectivity of the retaining wall opposite the Kessler Park neighborhood, prior to a proposed installation of sound absorbing material. An Executive Summary of the project and results is provided in Report 1052-01, and a detailed description of the testing and derivation of the mathematics underlying it are given in Report 1052-02. This report gives a description of the test procedure for reference by contractors and updates previous Reports 1052-03 through 1052-3D.

The test procedure begins on the next page to facilitate copying into the drawings.

1. SETUP

1.1. Mark or find the source location K in the northernmost westbound lane of IH-30 near the following coordinates (paint marks have been placed on the pavement and on the barrier at the foot of the retaining wall). Place the speakers at the designated distance from the retaining wall.

Table 1: Source Location

Location	North	West	Distance from Retaining Wall
K	32.764643°	-96.843245°	13'-1" (4 m)

1.2. Place (11) pieces of 7/16" OSB Plywood on the roadway surface in the arrangement shown in Figure 1 below (speaker locations in blue circles are approximate):

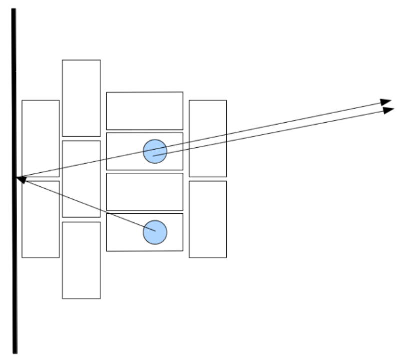

Figure 1: Plywood Layout for Source Location K

1.3. Place two loudspeakers equidistant from the nominal source location along a line parallel to the retaining wall. Aim one directly at the receptor location microphone ("direct"), and, using a mirror temporarily attached to the wall, aim the other at the retaining wall ("image") so that its reflection from the wall is viewed from the receptor location as having the same orientation and is collinear with the first.

1.4. Adjust the loudspeakers for flat frequency response and equal amplitude.

1.5. Position the microphone at the corresponding receptor location near the following coordinates, at the designated height above the Edgefield Ave. bridge road surface. Paint marks have been placed on the ground and/or retaining wall at the appropriate locations.

Table 1: Receptor Locations

Location	North	West	Height above Grade
K	32.764388°	-96.842966°	12 ft

1.6. If the sound-absorbing material has been applied, the traffic barrier at the base of the wall must be covered to its full height along the width of the plywood with 4" thickness, unfaced, glass-fiber insulation.

2. OPERATION

2.1. The test signal is a 15-th order maximum length sequence (MLS), filtered to a pink-noise response (equal power per octave), and played at a sampling rate of 25,600 Hz.

2.2. The signal shall be repeated continuously for a minimum of 400s.

2.3. Adjust the dynamic range of the recording instrument to maximize the signal-to-noise ratio and avoid clipping.

2.4. Record the pressure signal at the receptor location and save to calibrated WAV files.

2.5. Turn off the loudspeaker output. Without changing the gain or frequency response, move the "direct" loudspeaker to the "image" loudspeaker position and orientation, and move the "image" loudspeaker to the "direct" loudspeaker position and orientation.

2.6. Turn on the loudspeaker output and repeat the measurement.

2.7. Return the loudspeakers to their original positions and orientations defined in Section 1.3.

2.8. Iterate Sections 2.4 through 2.7 a total of eight times.

Note: a list of equipment used to perform this test is given in Appendix A of this Report.

3. ANALYSIS

3.1. For each iteration, cross-correlate each of the 32,768-sample frames of the recorded signal with the original, unfiltered, 15-th order MLS to find the impulse response (IR).

3.2. Time-align and synchronous-average the IR frames. Many of the frames will be compromised by physical blockage of the signal by vehicles or by multi-path effects. To determine which frames to reject,

3.2.1. A-weight the IR response,

3.2.2. Reject frames whose highest "direct" A-weighted peak value does not exceed a threshold value. The value shall be adjusted until 100 +/- 10 frames are retained,

3.2.3. Reject frames for which there is not at least one discernible A-weighted peak above threshold for each of the direct and reflected portions of the IR,

3.2.4. Reject frames for which the first A-weighted peak in the direct sound is not the largest.

3.2.5. Each A-weighted IR frame shall be shifted in time so that its peak is time aligned with the others. Add all of the retained IR frames to give one aggregate Impulse Response.

3.3. Square the impulse response, classify the returns as "direct" and "reflected", divide the sum of the reflected response by the sum of the direct response. Compute the arithmetic average of these quotients across all eight iterations of the test.

3.4. Multiply the average quotients by factors for distance ratio (r_2/r_1) and ground reflection ($\chi_D(f)/\chi_R(f)$) as defined in Nelson Acoustics Report 1052-R02.

3.5. Multiply the result of 3.4 by Image Adjustment coefficients.

3.5.1. The initial Image Adjustment coefficients shall be 0.50, 1.00, 1.00 and 1.00 for 250, 500, 1000 and 2000 Hz, respectively. If required, these will be amended in step 3.7.1.

3.6. Compute the adjusted Reflection Coefficient R, the Added Energy ΔdB, and the Sum of Contributions S_C as

$$\Delta dB_i = 10\log(1 + R_i^{\,2})$$

$$L_{PA,i} = 65.2 \quad 72.8 \quad 76.2 \quad 66.3$$

$$S_C = 10\log\left(\sum_i 10^{0.1(L_{PA,i} + \Delta dB_i)}\right)$$

3.7. The following steps are performed *only* for measurements prior to application of the sound-absorbing material.

3.7.1. Alter any Image Adjustment coefficient, whose corresponding Adjusted Reflection Coefficient result is greater than or equal to 1.00, to yield a result of 0.99.

3.7.2. Determine the Sum of Contributions, $S_{C,Before}$.

3.7.3. Plug this value in as the lead constant in the formula for Line 10 of both "before" and "after" worksheets.

3.8. Compute the Noise Level Reduction (NLR) as $NLR = S_{C,Before} - S_{C,After}$

3.8.1. The NLR from the "after" worksheet shall be compared to the requirements of the Specification.

3.8.2. The 95% confidence interval of NLR is believed to be +/- 0.25 dBA. This means that the results of any two complete eight-iteration before-and-after tests have a 95% probability of being with 0.25 dBA of one another.

Note: By comparison, the standard deviation of reproducibility of a widely accepted engineering grade sound power test (ISO 3744) is reported as 1.5 dBA.

Sample worksheets, showing "before" and "after" cases, are provided below. In each case Line 1 is filled with hypothetical example values. Actual measured values in Line 1 will differ.

Line	Description	250	500	1000	2000	
①	Avg. Reflected/Direct Sum p^2	1.11	0.62	0.77	0.65	input
②	Distance Ratio	1.183	1.183	1.183	1.183	given
③	Ground Reflection	1.38	1.33	1.14	1.00	given
④	Image Adjustment	0.50	1.00	0.95	1.00	given
⑤	Adjusted Reflection Coefficient	*0.91*	*0.98*	*0.99*	*0.77*	product of ①②③④
⑥	Added Energy	2.6	2.9	3.0	2.0	10 log(1 + ⑤²)
⑦	Baseline Spectrum	65.2	72.8	76.2	66.3	given
⑧	Contribution	6.0.E+06	3.7.E+07	8.2.E+07	6.8.E+06	10^(0.1(⑥+⑦))
⑨	Sum of Contributions	81.21				10 log∑⑧
⑩	Noise Level Reduction	*0.00*				$S_{C,Before}$ - ⑨

Figure 2: Sample Worksheet, Before Application

Line	Description	250	500	1000	2000	
①	Avg. Reflected/Direct Sum p^2	0.50	0.25	0.15	0.10	input
②	Distance Ratio	1.183	1.183	1.183	1.183	given
③	Ground Reflection	1.38	1.33	1.14	1.00	given
④	Image Adjustment	0.50	1.00	0.95	1.00	given
⑤	Adjusted Reflection Coefficient	*0.41*	*0.39*	*0.19*	*0.12*	product of ①②③④
⑥	Added Energy	0.7	0.6	0.2	0.1	10 log(1 + ⑤²)
⑦	Baseline Spectrum	65.2	72.8	76.2	66.3	given
⑧	Contribution	3.9.E+06	2.2.E+07	4.3.E+07	4.3.E+06	10^(0.1(⑥+⑦))
⑨	Sum of Contributions	78.66				10 log∑⑧
⑩	Noise Level Reduction	*2.55*				$S_{C,Before}$ - ⑨

Figure 3: Sample Worksheet, After Application

5. CONCLUSION

This report presents a brief description of the test method for inclusion in TxDOT specifications and drawings. An equipment list follows in the Appendix.

Please feel free to contact me with questions about the test method, the results, or the assessment method.

Sincerely,

NELSON ACOUSTICS (TX F-3001)

David A. Nelson, INCE Bd. Cert., PE (OR 17635, TX 81329)

Principal Consultant

Appendix A

A. EQUIPMENT

A.1. Receptor Location

- ½" microphone (Bruel and Kjaer or similar) with foam ball windscreen and extension cable
- Surveyor's pole
- Digital Signal Analysis board with 25,600 Hz sampling rate (National Instruments 9234 or similar)
- Nelson Acoustics Trident Multichannel Real-Time Analyzer Software.
- Computer with Windows Operating System

A.2. Source Location

- Computer with Windows Operating System
- Nelson Acoustics custom LabVIEW software to play MLS signal
- Analog Output Board with 25,600 Hz sampling rate (National Instruments 4431 or similar)
- (2) JBL Eon 15 loudspeakers
- (12) 4x8 pieces 7/16" OSB plywood
- Portable Electric Generator

A.3. Post-Processing

- Nelson Acoustics LabVIEW impulse response analysis routine
- Nelson Acoustics LabVIEW ground-reflection compensation routine
- Nelson Acoustics Excel spreadsheet final calculation