Development of Wood Highway Sound Barriers

Thomas E. Boothby, Harvey B. Manbeck, Courtney B. Burroughs, Craig A. Bernecker, Stefan Grgurevich, and Steven Cegelka, The Pennsylvania State University
Michael A. Ritter, Forest Products Laboratory, USDA Forest Service

Abstract

Prototype designs for wood highway sound barriers meeting the multiple criteria of structural integrity, acoustic effectiveness, durability, and potential for public acceptance are being developed. Existing installations of wood sound barriers were reviewed and measurements conducted in the field to estimate insertion losses. A complete matrix of design options for wood barriers was developed into a set of slides along with several concrete designs, and presented in a controlled test to a group of human subjects for evaluation. The 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 indicated a preference for moderate relief treatment, or a variety of design elements. The results of the human subject and acoustic testing have been incorporated into a series of designs for wood sound barriers. A prototype barrier will be built and tested.

Keywords: noise, barriers, acoustics, aesthetics.

Introduction

The use of sound barriers in the United States has gained popularity as real estate developments along highways continue to grow. The total length of sound barriers constructed in this country equaled over 1,486 linear kilometers in 1992 (FHWA, 1994). These barriers are constructed using earth, precast concrete, concrete block, brick, wood, metal, and combinations of these materials at a total cost of over 875 million (in 1992 dollars) (FHWA, 1994). Most of these barriers are constructed of concrete masonry and concrete, followed by earth berms and wood. Approximately 17 percent of barriers were constructed of wood or a combination of earth berm and wood (Cohn and Harris, 1990). Recent trends concerning the percentage of wood barriers constructed with respect to masonry, concrete, and combinations of the above materials show that this percentage is decreasing (Weiss, 1989). Much of the reason for the trend against the use of wood barriers relates to problems concerning durability, aesthetics, and acoustic effectiveness. Due to inadequate design and detailing many wood barriers deteriorate due to exposure, causing them to degrade, not only in appearance, but acoustic effectiveness as well. Panels in the barrier may deform and pull apart, causing sound to leak through the barrier.

A goal of this research is to develop a coordinated approach to the design of wood highway sound barriers. The acoustic effectiveness and public acceptance of barriers will be evaluated first in order to limit design options for assessment of costs, durability, and structural integrity of wood and concrete barriers. Acoustic testing of existing barriers is used to evaluate the acoustic effectiveness of several design types. Testing of human subjects' impressions of computer edited images is used to evaluate the public acceptance of different design types. These initial testing programs were used to develop guidelines for the design of wood barriers, including guidelines for effective acoustic design and for aesthetic treatments generally acceptable to the public. These guidelines are now being applied to the development of a series of prototype designs of highway sound barriers.

Acoustic Effectiveness

In-situ measurements

The acoustic effectiveness of sound barriers was determined by in-situ testing of existing sound barriers. Because extensive data on insertion losses and transmission losses of different barrier types do not exist, the in-situ testing of the different design types and materials was necessary. The goal of this testing is to determine the insertion losses and transmission losses of different wood and concrete barriers. These data were normalized for geometric differences among the barriers to allow for direct comparison between the different barrier design types. The objective was to determine if wood and concrete barriers are equivalent in terms of acoustic effectiveness.

The wood barrier designs investigated in the in-situ testing are listed in the Guide Specification for Highway Noise Barriers (NFPA, 1985). The three design types listed include timber plank, plywood, and glued-laminated barriers. Timber barriers, also called post & panel barriers, are barriers that employ heavy timber posts along with dimension lumber panels. Plywood barriers are barriers that employ plywood panels, usually supported by dimension lumber. Glued-laminated barriers employ glued-laminated wood members to create a noise barrier.

With the assistance of the Departments of Transportation of Pennsylvania, Maryland, New York, and New Jersey, as well as from representatives from the wood industry, wood barriers were located in these states. Barriers selected for testing were located on relatively flat ground and were accessible from both sides. Ten wood barriers were selected for the in-situ testing four glued-laminated barriers, four timber barriers, and two plywood barriers. The glued-laminated barriers were located in Erie on the east and west sides of I-79, outside Washington D.C. on I-495, and near Troy, New York, on Route 7. Of the timber barriers, two were located on the Hutchinson River Parkway outside New York City and the other two were on the Long Island Expressway in New York. The plywood barriers were located at a truck weigh station across the Pennsylvania / Maryland border on I-83 and outside Baltimore on I-95. Five precast concrete panel barriers were also identified for the in-situ testing. The concrete barriers were located on I-79 in Erie, I-695 outside Baltimore, I-95 outside New York City, Route 24 outside Whippany, New Jersey, and I-78 in New Jersey. The Erie glued-laminated barriers were 15 years old while the rest of the barriers were less than 10 years old.

Insertion Loss Calculations

Insertion losses of the selected barriers were determined. Because measurements prior to installation of the barriers were not available, and equivalent sites without the barrier could not be located, the indirect predicted method given in ANSI S12.8-1987, *Methods for Determination of Insertion Loss of Outdoor Noise Barriers,* was used with the prediction model specified in the FHWA Highway Traffic Noise Prediction Model (FHWA-RD-77-108, 1978).

With the estimated pre-barrier and measured post-barrier sound levels, it was possible to estimate the insertion losses. The pre-barrier sound levels were corrected for sound level, spreading loss and ground effects, and sensitivity differences between microphones to predict levels without the barrier. The post-barrier sound levels were corrected for background noise, and barrier insertion loss was determined by subtracting post-barrier sound level from the pre-barrier sound level. These calculations were done for each of the two or three measurements made at each of the three receiver locations of 3.1, 7.6, and 15.3 m behind the barrier. The insertion losses of each barrier were the calculated mean in each l/3-octave band between 200 Hz and 5 kHz.

Normalization of Estimated Insertion Loss

Variation was observed in the insertion losses within groups of barriers of similar design type Much of the variation was due to differences in height of the barriers, topography, and distance of the barrier from the roadway. The barrier heights and distances from the roadway, for the barriers for which valid sound

Table 1 –Barrier Heights and Distances from Roadway

Barrier Type	Barrier Location	Height (m)	Road to Barrier (m)
Precast Concrete	I-695, Baltimore	6.7	9.0
Precast Concrete	I-95, New York City	4.9	6.6
Precast Concrete	I-78, New Jersey	2.5	10.9
Precast Concrete	Rt. 24, Whippany, NJ	5.3	9.8
Plywood	I-95, Baltimore	3.3	2.4 (6.1)
Plywood	I-83, Maryland Weigh Station	4.3	24.4
Glu-lam	I-495, Washington D.C.	5.1	1.5 (6.1)
Glu-lam	Route 7, Troy, NY	2.5	4.9
Post & Panel	Long Island Expressway, NY	6.7	12.2
Post & Panel	Hutchinson River Parkway, NY	1.9	7.6
Post & Panel	Hutchinson River Parkway, NY	3.3	14.0

measurements were made, are listed in Table 1 for each barrier. The normalization of the insertion losses for the three different receiver locations involved the use of the prediction model presented in FHWA-RD-77-108 (FHWA, 1978). The difference between the insertion loss of a barrier estimated from measurements and the predicted value for a barrier at a given height and distance from the road on a flat site was the normalization factor for a barrier. The estimated insertion losses are normalized by subtracting the normalization factor from the estimated insertion loss. 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. The height, 4.3 m, was chosen as a typical height for barriers. The distance, 9.2 m, was chosen because it is the mean of the source-to-barrier distances for barriers used in this research project. Normalization of estimated insertion losses allowed direct comparisons of all the test barrier types and locations.

A-weighting of Insertion Losses

To approximate the sound heard by the normal human ear, A-weighting was applied to the normalized insertion losses and transmission losses. The A-weighted sound level, with the units of dBA, is the sound pressure levels in decibels measured with a frequency weighting network corresponding to the A-scale specified by ANSI S1.4-1971 (ANSI, 1971). The A-scale tends to attenuate levels of frequencies below 1000 Hz. The A-weighted normalized insertion and transmission losses are presented in Table 2. The tabulated values are the A-weighted normalized insertion losses for the three receiver locations as well as the A-weighted transmission losses for each barrier.

Results

The A-weighted insertion losses in Table 2 allowed comparisons of the insertion losses for different barrier design types. The same data allowed comparison of each barrier's performance to a target minimum insertion loss of 10 dBA at 3.1, 7.6, and 15.3 meters behind the barrier.

The mean standard error values, as well as the range and coefficients of variation of the standard error values, are presented in Table 3. Tabulated values are for the three insertion loss calculations as well as for the transmission loss calculations. The table further breaks down the standard error by finding the error in calculations affected by background noise and calculations not affected by background noise.

Table 3 –Standard Errors for Insertion Loss Calculations

receiver @^{3}	3.1 m	7.6 m	15.3 m
mean (dB)	1	1	1
max. (dB)	2	2	2
min. (dB)	1	1	1
C.O.V. (%)	7	9	10

With the exception of the concrete barrier on I-87, the estimated transmission losses are higher than the estimated insertion losses, indicating that transmission through the barrier is not a dominating factor in the acoustic performance of the barriers.

The precast concrete barriers generally had a fairly high insertion loss (7 to 20 dBA) for the three receiver positions shown with lower losses at 15.3m (7 to 16 dBA) than closer to be barrier at 3.lm (12 to 19 dBA).

Table 2 –A-Weighted Normalized Insertion Losses and Transmission Losses

Type	Location	Height (m)	Road to Barrier (m)	IL @3.1m (dbA)	IL @7.6m (dbA)	IL@ 15.3m (dbA)	TL (dbA)
PC[a]	I-695, MD	6.7	9.0	12	10	7	19
PC	I-95, NY	4.9	6.6	18	17	12	22
PC	I-78, NJ	2.5	10.9	19	16	16	17
PC	SR 24, NJ	5.3	9.8	19	14	14	22
Plywood	I-95, MD	3.3	6.1	17	12	8	15
Plywood	I-83, MD	4.3	24.4	7	6	7	14
Glu-lam	I-495, DC	5.1	6.1	15	11	7	21
Glu-lam	SR 7, NY	2.5	4.9	16	14	10	20
P & P[b]	LIE[c], NY	6.7	12.2	18	11	7	15
P & P	HRP[d], NY	1.9	7.6	21	18	15	15
P & P	HRP, NY	3.3	14.0	12	14	15	15

[a] Precast Concret
[b] Wood Post and Panel
[c] Long Island Expressway
[d] Hutchinson River Parkway

There are significant differences in the estimated insertion losses for the two plywood barriers; the losses for the barrier on I-95 range from 17 to 12 dBA at 3.1m and 7.6m, where the losses for the barrier on I-83 range from 7 to 6 dBA at 3.lm and 7.6m. This is partly due to the differing distance of these two barriers from the roadway the barrier on I-95 was 2.4m from the roadway and the barrier on I-83 was 24.4 meters from the roadway, almost twice the distance for any of the other barriers tested in the program. This, along with clearly observable leaks in the barrier produced the low estimated losses presented in Table 2. However, the I-95 barrier does show losses that fall within the range of the losses for the concrete barriers, except for the transmission loss, which is lower than any of the transmission losses for the concrete barriers. The estimated insertion losses and transmission losses for the glued-laminated barriers are within the range of both the estimated losses for the concrete barriers. The only estimated insertion loss that falls below 10 dBA is for the barrier on I-495 at 15.3m. Because this barrier was very close to the four one-way lanes of I-495, an accurate equivalent source location was difficult to provide, and the sensitivity to the normalization factor is higher for smaller barrier-to-roadway distances. The lower estimated insertion loss for the I-95 barrier at 5.3m may be partly due to the inability to provide an accurate normalization. All of the concrete barriers had much greater roadway to barrier distances (see Table 1). The high value of transmission loss (21 dBA) indicates that the acoustic performance for this glued laminated barrier is similar to the concrete barriers with estimated transmission losses of 19 to 22 dBA.

The post & panel barriers, on the other hand offered the most divergent set of estimated insertion losses. Two reasons can account for the variable results. Background noise masked some of the 1/3 octave band levels for the 1.9 meter high Hutchinson River Parkway barrier, providing incomplete results. At the same time, both of the Hutchinson River Parkway barriers were influenced by high correction factors in the normalization process, since the barrier was low, and the distance from the roadway was large. The attenuation results should, consequently, not be used to make final decisions about post & panel barriers. The only remaining barrier, the one on the Long Island Expressway, had insertion loss values of 18 dBA at 3.1 m, 11 dBA at 7.6 m, and 7 dBA at 15.3 dBA and a transmission loss of 15 dBA.

Public Acceptance

Selection of Design Types

Computer edited images, presented in 35 mm slides, were designed for subjects to make evaluations on the general appearance of the barriers rather than the appearance of specific barrier design types. Thus, 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. Variations included flat or linear plan, relief

Table 4–Matrix of Barrier Design Types for Public Acceptance Evaluation

	FLUSH	RELIEF	SHADOWBOX
Vertical - wide strips	F1 / B1	F2 / B2	F3 / B3
Horizontal - narrow strips	F4 / B4	F5 / B5	F6 / B6
Vertical - narrow strips	F7 / B7	F8 / B8	F9 / B9
Horizontal - 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

plan, or 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 line while the panels alternate being connected to the posts' front arid back. The panels were either connected to the front of one post and to the back of the next or alternated being connected front-to-front and back-to-back of posts. The shadowbox plan was similar to the relief plan except that the relief in the barriers are deeper, requiring separate posts to be installed to achieve the depth of the relief

Panel orientation considered variations in the elevation of the barriers. Variations included wide and narrow strips, horizontal and vertical strips, and combinations of these variations. All these variations in plan and elevation were developed after reviewing designs of existing barriers. With the wide variety of designs, the goal was to include most of the feasible barrier designs in the public acceptance evaluation. Even tbough it did not identify the kind of wood products to use in the design, it did identify the appearance of the barriers more likely to be accepted by the public.

For comparison purposes, slides of concrete barriers in the three 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 allowed for a wide variety of wood barriers to be compared.

The combination of letters and numbers shown in Table 4 are codes which 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 box in the matrix which had its own unique number. For example, Slide F5 was the slide with the barrier constricted of widehorizontal panels in the relief plan layout and viewed from the front or highway side. Altogether, there were 36 slides with half containing views from the front and half containing views from the back. Figures 1 and 2 illustrate example front and back views of Slides F5 and B5.

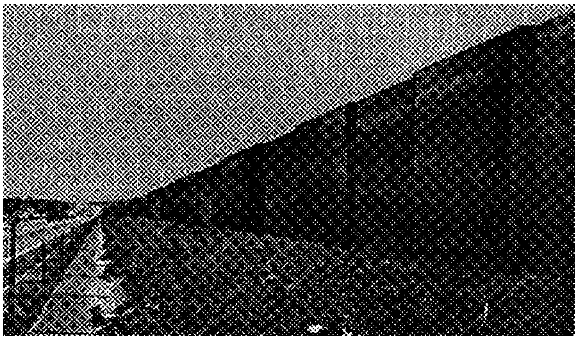

Figure 1–Computer-generated front view of a wood sound barrier.

Figure 2–Computer-generated back side view of a wood sound barrier.

Human Subjects Testing

Human subjects evaluated the appearance of highway sound barriers using the 36 computer-edited slides of barriers.

Twenty-four human subjects rated the 36 slides using semantic-differential (SD) rating scales and individual rating scales. Both of these scales are described later. The human subjects were divided into three groups of eight subjects each. Each group rated all 36 slides using the SD scales and a select group of slides using the individual rating scales. The two scaling techniques were used in separate sessions by each group. This divided the concentration time for each group into more reasonable intervals. Within the two sessions, the slides were divided into two groups, the slides of barriers viewed from the highway side and those viewed from the residential side. The subjects were first presented with slides of barriers viewed from the highway side and were asked to rate the barriers from the perspective of a driver. After a five minute break, the subjects were presented with slides of barriers viewed from the residential side and were asked to rate the barriers from the perspective of a homeowner living next to the barrier. The goal was to determine if differing perspectives would result in different ratings.

The subjects included undergraduate students, graduate students, and staff at the Pennsylvania State University, as well as people employed elsewhere in State College. The undergraduate and graduate students were from a variety of locations throughout the United States and world. The subjects' ages ranged from 20 to 40, with the majority of subjects having their age in the mid to high 20s. All the subjects were read the same set of instructions, were given the same set of forms to read and sign, were presented with same examples of sound barriers, and were presented the same set of slides. Each group had the slides presented in a different sequence.

Semantic Differential Rating Scales. –Subjects first used semantic-differential (SD) scales to evaluate the 36 slides. The SD scales were designed to elicit specific responses to attributes of the various barrier designs. They attempted to identify all the factors involved in a person's opinion about sound barrier designs. The subjects' responses obtained by these scales were statistically examined to determine how many factors influenced the subjects' responses and which attributes of the barriers caused these responses.

Principal components factor analysis and analysis of covariance were used to determine which scales were used in a consistent manner and the statistical significance of the results. However, the results of the SD scales also helped select the slides shown in the individual rating scales. The slides selected were those which drew favorable responses in the SD scales on both the highway and residential sides. For comparison purposes, the concrete barrier which received the most favorable responses, as well as the barrier which received the most unfavorable responses, were included in the individual rating scales.

Individual Rating Scales –The slides selected from the SD scales were displayed again to the human subjects, who were asked to rate these barriers with individual rating scales. These differed from the SD scales since they asked the subject to rate the barrier using whatever criteria they establish. Thus, while SD scales attempted to evaluate specific areas of subjective impression, the individual scales attempted to evaluate the overall impression of the slide.

The individual ratings themselves were quite simple. After selecting the slides by reviewing the results of the SD scales, these slides were all presented to the subjects before any ratings were performed. The subjects were then 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, this procedure was repeated twice within each group of human subjects, once for the slides viewed from the driver's perspective and once for the slides viewed from the homeowner's perspective.

Analyses of covariance (ANCOVA) determined if variations between the averaged results of the groups and slides were statistically significant. The set of slides used in the individual ratings contained slides that received favorable and unfavorable responses in the SD scales. The ANCOVA determined if statistical significance existed between ratings of slides favored and unfavored in the SD scales. The set contained slides of wood and concrete barrier designs allowing for the ANCOVA analyses to determine if the ratings of concrete barriers showed statistically significant differences from ratings of wood barriers. Thus, in many ways, the individual rating scales served as a check of the findings obtained by the SD scales. Barriers which were favored in the SD scales were evaluated by the individual rating scales. If the responses of the individual rating scales reinforced the findings of the SD scales, then the SD scales were given more validity. If the individual rating scales and SD scales did not have the same trend, it may be inferred that the SD scales did not find the correct responses or factors which are involved in a subject's opinion. Thus, individual rating scales and SD scales were a pair of tools which, when used together, greatly strengthened the survey results.

Analysis of Rating Scales

Principal Component Factor Analysis of Semantic-Differential Rating –The group averages of the SD scales for each slide were subjected to a principal components factor analysis (Flynn, 1979). 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. Strong differences in subjects' ratings of factors are not required, but rather consistent rankings of alternatives result in high intercorrelation. When the ratings' means are calculated, these factor subsets can be plotted so that alternatives being tested can be directly compared. Their validity can be seen in the graphs if scales that should have a high intercorrelation consistently rank alternatives in a similar manner. Reasons for inconsistent rankings must be determined.

Three factors, which were identified and named after the data analysis, 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 perspectives, indicating that the three factors were the same for the two perspectives. Because the rest of the factors for both views only explained about four percent, or less, of the variances, the three factors mentioned above will be used for the rest of this analysis and the analysis of variance.

The three factors which caused a majority of the variances in the ratings were named for identification purposes. The first factor had the scales such as appropriate/inappropriate, pleasant/foreboding and attractive/unattractive, were the subjects' emotional responses to the barrier designs and were given the name *evaluative.* The second factor had scales such as darkening/lightening, bright/dim, public/private, and rural/urban, were concerned with the subjects' impressions of the effect barrier designs had to the surrounding and were given the name *environmental.* The third factor had the scales fortifying/weakening and safe/unsafe, were concerned with subjects' impressions of the personal state of being caused by the different barrier designs and were given the name *physical.*

The results of the statistical analysis of the SD ratings, reveals that barriers which were more "disliked" had distinctive results in the SD scales while barriers which were "liked" did not have distinctive results. The subjects' individual SD ratings consistently rated certain barriers unfavorably, causing the distinctive results. The subjects' individual SD ratings, however, rated different barriers favorably. The group means of the barriers favored by the majority of subjects are slightly lowered by the unfavorable ratings from a few subjects, causing the results to be less distinctive. One of the tendencies in the results was the dislike of the shadowbox plan Except for slide F3, all the slides of shadowbox designs received negative responses from the subjects.

Another tendency shown in the results was the negative responses towards precast concrete barriers. Except for slide F17, all the other concrete barriers received negative responses. For comparison purposes, the slides F17/B17 were included in the individual rating scales to check this assumption. Even though the concrete barriers received responses such as "bright" and "lightening" these barriers did not receive more favorable evaluative responses. These barriers were rated as more "fortifying" and "urban" than the wood barriers They also received negative evaluative responses, making the color of the barrier a trait which can only help, not cause, a barrier to be acceptable. That the only wood barrier receiving a "lightening" and "bright" response were F7 and B7, this tendency is reinforced. These two slides did not receive as many positive responses as some of the other barriers. Since the results of this study suggest that a lighter finish on a wood barrier was more favorably received than a darker finish, the value of the finish on a wood barrier is a factor meriting further investigation.

Analysis of Variance of Semantic-Differential Rating Scale Results –The results from the semantic-differential scales and the principal components analysis were used to determine critical differences in value. The critical differences were determined in two steps. One, the mean of the scales contributing to a factor were determined. Then, these means were subjected to an analysis of covariance (ANCOVA) with post hoc tests to determine which means have critical differences. These steps are described in this section.

An analysis of covariance was conducted to determine if any mean of a group is significantly different from the other group means and if any mean of a slide is significantly different from the other slide means. Because it is an omnibus test, it did not specify which group's mean was significantly different from the others nor did it specify which slide's mean was significantly different the others. It only alerted the user that there are significant variations in the results. An F-test was conducted to determine if there was significant variation between the group and slide means at a significance level a = 0.05. A Tukey, HSD (honestly significant difference), post hoc test was used to determine significant differences between individual means (Stoline, 1981).

The variation between slides ratings for each of the factors were analyzed with a Tukey post hoc test. The results reinforce the tendencies identified earlier in the SD ratings. Barriers which were disliked, such as F6, had distinctive ratings while barriers which were liked did not have distinctive ratings. At best, their acceptance was lukewarm. Again, a simple plan layout and panel orientation for barriers was favored while the concrete and shadowbox barriers were disliked. Thus, it was concluded that no significant difference in values was observed between the groups and that the preliminary observations can be investigated further with the individual rating scales.

Analysis of Variance of Individual Rating Scales -The variation between individual rating scale group means was analyzed using analyses of covariance 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 ANCOVA determined the F-test values for the variations between slides and between subject groups for each slide. Using a significance level of 0.05, the critical values of F for the slides and groups were determined to be 2.15 and 1.74, respectively. While both perspectives had significant values for the variations between slides, neither view had significant values for the variations between groups.

Comparison of Rating Scales Results

With the semantic-differential and individual rating scales completed and analyzed, results were combined to observe tendencies which would aid in developing general design guidelines for wood sound barriers. The preliminary guidelines established by the SD scales were the unfavorable response towards concrete and shadowbox designs and the favorable response towards simple designs. By comparing the preliminary guidelines with the results of the individual rating scales, it was possible to determine if these guidelines were reinforced by the individual rating scales.

The first preliminary guideline was the dislike of the shadowbox design. This design type received negative responses by both rating scales (e.g., the slides receiving the most negative responses was F6/B6). Not only did the subjects dislike its appearance, but they found it more "fortifying" than barriers with the same panel elements organized in the flat and relief plan layouts. Thus, shadowbox designs are not recommended for wood sound barriers from aesthetic viewpoint.

The second preliminary guideline was the negative response towards precast concrete barriers. The subjects gave negative responses concerning the appearance of these barriers and also found them to be more "fortifying" and "urban" than the wood barriers. By including the most, and only, favorably received concrete barrier slide and its view from the other side, F17/Bl7, in the individual rating scales, it was found that the barrier received an unfavorable response on the view of the back side only. It appears that the unfavorable ratings of concrete barriers may result from the backyard view of these barriers

The final preliminary guideline from the SD scales was that the design type should be simple in plan layout and panel orientation. The four barriers receiving favorable responses in the individual rating scales shared this trait. The slides of these barriers were F2/B2, F4/B4, F10/B10, and F1l/B11. Even though there was not one plan or panel layout that these slides favor, the slides F13/B13 and F17, which received ratings close the favored barriers' ratings, offered some more insights into the preferred design traits of barriers. These slides had simple flat or relief barriers as well. Thus, all of these barriers suggested simplicity for the designs receiving the most favorable responses without a plan layout or panel orientation being specified.

Barrier Design Development

Design of Barrier System

On the basis of the testing programs, the original matrix of barriers shown in Table 4 has been modified by ruling out the shaded cells in Table 5, to a more manageable series of eight design options. The shadowbox designs have been ruled out on the basis of their generally poor acceptance in the human subjects testing Vertical orientation of timber plank and glued laminated panels

Table 5-Matrix of Barrier Design Types for Standard Drawing Production

	FLUSH	RELIEF		SHADOWBOX
	X	FLAT	SKEW	
Vertical - wide strips	X	▨	▨	▨
Horizontal - narrow strips	X	X	X	▨
Vertical - narrow strips	X	▨	▨	▨
Horizontal - wide strips	X	X	X	▨

requires a horizontal purlin for stability, which is incompatible with the relief design options. The remaining options are shown in Table 5 are being incorporated into a series of standard drawings and specifications, using either glued laminated or dimension lumber. Two different types of relief treatments are shown on the matrix and will be presented in the final design: in the flat relief treatment, panels between the posts are parallel to the roadway and attach at both ends to the front or back of the pints in alternating fashion. In the skewed treatment, the panels and posts are rotated slightly with respect to the roadway and the panels all attach to the back of one post and the front of the adjacent post.

The final design matrix consists entirely of design options that have common details, allowing for a systematic approach. The posts, for instance will be the same for any of the designs under equivalent conditions of height, geography, etc., and will only need to be designed once for all eight proposed design options. The intermediate panels will not differ significantly from one configuration to another and will not require an entire set of eight designs. Thus, the end user of the designs, will have available an entire palette of designs that may be used uniformly, or may vary within a single barrier design, depending on the preferences of the designer, the community, and the adjacent property owners.

Prototype Construction and Testing

Among the eight design options within the final scheme, it has been chosen to build the proposed test barrier in the flush configuration using glued laminated posts and tongue and groove timber plank panels. This configuration has been chosen as the simplest to build, and as having met the criteria for public acceptance based on the testing completed to date. However, the same post configuration can be used for most of the other design alternatives in the matrix, including variations in the relief treatment the substitution of glued laminate panels for solid sawn panels, and the use of alternative top treatments. The panel material will be 2x6 T & G Southern Yellow Pine, CCA treated (0.40 pcf retention), and field treated with a water repellent coating. The posts will be glued laminated SYP 16F-V5 6 3/4 X 11, CCA treated (0.60 pcf and field treated with a water repellent coating. The test barrier will be assembled on the test facility at the Pennsylvania Transportation Institute in May 1996.

The testing program for the prototype barrier will include acoustical measurements before and after construction of the barrier, and will include measurements made with horizontal cracks intentionally inserted within the panels and with and without a T-profile top treatment.

The prototype barrier will also be used to improve methods for estimating insertion losses of existing sound barriers. In the in situ study described above, it was necessary to rely on noise measurements made only after the barrier was in place and to estimate noise levels that would exist without the barrier. Measurements were also limited to favorable atmospheric conditions, that is, wind speeds less than 5 km/h. It is clear from this experience that improvement in prediction of noise levels without the barrier based on measurements made with the barrier under a wide range of atmospheric conditions is needed. So, the wood barrier that is under construction will be used for extensive measurements of noise propagation under differing atmospheric conditions, both before and after construction of the barrier. Measurements will also be made at an equivalent site near the barrier under a wide range of atmospheric conditions. These measurement, along with computer models of outdoor sound propagation, will be used to develop methods for the use of in-situ measurements to accurately estimate insertion losses for barriers.

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 sound 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 road served by the sound barrier, 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 construction and testing of a prototype will furnish valuable information on the susceptibility of wood sound barriers to cracking and the influence of these cracks on acoustic performance, and will help in broadening the conditions under which insertion loss measurements can be made on existing sound barriers

The continuing study will result in a development of a prototype system of wood sound barriers offering a variety of configurations and constructible with a variety of wood materials.

References

ANSI. 1987. Methods for Determination of Insertion Loss of Outdoor Noise Barriers. American National Standards Institute, ANSI s12.8-1987, New York.

Cohn, L.F.; Harris, R.A. 1990. Cost of noise barrier construction in the United States. Transportation Research Record 1255: 102-107.

FHWA. 1978. FHWA Highway Traffic Noise Prediction Mode. Federal Highway Administration Report Number FHWA-RD-77-108. Washington, DC.

FHWA. 1994. Summary of Noise Barriers Constructed by December 31, 1992. Washington, DC. Federal Highway Administration

Flynn, J. E. A study of subjective responses to low-energy and non-uniform lighting systems. Lighting Design and Application. 7(2):6-15.

NFPA. 1985. Guide Specification for Highway Noise Barriers. National Forest Products Association, Washington, DC.

Stoline, M.R. 1981. The status of multiple comparisons: simultaneous estimation of all pairwise comparisons in one-way ANOVA designs. American Statistician. 35:134-141.

Weiss, M. 1989. Summary of highway noise barrier construction in the United States. Transportation Research Record 1176: 1-4.

Acknowledgments

This project was funded by the USDA Forest Products Laboratory under Research Joint Venture Agreement FP-94-2274, Development of Wood Sound Barriers.

In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., ed(s). National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL- GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.