A COMPARATIVE STUDY OF WOOD HIGHWAY SOUND BARRIERS

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ABSTRACT

Prototype designs for wood highway sound barriers meeting the multiple criteria of structural integrity, acoustic effectiveness, durability, and potential for public acceptance have been developed. Existing installations of wood sound barriers were reviewed and measurements conducted in the field toestimate acoustic insertion losses. A complete matrix of design options for wood barriers was developed into a set of 35-mm slides along with several concrete designs, and presented in a controlled test to a group of human subjects for evaluation. Results of this testing showed that the wood barrier designs present an acceptable appearance, both to the driver and to the community behind the barrier. Moreover, the tests indicate a preference for moderate relief treatment, or a variety of design elements that are simple in plan layout and panel orientation. The results of the human subject and acoustic testing have been incorporated into B modified design matrix of wood barriers with common details, allowing fora systematic approach to the design of several types of sound barriers. A prototype barrier was built and its acoustic insertion loss measured with horizontal gaps between panels, without gaps and without a T-top, and without gaps with a T-top.

As new and existing residential areas and high volume highways in the United States continue to intermingle, soundbarriersplacedbetweenhighways and residential neighborhoods provide an effective tool in traffic noise control. In a 2000 study (10), sound barriers constructedofearth,precastconcretepanels, concreteblock,brick,wood,metal,anda combination of these materials accounted for a total cost of over 1.9 billion dollars (1998 dollars). Their total length of sound barriers in the United States exceeded 2,610 kilometers in 1998. Atthat time, wood and the combination of wood and earth berm accounted for approximately 12 percent of all sound barriers on U.S. highways. In a similar 1990 study, approximately 17 percent of all sound barriers were wood or a combination of wood and earth berm barriers (7). Much of the reason for the declining proportion of wood sound barriers is attributed to concerns of durability. Durability is a measure of the length of time a sound barrier remains aesthetically acceptable, and structurally and acoustically effective. For a wood sound barrier, weathering, which causes dimensional changes in wood, and decay are the main concerns. Due to inadequate design and detailing, many wood barriers deteriorate due to exposure, causing them to degrade, not only in appearance, but also in

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TABLE 1. — A-weighted normalized insertion losses and transmission losses.[a]

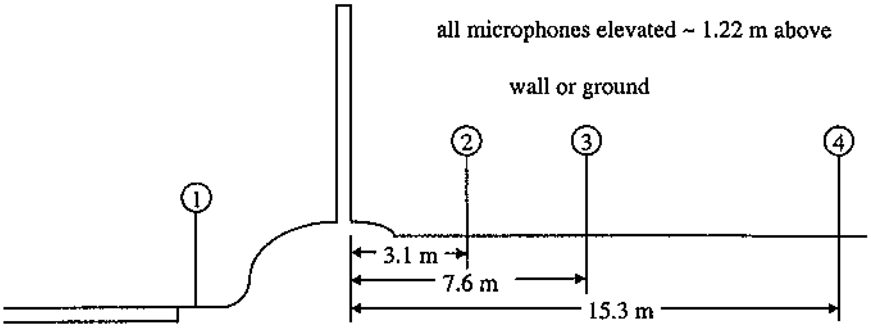
Barrier type	Barrier location	Height	Road to barrier[b]	IL[c] at 3.1 m	IL at 7.6 m	IL at 15.3 m	TL[d]
		(m)		(dBA)			
Precast concrete	I-695, Baltimore	6.7	9.0	12	10	7	19
	I-95, New York City	4.9	6.6	18	17	12	22
	I-78, New Jersey	2.5	10.9	19	16	16	17
	Rt. 24 off I-287, N.J.	5.3	9.8	19	14	14	22
Plywood	I-95, Baltimore	3.3	2.4 (6.1)	17	12	8	15
	I-83, Maryland Weigh Station	4.3	24.4	7	6	7	14
Glu-lam	I-495, Washington, D.C.	5.1	1.5 (6.1)	15	11	7	21
	Route 7, Troy, N.Y.	2.5	4.9	16	14	10	20
Wood post and panel	Long Island Expressway	6.7	12.2	18	11	7	15
	Hutchinson River Parkway, N.Y.	1.9	7.6	21	18	15[b]	15
	Hutchinson River Parkway, N.Y.	3.3	14.0	12	14	12[b]	15

[a] Normalized to a height of 4.3 m, a distance of 9.2 m from the roadway, and a flat site.

[b] First number is distance to edge of road. Number in parentheses is distance to center of driving lane.

[c] Insertion loss.

[d] Transmission loss.



caused by the deformations of the barrier.

The goal of this research was to develop a coordinated approach to the design of wood highway sound barriers so that they meet the design criteria of strength, durability, acoustic effectiveness, and public acceptance. The acoustic effectiveness and public acceptance of barriers were evaluated in order to limit design options for assessment of costs, durability, and structural integrity of wood and concrete barriers. Acoustic testing of existing barriers evaluated the acoustic effectiveness of several design types. Testing of human subjects' impressions of computer-edited images evaluated the public acceptance of different design types. These initial testing programs were used to develop guidelines for the design of woad barriers, including guidelines for effective acoustic design and for aesthetic treatments generally acceptable to the public. The guidelines were then used to develop a rier designs, one of which was built and tested.

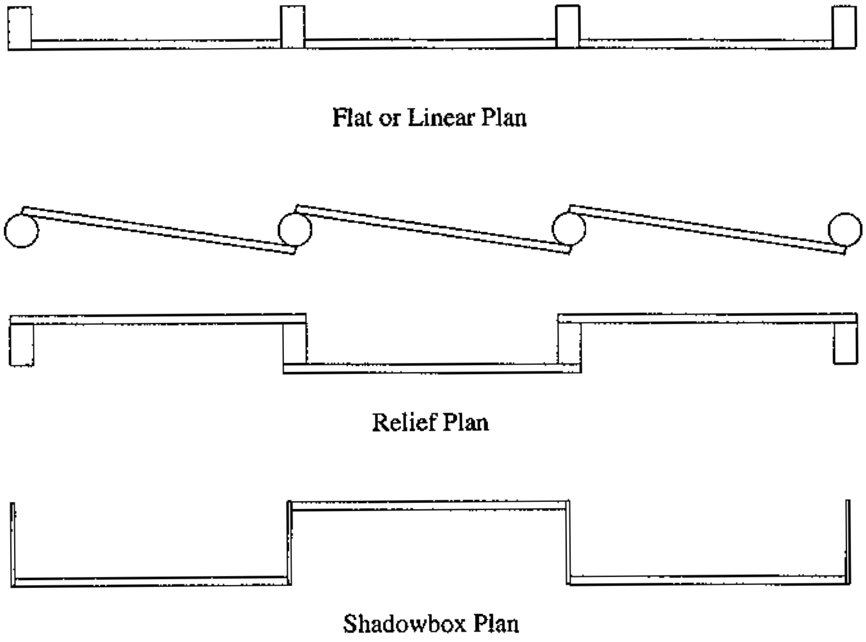
ACOUSTIC EFFECTIVENESS

The acoustic effectiveness of concrete and wood sound barriers was determined by *in-situ* testing of existing sound barriers. The goal of this testing was to determine the acoustic transmission losses and insertion losses of different wood and concrete barriers. Insertion loss is defined as the difference in sound pressure level, at a point behind the barrier, between the case where the barrier is present, and the case where the barrier is absent. Transmission loss is the difference in sound pressure level between the traffic side of the barrier and the back side. Both of these parameters are expressed in decibels, which are a logarithmic unit of gain, where 10 decibels represents a doubling of the sound pressure level.

It is most straightforward to determine insertion loss by measuring sound pressure level before a sound barrier is installed, and then making the same measurement after installation of the barrier. This is the method employed in the measurements on the test barrier, described later in the paper. However, for existing barriers, this method is infeasible. Insertion losses of the selected bar-

Highway Traffic Noise Prediction Model (9). This method was used for the determination of insertion losses at the distances of 3.1, 7.6, and 15.3 m (10, 25, and 50 ft.) behind the barriers in the in-situ measurements. **Figure 1** provides a schematic sketch of the test setup for the *in-situ* measurements. A measured free-field sound level, taken on top of the barrier, was adjusted to predict sound levels that would occur at the receiver positions in the absence of the barrier. Pre-barrier and post-barrier sound levels were corrected for sound level differences between records, spreading loss and ground effects, sensitivity differences between microphones, and background noise. Barrier insertion loss was determined by subtracting post-barrier sound level from the pre-barrier sound level. The insertion losses for all the barriers were normalized to a height of 4.3 m, a distance of 9.2 m from the roadway, and a flat site using the prediction model presented in FHWA-RD-77-108 (9). Normalization of estimated insertion losses allowed direct comparisons of all the test barrier types and locations. The method for the determination of transmission losses for the different barriers is similar to the method employed for insertion losses. Pre-barrier and post-barrier sound levels were corrected for spreading loss and ground effects, sensitivity differences between microphones, and background noise. The transmission loss is the difference between the two adjusted sound levels.

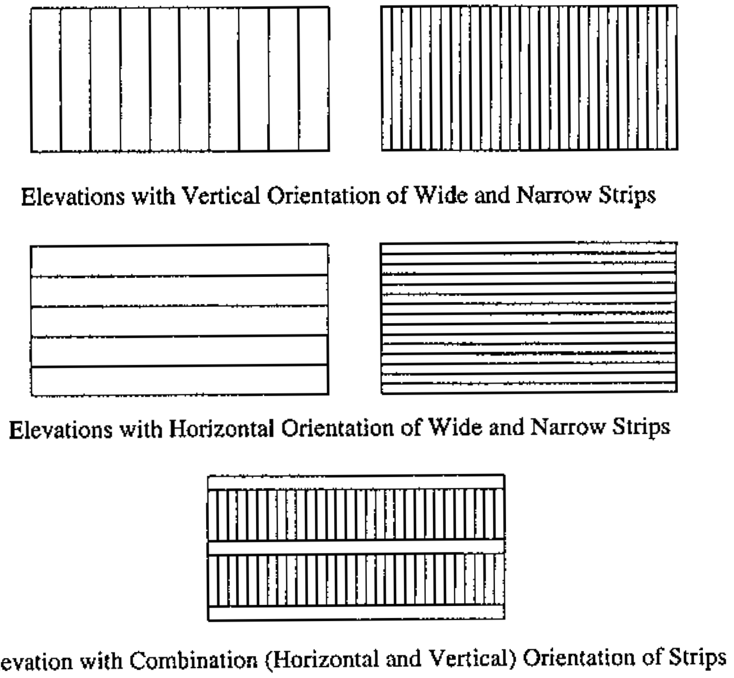
A-weighting, specified by ANSI S1.4-1971, was applied to the normalized insertion losses and transmission losses. A-weighting approximates the perceived sound level by reducing the weight of sounds at frequencies below 1000 Hz and increasing the weight of frequencies from 1000 to 5000 Hz. The A-weighted normalized insertion and transmission losses are presented in **Table 1** with a maximum error of ± 2 dB. Most of the A-weighted insertion tosses reported in **Table 1** satisfy the 10 dBA minimum insertion loss goal, which is given in the *FHWA Noise Barrier Design Handbook* (8) as a practical goal in sound barrier design. Barriers whose insertion losses do not satisfy the 10 dBA insertion loss goal are affected by poor detailing, low surface mass, and large distance between sound source and barrier. The values of transmission loss for the concrete and glued-laminated barriers are high enough to have little impact on the insertion losses. The low values for the plywood and post and panel barriers are the result of low surface mass of plywood barriers as well as the poor detailing of both types of barriers. Details of the in-situ acoustic evaluations are presented in Grgurevich (13).


Flat or Linear Plan

Relief Plan

Shadowbox Plan

Figure 2. —Barrier layout variations for public acceptance evaluation.


Elevations with Vertical Orientation of Wide and Narrow Strips

Elevations with Horizontal Orientation of Wide and Narrow Strips

Elevation with Combination (Horizontal and Vertical) Orientation of Strips

Figure 3. — Panel orientation variations for public acceptance evaluation

PUBLIC ACCEPTANCE

The research on public acceptance focused on the perception of visual compatibility. The research involved asking subjects to evaluate computer-edited images, presented on 35-mm slides, using a series of rating scales. The slides presented images that vary in barrier layout and panel orientation rather than finish or detail. Barrier layout considered variations in the plans of the barriers developed after review of existing barrier designs. Variations, which are illustrated in **Figure 2,** included flat or linear plan, relief plan, and shadowbox plan. The flat plan had the posts and panels centered on a single line. The relief plan had the posts centered on a single tine while the panels alternate being connected to the posts front and back. The shadowbox plan was similar to the relief plan except that the relief in the barriers is deeper, requiring installation of separate posts to achieve the depth of the relief. Panel orientation considered variations in the elevation of the barriers. Variations, which are illustrated in **Figure 3,** included wide and narrow strips, horizontal and vertical strips, and combinations of each treatment. For comparison purposes, slides of concrete barriers in the three

TABLE 2. — *Matrix of barrier design types for public acceptance evaluation.*

	Flush	Relief	Shadowbox
Vertical orientation - wide strips	F1/B1	F2/B2	F3/B3
Horizontal orientation - narrow strips	F4/B4	F5/B5	F6/B6
Vertical orientation - narrow strips	F7/B7	F8/B8	F9/B9
Horizontal orientation - wide strips	F10/B10	F11/B11	F12/B12
Combination - vertical and horizontal	F13/B13	F14/B14	F15/B15
Concrete	F16/B16	F17/B17	F18/B18

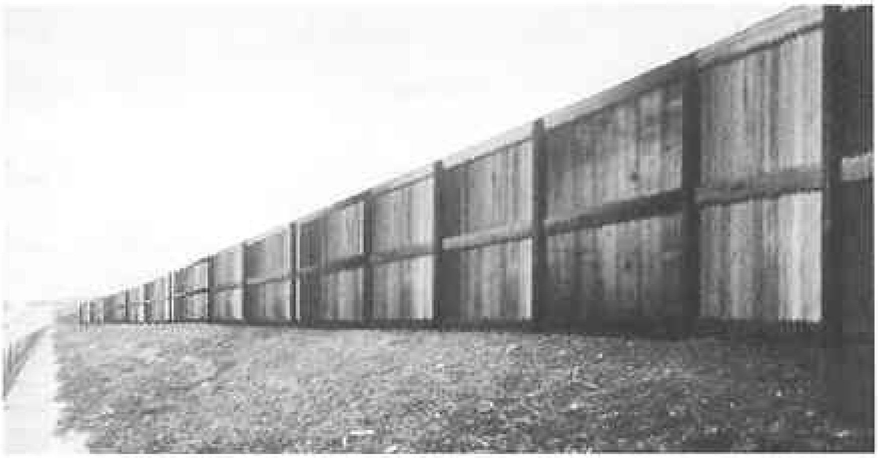


Figure 4. — Computer-generated front view of a wood sound barrier.

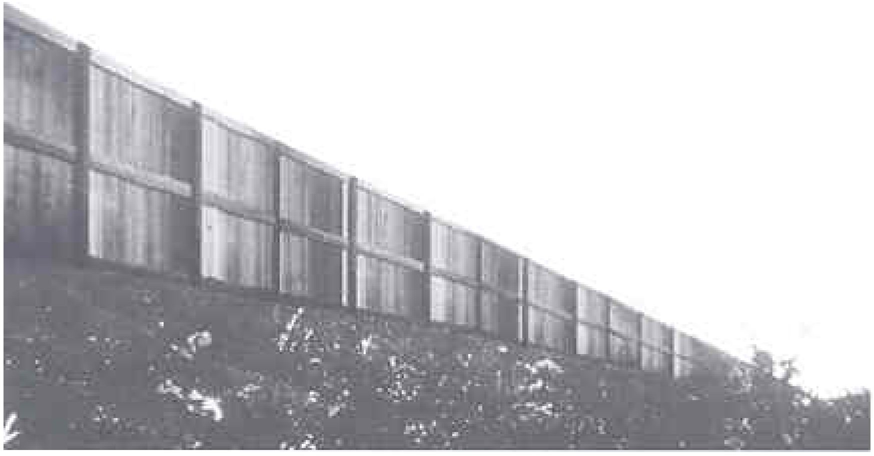


Figure 5. — Computer-generated back side view of a wood sound barrier.

layout variations were created and also evaluated by the subjects. These barriers have the standard wide horizontal panels used for precast concrete barriers in the three different plan layouts. Together, all these variations allowed development of a matrix of different barrier designs. This matrix, shown in **Table 2,** allowed comparison of a wide variety of wood barriers to precast concrete barriers. The combination of letters and numbers shown in **Table 2** are codes that identified the slides for the rest of this research. The letters F and B refer to front side (highway side) and back side (residential side). These letters were then applied to each cell in the matrix, which had its own unique number. Altogether, there were 36 slides, half containing views from the front and half containing views from the back. **Figures 4** and **5** illustrate example front and back views of Slides F14 and B14.

Twenty-four human subjects (3 groups of 8 subjects) rated the 36 slides using semantic-differential (SD) rating scales and individual rating scales (11,16). Subjects first used SD scales to evaluate all 36 slides in 2 separate sessions. One session displayed slides of barriers viewed from the highway side while the following session displayed slides of barriers viewed from the residential side. The SD scales were designed to elicit specific responses to attributes of the various barrier designs. The SD scales were used to identify all the factors involved in a person's opinion about sound barrier designs. An example page of the SD scales used in this experiment is presented in **Figure 6.** Principal components factor analysis and analysis of covariance (ANCOVA) were used to determine which scales were used in a consistent manner and the statistical significance of the results (12). The results of the SD scales also helped select the slides shown in the individual rating scales, The slides selected were those that drew favorable responses in the SD scales on both the highway and residential sides. For comparison purposes, the concrete barrier that received the most favorable responses, as well as the barrier that received the most unfavorable responses, were included in the individual rating scales.

The group averages of the SD scales for each slide were subjected to a principal components factor analysis (12). This analysis statistically determined the subsets of rating scales that were used in similar or consistent ways by the subjects. A group of scales evaluated in a consistent manner had high intercorrelation. Seven components, or factors, were computed. Three factors, which were identified and named evaluative, environmentat, and physical, caused 75.7 percent of the variance in the ratings for the driver's perspective and 76.4 percent of the variance in the ratings for the homeowner's perspective. These three factors were evaluated by the same SD scales for both viewpoints. Because the rest of the factors for both views only explained about 4 percent, or less, of the variances, the three factors just mentioned were used for the rest of this analysis and the analysis of variance. The critical differ-

TABLE 3. — Tukey post hoc rest results for individual rating scales of barriers viewed from the driver's perspective.[a]

Slide[b]	Mean[c]	F6[d]	F13	F17	F11	F2	F4	QCV[e]
F6	3.71							
F13	5.08	2.98						
F17	5.58	4.06	1.09					
F11	5.88	**4.72**	1.74	0.65				
F2	6.00	**4.98**	2.00	0.91	0.26			
F4	6.29	**5.61**	2.63	1.54	0.89	0.		
F10	6.46	**5.98**	3.00	1.91	1.26	1.00	0.37	4.22

[a] Boldface entries indicate significant difference between rating means (a = 0.05).

[b] Slides defined in Table 2.

[c] Individual ratings scale mean for slides.

[d] Q-value between slide ratings of column label and row label.

[e] Critical Q-value.

(1)appropriate	:____:____:____:____:____:____:____:	inappropriate
(2)pleasant	:____:____:____:____:____:____:____:	foreboding
(3)confining	:____:____:____:____:____:____:____:	spacious
(4)attractive	:____:____:____:____:____:____:____:	unattractive
(5)acceptable	:____:____:____:____:____:____:____:	unacceptable
(6)intimidating	:____:____:____:____:____:____:____:	inviting
(7)imposing	:____:____:____:____:____:____:____:	unimposing
(8)satisfactory	:____:____:____:____:____:____:____:	unsatisfactory
(9)gloomy	:____:____:____:____:____:____:____:	cheerful
(10)darkening	:____:____:____:____:____:____:____:	lightening
(11)bright	:____:____:____:____:____:____:____:	dim
(12)dreary	:____:____:____:____:____:____:____:	cheerful
(13)distinctive	:____:____:____:____:____:____:____:	ordinary
(14)offensive	:____:____:____:____:____:____:____:	unoffensive
(15)distracting	:____:____:____:____:____:____:____:	focusing
(16)appealing	:____:____:____:____:____:____:____:	unappealing
(17)interesting	:____:____:____:____:____:____:____:	uninteresting
(18)safe	:____:____:____:____:____:____:____:	unsafe
(19)fortifying	:____:____:____:____:____:____:____:	weakening
(20)secluded	:____:____:____:____:____:____:____:	exposed
(21)private	:____:____:____:____:____:____:____:	public
(22)cluttered	:____:____:____:____:____:____:____:	uncluttered
(23)rural	:____:____:____:____:____:____:____:	urban
(24)harmonious	:____:____:____:____:____:____:____:	clashing
(25)environmentally friendly	:____:____:____:____:____:____:____:	environmentally hostile

Figure 6. - Semantic-differential scales used in human subjects testing.

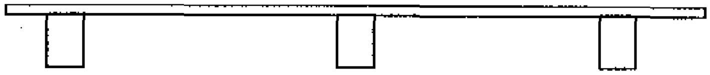
ences between the SD scale results were determined in two steps. First, the mean of the scales contributing to a factor was determined. Then, these means were subjected to an ANCOVA with Tukey post hoc tests (17) to determine which means have critical differences. Inspection of the results identified tendencies in the SD ratings and indicated no significant difference in values between the groups of subjects. Barriers that were disliked, such as F6, had distinctive ratings, while barriers that were liked did not have distinctive ratings. A simple plan layout and panel orientation for barriers such as a flat or relief plan with any panel orientation were favored while the concrete and shadowbox barriers were disliked.

The 14 slides selected from the SD scales were displayed again to the human subjects, who were asked to rate these barriers with individual rating scales. The subjects were asked to rate each design on a scale from 1 to 10 with the rating to be done relative to all the other designs shown. Again, the slides were evaluated in two separate sessions, one viewing the barriers from the highway side and the other viewing the barriers from the residential side. The slides in this second testing included the highway and residential views of seven barrier designs. The slides involved were F2/B2, F4/B4, F6/B6, F10/B10, F11/B11, F13/B13, and F17/B17. Slides F2/B2, F4/B4, F10/B10, F11/B11, and F13/B13 received favorable responses on both the residential and highway sides. Slides F4/B4, F10/B10, and F13/B13 use a flat plan while F2/B2 and F11/B11 use a relief plan. Slides F2/B2 use vertical wide strip elevation, slides F4/B4 use horizontal narrow strip elevation, slides F10/B10 and F11/B11 use horizontal wide strip elevation, and slides F13/B13 use combination horizontal and vertical elevation. Slides F6/B6 received the most negative responses white the slide pair F17/B17 was the concrete barrier design receiving the most favorable response. Slides F6/B6 use shadowbox plan and horizontal narrow strip elevation and slides F17/B17 use relief plan and concrete elevation. An analysis of variance was performed to determine if

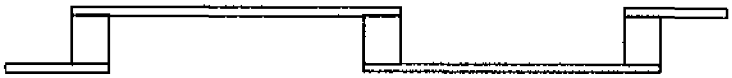
TABLE 4. — Tukey post hoc test results for individual rating scales of barriers viewed from the homeowner's perspective.[a]

Slide[b]	Mean[c]	B17[d]	B6	B13	B4	B11	B10	QCV[e]
B17	3.21							
B6	3.58	0.83						
B13	5.08	4.19	3.36					
B4	5.53	**5.42**	**4.60**	1.23				
B11	5.96	**6.16**	**5.33**	I.97	0.74			
B10	6.71	**7.85**	**7.02**	3.65	2.42	1.68		
B2	6.92	**8.32**	**7.49**	4.13	2.89	2.15	0.47	4.22

[a] Boldface entries indicate significant difference between rating means (a = 0.05).
[b] Slides defined in Table 2.
[c] Individual ratings scale means for slides.
[d] Q-value between slide ratings of column label and row label.
[e] Critical Q-value.



(A) Flat Flush



(B) Flat Relief

(C) Skewed Relief

Figure 7. - Plan layout options.

there were significant variations among the human subject groups' results, and between the results for different slides.

The variation between individual rating scale group means was analyzed using ANCOVA with Tukey post hoc tests. The results of the ANCOVA showed that there was no significant difference between the three human subjects groups but there was a significant difference between the slides. The results of this test are presented in **Table 3** for slides with barriers viewed from the highway side and in **Table 4** for slides with barriers viewed from the residential side. The resulting Q-values are presented in a table format in which the column label indicates the slide's mean being compared. A Q6 indicates the column in which the individual rating of slide F6 or B6, depending on the table, is being compared with the other slides individual ratings. The row label where the Q-value is located indicates the other slides mean being cornpared.

The statistically significant differences in means are shown in **Tables 3** and **4.** Slide F6's mean response was different from the responses of slides F2, F4, F10, and F11. Both slides B6 and B 17's mean responses were different from the responses of slides B2, B4, B10, and B11. The statistically significant ratings of slides F2/B2, F4/B4, F10/B10, and F11/B11 required that the design tendencies of the barriers illustrated in these slides be embodied in the final design guidelines because of the favorable responses. The design tendencies included either flat or relief plan and either vertical or horizontal orientation in the elevation. Slides F13, F17, and B13 had means that were not statistically different from either extreme. These three slides helped clarify and reinforce the final design guidelines because their means were close to the statistically significant ratings, but no slides provided a distinctive acceptable set of SD ratings.

With the SD and individual rating scales completed and analyzed, results were combined to observe tendencies that would aid in developing general design guidelines for wood sound barriers. The preliminary guidelines established by the SD scales and reinforced by the individual rating scales were the unfavorable response towards concrete and shadowbox designs and the favorable response towards simple designs (e.g., the slides receiving most negative responses were F6/B6, F15/B15, and F16/E16 and the slides receiving most favorable responses were F2/B2, F4/B4, F10/B10, and F11/B11). The design guidelines for wood barriers most likely to be accepted by the public include simple flat walls with either many elements or few elements in the elevation, or relief walls with few elements in the elevation. Barriers should employ many elements or a relief plan layout, but not both, to break up the monotony of long barriers. Panels between posts should employ elements with either vertical or horizontal orientation in the elevations. More detailed information on public acceptance research is presented in Boothby et al. (4,5) and Grgurevich (13).

STRUCTURAL REQUIREMENTS

A system of eight wood sound barriers encompassing several design alternatives with similar details was developed. The designs included the different details and plan layouts that were acoustically effective and aesthetically acceptable. The fundamental design was solid sawn timber or glued laminated wood posts with a panel material of either dimension lumber or manufactured glued laminated panels. This system included three plan layout formats (flat flush, flat relief, and skewed relief) and two panel orientations (vertical for all plan layouts and horizontal for the relief plan layouts). Plan layout formats are illustrated in **Figure 7.** Vertical orientation of timber plank and glued laminated panels requires a horizontal purlin for stability, which is incompatible with the relief design options. Each sound barrier in this system can be constructed according to one post design guideline and two different connection detail guidelines. The posts will be the same for any design under equivalent conditions of height, spacing, and geography; the panels will not significantly differ from one configuration to another; and the system requires only two different connection details, one for timber plank and the other for the glued laminated panel. Posts are selected from a chart that assigns a post size for a given bending and minimum shear stress. Minimum allowable bending stresses are specified for the panel material.

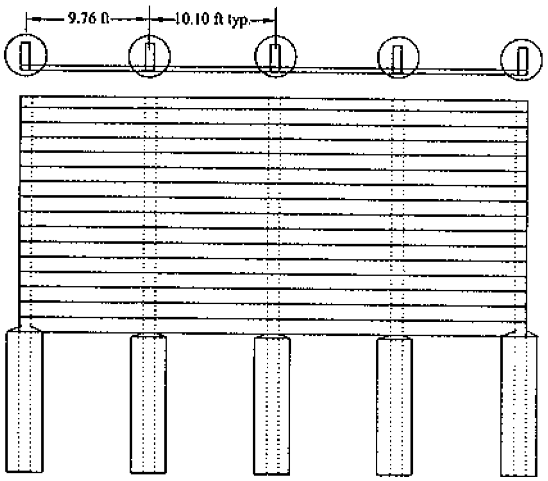
From the final design option matrix, the flat flush plan layout option with horizontally aligned timber planks combined with glued laminated posts was selected as the test barrier. It was the simplest and most economical to build, and it made it relatively easy to conduct acoustic tests with sight lines (gaps) in the panel. This sound barrier **(Fig. 8)** was structurally analyzed and designed according to the *Guide Specifications for Structural Design of Sound Barriers* (1), the *Guide Specification for Highway Noise Barriers* (14), and the *National Design Specification for Wood Construction and Supplement* (15). Design procedures for each element (posts, foundations, and general connections) have been developed for the test sound barrier, but can be applied to all wood sound barrier design options.

Post, Pier, and Plank Specifications:

Posts: Glued Laminated Southern Pine
16F-V5 6¾x12⅜x22
Pier: Diameter 24 in
Depth 8.0 ft
CCA Treated (0.60 lb/ft^3)
Planks: 2x6x10 Tongue and Groove Southern Pine
CCA Treated (0.40 lb/ft^3)

Nail Schedule:

-50d Galvanized Annular Threaded. (Ring Shank)
-12 inch spacing on center.
-Space to avoid splitting of planks. (¾ inch edge distance , Le)
-Pre-bore pilot holes(⅛ in. bit).
-Center on edge of face plank on end connectors.



Notes:

1. Place posts and planks allowing for 1.5 in space on center.
2. Install planks with tongues facing up and grooves facing down.
3. Planks on end panels must be aligned with outer edge of post.
4. Bottom of Barier must be approximately 6 in. below ground surface.
5. Pier foundations designed for 70 mph wind speed and 10 ft. post spacing.
6. Lateral soil pressure (S) of 200 psf/ft and phi=30 degrees.
7. Align planks with adjacent panels to ground elevation changes.

Figure 8. — Test sound barrier (height = 14 ft., length = 80 ft.).

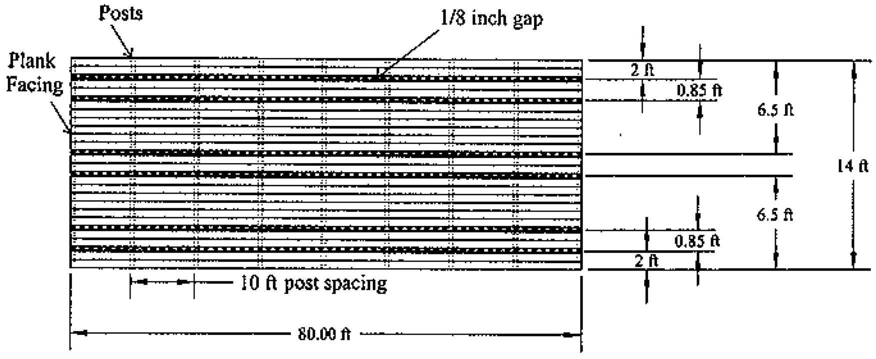


Figure 9. — Gap locations on test sound barrier (not to scale).

ACOUSTIC EFFECTIVENESS OF TEST SOUND BARRIER

The insertion loss of the test sound barrier was determined according to *Methods for Determination of Insertion Loss of Outdoor Noise Barriers* (2) using the direct measured method. This method is recommended by the specification and is used when sound measurements are taken before installation of the sound barrier. Insertion loss is the difference between the measured sound pressure levels before and after the sound barrier is installed. This method was used for the deterimination of insertion losses at the distances of 7.62, 15.24, 22.86, and 30.48 m (25, 50, 75, and 100 ft.) behind the test barrier. The standard requires that the reference and receiver microphone positions be the same and that measurements be taken with equivalent sound source, terrain, ground conditions, and atmospheric conditions before and after the sound barrier is installed. Sound levels were normalized by correcting for sound level differences between records. The test procedure involved emanation of a steady sound level from a single loudspeaker source and recording the sound pressure levels at different positions in front, on top, and behind the sound barrier with microphones. The point source was positioned 7.62 m (25 ft.) in front of the sound barrier for each test. The reference microphone, recording the free-field sound levels, remained positioned 1.52 m (5 ft.) above the top and at the center of the barrier for all tests.

Sound levels were measured for the no barrier condition and in each of the three barrier configurations: 1) with gaps; 2) without gaps and without T-top; and 3) without gaps and with T-top. The test sound barrier was first tested in the "with gaps" configuration. The gaps, meant to simulate diminished acoustic effectiveness due to gaps forming between planks over time, were installed by inserting six lines of sight 3.18 mm

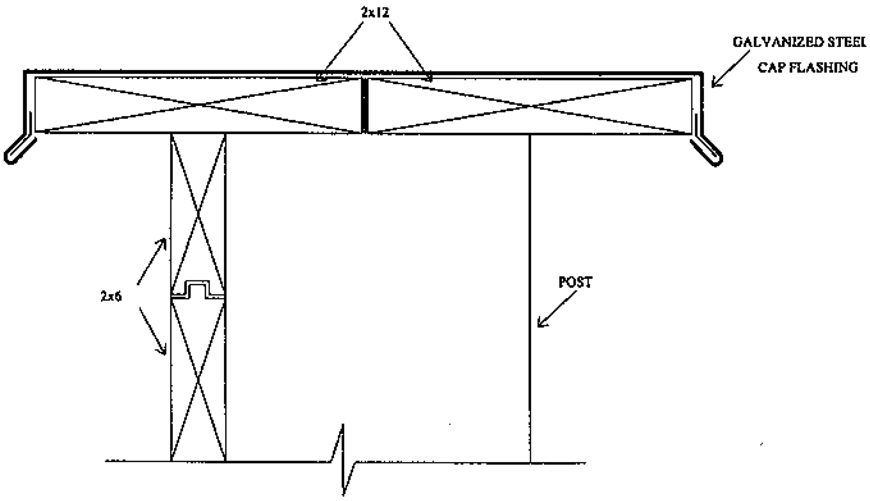


Figure 10. - T-top configuration for test sound barrier.

TABLE 5. — A-weighted insertion losses for the test sound barrier.

Factor	Treatment	7.62 m	15.24 m	22.86 m	30.48 m
		(dBA)			
Measured IL	Gaps	15	14	12	9
	No gaps	20	17	15	15
	T-top	21	19	17	15
Predicted IL	Gaps	18	17	17	16
	No gaps	22	21	20	20
	T-top	22	22	22	22

Location behind barrier: 7.62 m, 15.24 m, 22.86 m, 30.48 m.

(1/8 in.) wide between planks systematically installed in the lower, middle, and upper regions of each panel and extending the entire length of the sound barrier as shown in **Figure 9.** The configuration of the T-top used in the final test is shown in **Figure 10.**

The test sound barrier was then tested with the gaps removed so that it was configured as it would be in the field. This condition best models an actual wood sound barrier in service. The planks were entirely interlocked and shims were placed between the planks and the posts to eliminate gaps and potential sound leaks. A minimum measured insertion loss of 10 dBA was expected at all microphone positions behind the barrier. A 60-cm-wide dimension lumber T-top was then installed and the measurements repeated.

The predicted insertion losses were calculated by adjusting the normalized sound pressure levels at the reference microphone and subtracting the average normalized sound pressure levels of the receiver microphones. The free-field sound levels were corrected for spreading loss and were not corrected for ground effects or atmospheric conditions. The measured and predicted insertion losses are listed in **Table 5.**

The measured insertion losses are lower than expected, but reasonable. The decrease in insertion losses at the microphone positions further from the barrier is expected, since the difference in the direct path (available without the barrier) and the path over the barrier decreases at increasing distances from the barrier. Predictions of insertion losses (3), based on path length differences, indicate that the insertion loss for the path over the top of the barrier is more than 7 dB less than the predicted insertion loss for the receiver location 30.5 m (100 ft.). Diffraction around the edges may have existed but its effect was considered small. The results in **Table 5** show that the gaps in the panel dramatically reduce the acoustical effectiveness of the sound barrier. The transmission loss of (2 in. x 6 in) tongue and groove planks was assumed to be no less than 20 dBA (8), thus minimizing its effect on insertion loss. The T-top increased the insertion loss by 1 to 2 dB. Further details of the construction and testing of the specimen are provided in Cegelka (6).

CONCLUSIONS

The *in-situ* testing program of existing wood sound barriers has concluded that properly designed, detailed, and maintained wood sound barriers can achieve similar insertion losses to barriers of other materials, including precast concrete and masonry. Moreover, wood sound barriers of any of the general design types studied can be designed and built to achieve a 10 dB or more insertion loss.

The human subjects testing program has concluded that any of the wood barrier design types studied (with the possible exception of the shadowbox design) can be configured to be generally acceptable to the public, from the perspective of a driver on the highway side and the perspective of an adjacent property owner. The study also furnished indications that wood barriers may be preferred in certain environments to barriers of similar configuration built of harder materials such as precast concrete, The acoustic testing program of the prototype wood barrier demonstrated that the prototype barrier can achieve the Federal Highway Administration insertion loss god of 10 dB or greater.

A systematic set of designs consistent with the acoustic and aesthetic preferential findings of this study has been developed. The designs are for flush and relief plan layouts with glued laminated or solid sawn posts and tongue and groove dimension lumber planks or glued laminated panels. Details of the barrier designs are available in a Forest Products Laboratory publication (4).

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