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16. Abstract

The potential environmental impact of noise pollution from highway facilities has become a difficult problem to solve for the TxDOT planners and design engineers. Noise mitigation for projects can greatly increase their costs and public opposition. Additional right-of-way acquisition in urban areas is often cost prohibitive which limits design alternatives. Highway noise walls are a design solution that fits most transportation agency needs.

The research is focused upon a survey of practice sent to all state transportation agencies, Puerto Rico, and Ontario, Canada to determine their success and failures with noise abatement design issues such as policy, material selection, maintenance, aesthetics, acoustics, community participation and construction. Examples from transportation agencies and literature will show noise abatement projects in the United States, Canada and Europe. A list of available noise abatement systems and computer software for analysis and design are included in this report.

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HIGHWAY NOISE ABATEMENT MEASURES: 1994 SURVEY OF PRACTICE

by

Beverly B. Storey
Research Assistant
Texas Transportation Institute

and

Sally H. Godfrey, Landscape Architect
Assistant Research Scientist
Texas Transportation Institute

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Research Study Title: Highway Planning and Operations for the Dallas District, Phase III

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TEXAS TRANSPORTATION INSTITUTE
The Texas A & M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

The benefits suggested in the following paragraphs are expected to increase as a result of transportation agency awareness of aesthetic visual quality issues and community preferences regarding highway noise abatement walls. Benefits are attributed to more effective planning that encourages an interactive public involvement process. A comprehensive, corridor approach should be done when planning for noise mitigation and visual quality.

An interdisciplinary team of planners, designers, engineers, and landscape architects can work in a cooperative and continuing manner with community representatives to recognize the needs of the affected residents and transportation officials. Aesthetics can be addressed and developed as an integral part of the highway facility. A broader or more extensive palette of noise wall materials, based upon characteristics that include: acoustics, aesthetics, performance, maintenance, safety, cost and public preference, will enhance design capabilities and provide choices beyond those currently sought by transportation agencies.

It is difficult to estimate the cost benefit of a social value such as aesthetic visual quality. Attention to planning and design elements that surround this issue may be used as a vehicle to solicit community acceptance of highway noise abatement projects. A comprehensive program of public involvement to maintain public awareness for noise abatement projects and to assure that neighborhood and community interests are addressed may keep transportation agencies in a favorable position. Positive results have been cited in Texas and other states. Amenities packages that include design aspects not normally in noise wall projects have been used to comply with public demands for visual quality . Such practices may stimulate potential for funding at a local level.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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GLOSSARY

ABATEMENT: (As it relates to noise) The process of reducing the degree or intensity of noise.

ABSORPTION: The method of noise attenuation which represents sound energy losses into or through a material.

ABSORPTION COEFFICIENT: The ratio of energy absorbed by a surface to the sound energy incident upon that surface, taking on the numerical value between 0 and 1 with relation to the octave band (hz) at which it was tested, with 1.0 being a fully absorbent surface. This is also referred to as NRC, Noise Reduction Coefficient.

ANGLE OF DIFFRACTION: The angle through which sound energy is diffracted as it passes over the top of a noise wall and proceeds toward a receiver. Receivers deeper into the shadow zone have larger angles of diffraction, and therefore greater noise wall attenuation.

ATTENUATION: The change in the noise level at the receiver location caused by the diffraction of sound waves over the top or around the sides of a noise wall.

A-WEIGHTED SOUND LEVEL (dBA): The most generally used measure of the magnitude of traffic noise. It is defined as the sound level, in decibels, measured with a sound-level meter having the metering characteristics and frequency weighing specified in American National Standard Specification for Sound Level Meters, ANSI S1.4-1971. Colloquial practice often refers to values of A-weighted sound level as "dBA". The A-weighing tends to de-emphasize lower-frequency sounds (e.g., below 1,000 Hz) and higher frequency sounds (above 4 kHz).

BARRIER: A solid wall, berm or vegetation located between a source and receiver which breaks the line-of-sight between source and receiver.

DECIBEL: A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average pain level.

DESIGN NOISE LEVELS: Noise levels for various activities or land uses which represent the upper limit of acceptable traffic noise level conditions. These levels are used to determine the degree of impact of traffic noise on human activities.

DESIGN-YEAR NOISE LEVEL: The predicted noise level for a future year, usually 20 years, after the completion of a project.

DIFFRACTION: The bending of sound waves around an obstacle such that attenuation of their energy occurs in proportion to the degree of their bending into the shadow zone behind an obstacle. Only waves that are small compared to the obstacle will be affected in this way. Diffraction over the top of a noise wall generally accounts for the noise energy that appears in the shadow zone of the noise wall.

FREE FIELD: A sound field that is free from enclosure or boundaries. It is a field in which sound waves propagate without reflection, attendant interference and reverberation effects.

INSERTION LOSS (IL): The difference in the level of sound before and after noise wall insertion.

INSERTION LOSS DEGRADATION: The amount of degradation of performance of a noise wall when an opposing parallel noise wall is inserted. This is due to multiple reflection between the noise walls and is of particular importance when smooth reflective surfaces are used.

L_{eq}: The sound equivalent steady-state or average sound level which contains the same acoustic energy occurring during the time period when the measurements were made (usually measured hourly, $L_{eq}(h)$).

L_{10}: The sound level exceeded 10% of the time during period measured. Generally, no longer used in prediction modeling. $L_{10}(h)$ is the hourly value of L_{10}.

LINE-OF-SIGHT: A straight line between the receiver location and a specific noise source.

MITIGATION MEASURES: Controls which are used to lessen adverse noise impacts.

NOISE: A sound of any kind especially when loud and undesired.

NOISE ABATEMENT CRITERIA (NAC): An hourly A-weighted sound level in decibels (dBA) for five categories with varying degrees of activity. These are exterior measurements for exterior uses and interior measurements for location that would require a minimum noise level be maintained inside (i.e., residences, schools, hospitals, etc.). The NAC is the maximum traffic noise level which can be approached, reached or exceeded without considering noise abatement.

NOISE ABATEMENT MEASURES: Controls used to reduce the degree or intensity of noise impact at a given site. These may include physical barriers (sound wall, berm, etc.), psychological barrier (plant material to break line of sight), lateral clearance or buffer zone, or altering the vertical and/or horizontal alignment of a highway facility.

NOISE CONTOURS: An imaginary line shown in a plan along which sound levels of a designated value are all equal.

NOISE REDUCTION COEFFICIENT (NRC): The ratio of energy absorbed by a surface to the sound energy incident upon that surface, taking on a numerical value between 0 and 1 with relation to the octave band (Hz) at which it was tested, with 1.0 being a fully absorbent surface.

NOISE TRANSMISSION: The amount of sound that passes through a medium.

PROPAGATION: The passage of sound energy from noise source to receiver.

REFLECTION: Bouncing back of sound waves away from an object which is larger in exposed section than the wavelengths and of sufficient surface weight density and stiffness to present a very large increase in impedance compared to the air surrounding it.

RESONATING CAVITY: Utilizes a narrow opening which restricts the air movement, and sound energy flowing into the space. The sound is converted into heat by the flow resistance of the narrow opening or the movement of sound back and forth through the openings.

SHADOW ZONE: The area behind a noise wall that is blocked from direct view from the source of noise.

SHIELDING: An obstruction that breaks the line of sight between the source and receiver thereby lowering the level of sound to the receiver.

TRAFFIC NOISE IMPACTS: When the predicted traffic noise levels approach or exceed the noise abatement criteria in Title 23 Code of Federal Regulations Part 772 (23 CFR 772) , or when the predicted traffic noise levels exceed the existing noise levels by 10 dB(A) or more.

TRANSMISSION LOSS (TL): The energy loss (at a specified frequency) expressed in decibels as sound passed through a medium.

23 CFR 772 - Title 23 Code of Federal Regulations Part 772, Federal-Aid Highway Program Manual which explains processes to be followed in noise analysis.

SUMMARY

Highway traffic noise is an ever increasing problem for transportation agencies. The challenge presented to transportation agencies is to incorporate noise abatement into the highway environment without compromising the visual integrity of the surrounding communities. Since noise walls are the most frequently used method of noise mitigation, attention to the visual quality of the design must become a standard.

In an effort to guide highway designers, a survey of practice was sent to all state transportation agencies, Puerto Rico, and Ontario, Canada. The resulting responses provided invaluable information on policy, material selection, maintenance, aesthetics, acoustics, community participation, and construction. Many new products are available that provide aesthetically pleasing noise walls as well as providing the necessary noise level reductions required of transportation agencies. Innovative and versatile methods of using standard materials such as concrete have provided a continual supply of noise wall designs. Public participation in the design process has proven to be an effective method of ensuring the best design is implemented for both sides of the highway environment. This team approach to noise wall design is a valued part of the decision-making process. Community input has helped design engineers, planners, and landscape architects develop a strategy for design that includes the needs and desires of the surrounding developments as well as transportation agencies.

INTRODUCTION

Highway transportation systems are an integral part of our urban landscape. The adverse effects from the noise generated by automobile and truck traffic are ever increasing and pervasive. Noise pollution is a problem that has moved to the forefront as an environmental issue for transportation planners and designers, alike. Methods to alleviate the problem are generally categorized into controlling the noise at the source, the path of sound, or by regulatory and receiver controls. Source control methods have included the following: quieter pavements (26,30,31), more efficient vehicles, new tire tread designs (34), vehicle type restrictions, and vehicle speed modifications. Path controls include measures that cause the sound waves to be reduced or bypass the receiver. Examples of path controls include lateral clearance or buffer zones, depressed highway systems, altering the highway alignment, and noise walls. Regulatory and receiver controls are those measures implemented to restrict noise levels from being a nuisance. Compatible land use regulations, planning and zoning, subdivision laws, and environmental regulations are effective noise abatement methods for these types of controls. Many source controls, regulatory, and receiver controls require long-range research, planning, and implementation time frames.

Transportation agencies often propose path controls for noise mitigation since many alternate processes can be lengthy or beyond their control. Noise walls have been constructed by thirty-seven of the forty-six United States transportation agencies who responded to the TTI survey of practice. In comparison to alternate measures, noise walls have been a primary mitigation option in urban areas because of their timeliness, effectiveness, and relatively low cost. However, walls significantly alter the urban landscape by their visual dominance in the highway environment. Without careful attention to planning, design, and construction, noise walls can become visual pollution. The purpose of this document is to provide current information on aspects of noise wall use by transportation agencies, to report on noise abatement systems, and to provide current policy information.

SURVEY OF PRACTICE

To refine their established guidelines for highway noise mitigation, the Texas Department of Transportation (TxDOT), Dallas District, requested the researchers to collect information from other state transportation agencies as a survey of practice. The researchers reviewed previously done surveys as a gauge to follow the development of noise mitigation practices over time. Dr. Louis Cohn's *Highway Noise Barriers, NCHRP Synthesis of Highway Practice, 1981* (10) adequately covered the main issues that TxDOT was concerned with, so it was chosen as a baseline reference for comparisons in practice. The researchers tried to document trends and developments in policy procedures, materials, noise analysis, community involvement, and construction methods. Dr. Cohn granted permission to repeat several NCHRP survey questions in the TTI survey of practice as shown in Appendix A.

Representatives of the district's advance project development sections requested information that emphasized the areas of policy, noise wall materials, costs, maintenance, aesthetics, acoustical performance, perceived effectiveness and community involvement, construction, and safety. Once the research team documented the district's needs for planning purposes, the survey instrument was developed to address these issues. A highway noise abatement survey of practice was sent to all transportation agencies within the United States, Puerto Rico, and the providence of Ontario, Canada. As many agencies surveyed were extremely busy with their respective noise abatement programs, not all areas of the survey were answered with equal completeness. However, 90 percent of the transportation agencies responded to the survey and are referenced in Appendix B.

The researchers did an extensive review of relevant literature to provide a background on highway sound physics, current research and development, and technological advances. The research team reviewed the Federal Highway Administration's (FHWA) current noise policies and assessed the needs of highway planners in aesthetic design criteria. From this review, the researchers found that the areas (within and beyond the U.S. boundaries) concerned with aesthetic issues most often used a multi-disciplinary team of individuals to solve their noise problems. Tennessee's report, *Determination of Traffic Noise Barrier Effectiveness, An Evaluation of Noise Abatement Measures Used on I-440* (18), suggested that a multi-disciplinary noise abatement committee be established for **each** project. Land planners, environmental noise specialists, community representatives, design and acoustic engineers, and landscape architects were recommended for representation. Noise has become a high profile issue with new products, computer software for analysis and design, and changing policies and procedures for implementation.

POLICY

The Federal Highway Administration (FHWA) set forth the 23 Code of Federal Regulations Part 772 (23 CFR 772 in Appendix C) in response to the National Environmental Protection Act (NEPA) and the 1970 Federal-Aid Highway Act for noise analysis and mitigation. Provisions for receiving federal funding are included for Type I and Type II projects as defined by the FHWA. Type I projects are defined as *proposed Federal or Federal-aid highway projects for the construction of a highway on a new location or the physical alteration of an existing highway which significantly changes either the horizontal or vertical alignment or increases the number of through-traffic lanes.* Type II projects are defined as *a proposed Federal or Federal-aid highway project for noise abatement on an existing highway.*

Type I Projects

From the survey questionnaire, a summary of guiding policies and procedures for determining the need for noise mitigation included the following information. Ninety percent of the responding transportation agencies followed the FHWA Noise Abatement Criteria (NAC) (shown in Table A) for their decision-making basis for Type I projects. The remaining 10 percent (Kansas, Florida, Ontario and Kentucky) have generated their own noise abatement criteria. Seventy percent of the states use the FHWA, STAMINA 2.0/OPTIMA prediction analysis program and the national reference energy mean emission level used with 23 CFR 772 to predict and model noise. Currently, Colorado and Washington are developing prediction models.

Table A: Noise Abatement Criteria for Considering Noise Walls

NOISE LEVEL CRITERIA		
ACTIVITY CATEGORY	Leq (h)* (dBA)	DESCRIPTION OF ACTIVITY CATEGORY
A	57 Exterior	Lands on which serenity and quiet are of extraordinary significance and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 Exterior	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 Exterior	Developed lands, properties, or activities not included in Categories A or B above.
D	————	Undeveloped lands.
E	52 Interior	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.
*"Leq" means the equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same period. For purposes of measuring or predicting noise levels, a receptor is assumed to be at ear height, located five feet above ground surface. "Leq(h)" means the hourly value of Leq. Use of interior noise levels shall be limited to situations where exterior noise levels are not acceptable.		
History: Cr. Register, August, 1989, No. 404, eff. 9-1-89.		

As a part of the decision-making process, the abatement method chosen must meet individual states, established criteria for *reasonableness* and *feasibility.* The states responded with their own definition of reasonableness that is summarized as follows, *common sense and good judgement shall prevail in the noise abatement decision process.* If an abatement measure was found at or below the cost/benefit limit and was cost effective in terms of cost/receiver, then the decision to implement a noise wall was usually given to the impacted residents. Feasibility was summarized as *the ability to construct a noise wall in a given location with consideration for the physical and acoustical limitations of the site.* Several agencies have developed a "checklist" approach decision-making process that included the criteria from 23 CFR 772. These documents can be found in Appendix D. In relationship to the decision to implement noise walls, the process generally follows the flowchart as shown in Figure 1.

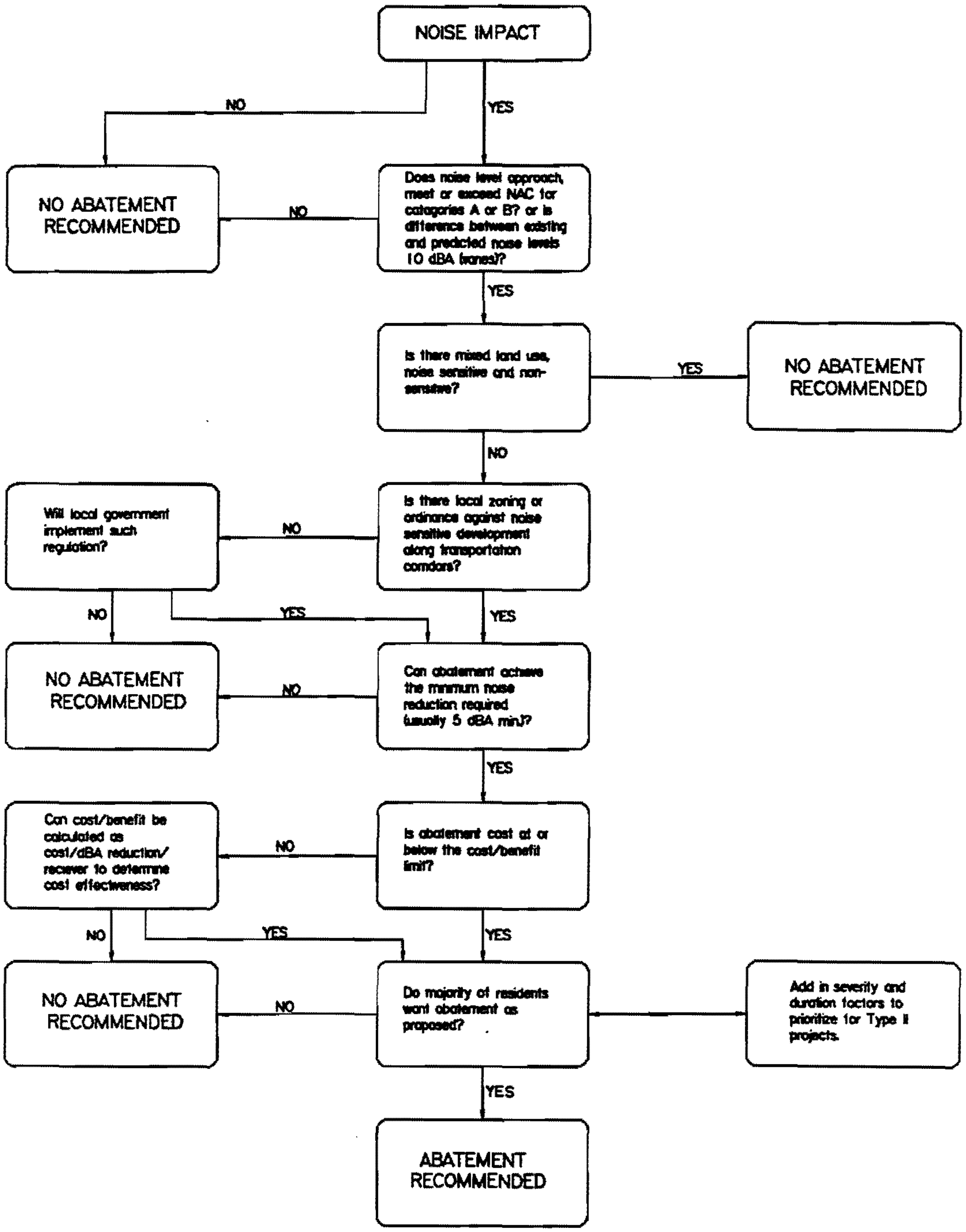

Figure 1: Flowchart Demonstrating the Decision-Making Process for Noise Abatement

Type II Project Prioritization

Prioritization for determining which location receives retrofit noise abatement can create considerable controversy between local governments, transportation agencies and constituents. Political push for various abatement projects has been felt by many surveyed states; yet, they have been able to stand fast on their polices for prioritization. Processing noise complaints into a formula that will rank projects without coercive decision-making as a factor has been a difficult task for states involved in Type II noise abatement construction. States currently participating in Type II noise abatement programs and those in the process of carrying out such policy are shown in Table B. Of course, as the traffic volumes and persistent complaints from residents increase, so will the number of states with Type II noise abatement. From the responding transportation agencies, the number of Type II programs has increased by seventy-three percent since 1981.

Table B: Comparison of States with Type II Policy, 1981 and 1994

TYPE II STATES 1981*	TYPE II STATES 1994
California	California
Colorado	Colorado
Connecticut	Connecticut
Georgia	Georgia
Iowa	Iowa
Maryland	Louisiana
Michigan	Maryland
Minnesota	Massachusetts
New Jersey	Michigan
New York	Minnesota
Washington	Missouri (in development)
	New Jersey
	New York
	Ohio
	Ontario, Canada
	Pennsylvania (in development)
	Utah
	Washington
	Wisconsin

* Source: Highway Noise Barriers (10)

Methodology and Formulas

The researchers requested examples of cost guidelines, cost/benefit ratios, prioritization methodology, and mathematical formulas for Type I and/or Type II noise abatement. Most of the cost/benefit analysis was reported being done (in simple terms) by dividing the total cost of abatement by the number of impacted receivers within the 67 dBA L_{eq} contour. If the state's allowable limit becomes exceeded with this method, alternate methods of deciding reasonableness must be used. TxDOT's cost per receiver, reported from their policy guide on noise mitigation (38), is twenty-five thousand dollars ($25,000) per protected receiver or five thousand dollars ($5,000) per dBA reduction per receiver. This has allowed increased flexibility when figuring cost/receiver in excess of $25,000. Additional factors of severity and duration of impact are usually added by those states with Type II prioritization. The average allowable limit for the states responding was twenty-three thousand dollars ($23,000) per protected receiver. As shown in Figure 2, Nevada listed its cost evaluation for impacted 1st row receivers as ten thousand dollars ($10,000) per receiver. New Jersey reported a cost per receiver range of forty to fifty thousand dollars ($40,000-50,000.)

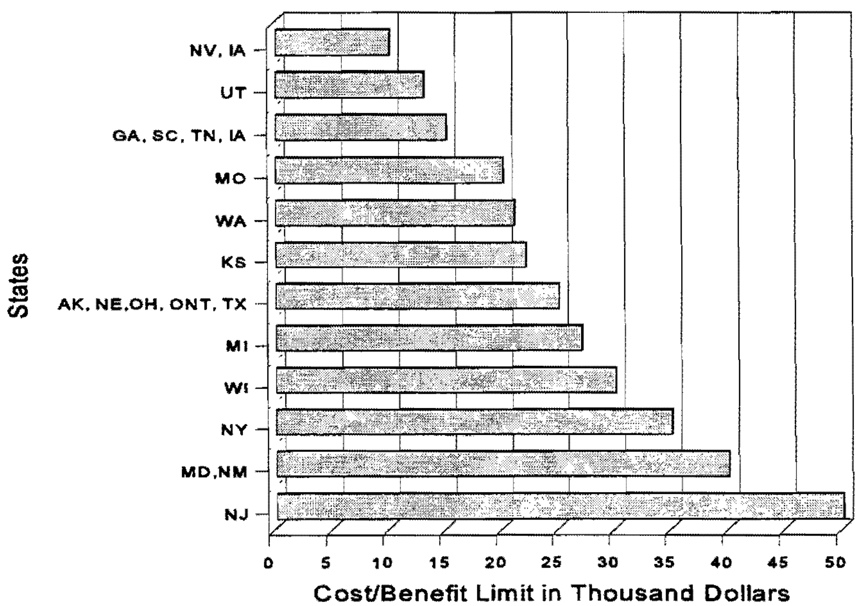

Figure 2: Cost/Benefit Limits and Corresponding States

Prioritization and associated policy for Type II projects received from other states are presented to provide information to states or areas that do not currently have Type II policy as requested from the research team. Excerpts from current noise guidelines were received by the researchers and included in this document from Colorado, Connecticut, Idaho, Maryland, Massachusetts, New Jersey, Ohio, Texas, Utah, and Wisconsin.

Colorado

Analysis

This section of Colorado's draft policy states that a noise analysis should be done when potentially impacted receivers are present. Analysis may be conducted using a nomograph, NOISE 4, STAMINA 2.0 (Colorado version), or narrative. Excerpts from the Type I projects include noise level guidelines for abatement. Whenever noise levels are likely to be within the "approach" range (loudest hour field measurements are within 4 dB(A) of the NAC) or exceed NAC, an analysis is done. Colorado's proposed Type II projects are analyzed using CDOT's version of STAMINA 2.0 prior to placing said project on the Noise Barrier Location List in the Statewide Transportation Improvement Plan (STIP). Priorities shall be determined by a rating factor (RF) and arranged into groups of ten projects. This factor may be determined by the formula:

$$\mathbf{RF} = \frac{\sum(\mathbf{ENL}_i\text{-}\mathbf{DNL})^2 \times \mathbf{N}_i}{\mathbf{Cost}}$$

where,

ENL_1 = Existing noise level at each group of dwelling units and/or activity area.

DNL = Design noise level (FHPM 7-7-3)

N_i = Number of ground level dwelling units and/or activity area subjected to the same noise level that will be brought into compliance.

Cost = Total cost of noise abatement/1000

Connecticut

Type II prioritization.

Type II noise abatement in Connecticut must first follow the steps in the Federal Highway Program Manual 7-7-3 (FHPM 7-7-3), *Procedures for Abatement of Highway Traffic Noise and Construction Noise.* Connecticut's guidelines for establishing priorities for Type II noise abatement projects were last revised in 1986. After a project qualifies as a

Type II project, a Project Priority Ranking Number (PPRN) is assigned. The PPRN is determined in the following manner:

A. Calculate the Benefits Factor (BF)

$$BF = (PI \times N_b \times SF) + (PI \times N_a \times SF)\ 1/3$$

Where,
PI = Project effectiveness index
N_b = Number of receptor units in existence before the highway was built
N_a = Number of receptor units in existence after the highway was built
SF = Sensitivity Factor

Project Effectiveness Index (PI). This is determined by locating the L_{10} noise level measured at the receptor and then reading the corresponding project effectiveness index (PI). Connecticut did not supply a chart for this step.

Number of Receptor Units (N_b and N_a). Each family living in a house or residence is considered a receptor unit. For other land uses, as described in land use categories A and B, the equivalent number of receptor units is determined by the formula:

Number of receptor units = a x b x c x d

Where,
a = Number of families using facility
b = Number of days of use per week ÷ (7)
c = Number of hours of use per day ÷ (24)
d = Number of months of use per year ÷ (12)

Sensitivity Factor (SF). A factor giving consideration to the sensitivity of the land user to noise is provided as indicated below:

Land Use Category (FHPM 7-7-3)	Factor
A	1.5
B	1.0

This equation gives consideration to the three cases that could arise. One, where all the receptors were in existence before the highway was built; two, where all the receptors were in existence after the highway was built, but before the issuance of FHPM 7-7-3; and three, where there is a combination of one and two. In case one, the second half of the equation becomes zero; in case two, the first half of the equation becomes zero; and in case three, the whole equation applies. The second half of the equation is reduced by a factor of one-third to give more weight to receptors in existence before the highway was built.

B. Estimate Total Project Costs. The total project cost includes all items contributing to the cost of the project expressed as a cost per foot multiplied by the length of barrier.

C. Calculate the Project Priority Ranking Number (PPRN)

PPRN = (Benefits factor ÷ Total Project Cost) x 1000

The PPRN's for all projects are then listed with high priority projects being represented by high PPRNs.

Idaho

Project Cost Guidelines

Traffic noise predictions are based upon the model in FHWA-RD-77-108 or FHWA-DP-58-1. In the noise analysis, the traffic noise impacts must be determined and are called relative impacts and absolute impacts. Relative impacts are figured by comparing the predicted noise levels for the design year at selected transect points/receptors to the noise level for existing conditions. Absolute impacts are determined by comparing the predicted noise levels (exterior only) for the design year to the noise "abatement criteria" levels (23 CFR 772) to decide if the criteria are approached or exceeded. Table C shows their guidelines for Noise Impact/Barrier Cost.

Table C: Idaho Noise Impact/Noise Wall Cost Guidelines.

Noise Impact/Noise Wall Cost Guideline		
Absolute Impact Created by Project	Relative Impact Created by Project	Minimum Reasonable Cost per Residence ($)
<3 dBA	None	0
3-5 dBA	Minor	15,000
5-10 dBA	Moderate	27,000
>10 dBA	Severe	42,000

Maryland

Type II Prioritization

Maryland provided their Type II Priority Rating Criteria that included sections on the degree of traffic noise impact, impact density factor, point score, and other considerations.

I. Degree of Traffic Noise Impact

A. Five (5) points for each year the residential development has existed since highway was opened to traffic.

B. "Per Residence" point system:

Decibel range (whichever is higher)*

L_{10}: 71-75 dBA/L_{eq}: 68-72 dBA - 1 point per residence

L_{10}: 76-80 dBA/L_{eq}: 73-77 dBA - 5 points per residence

L_{10}: > 80 dBA/L_{eq}: 78-25 points per residence

NOTE: For multi-story apartment building only first floor/ground floor units are considered. Abatement for upper floor units is usually not cost-effective.

C. Schools and Parks:

Decibel Range (whichever is higher)*

L_{10}: 71-75 dBA/L_{eq}: 68-72 dBA - 10 points per school or park

L_{10}: > 75 dBA/L_{eq}: > 72 dBA - 50 points per school or park

D. Churches:

Decibel Range (whichever is higher)*

L_{10}: 71-75 dBA/L_{eq}: 68-72 dBA - 5 points per church

L_{10}: > 75 dBA/L_{eq} - 25 points per church

* If field monitoring yields, for example, L_{10} of 70 dBA and L_{eq} of 68 dBA in same measurement period, L_{eq} decibel range would be used.

II. Impact Density Factor. The ratio of impact points to the total length of the required noise attenuation barrier is an indication of the linear density of the noise problem and provides a relative estimate of a project's cost effectiveness. The impact points are divided by the estimated barrier length, then multiplied by 100 to obtain the impact density factor.

III. Point Score The point score is the product of the impact points and the impact density factor. This is interpreted as a combined measure of the degree and density of noise impact and cost effectiveness. The weighing tends to favor high noise levels and allows smaller but more highly impacted project areas (with fewer receptors) to be competitive with larger areas in determining priority.

IV. Other Considerations. Project scheduling also will consider the feasibility and practicality of construction, achievable noise reduction, funding availability, and the magnitude of cost for a project. Public attitude and involvement will be considered. In general, the public has a desire for noise abatement. Public inquiry and complaint may serve as notification of a potential problem; however, the subjective nature of noise makes it necessary to base priority on factors other than public reaction, since unavoidable built-in bias is normally associated with a noise complaint. If, during the development of a specific project, the community indicates that abatement is undesirable from its viewpoint, the project will be abandoned.

Massachusetts

Massachusetts priority rating for Type II barriers consists of "Priority Points" for a Primary Rating and is computed as follows:

Priority Rating.

Five points accrue for each year of noise impact. If the receptors preceded the Interstate, then impact started when the interstate was opened to traffic--and continues up to the present. On the other hand, if the Interstate preceded the receptors, then impact stated when the receptor arrived--and continues up to the present. For uniformity, MDPW policy dates the arrival of receptors as the year when the first study-zone receptor arrived--that is, the date the oldest noise-sensitive activity originated.

For residences of all types, the following points accrue:

- Each residence now 68-72 dBA L_{eq}: 1 point
- Each residence now 73-77 dBA L_{eq}: 5 points
- Each residence now over 77 dBA L_{eq}: 25 points

For places of worship, the following points accrue:

- Each place of worship now 68-72 dBA L_{eq}: 5 points
- Each place of worship now over 72 L_{eq}: 25 points

For schools, hospitals, nursing home, library or recreational areas of all types, the following points accrue:

- Each school, hospital, nursing home, library or recreational area now 68-72 dBA L_{eq}: 10 points
- Each school, hospital, nursing home, library or recreational area now over 72 dBA L_{eq}: 50 points

The Primary Rating is the summation of all such points for all noise sensitive activities in the barrier's study zone.

Supplemental Rating

In essence, the MDPW's Supplemental Rating is a measure of the average cost-effectiveness of protecting the activities in each barrier's study zone. It is computed as the barrier's estimated 1987 cost, divided by the number of activity units it protects. This Supplemental Rating is abbreviated as the "Cost/Reduction/Unit Rating" and has units of $/dB/unit.

Comparison of Supplemental Ratings With Those of Existing Barriers. For potential future barriers, the Cost/Reduction/Unit Ratings average to the following:

Roadway Character	$/dB/unit
Flat, elevated	2,000
Flat, at grade	2,500
Flat, depressed	1,500
Rolling, elevated	4,000
Rolling, at grade	4,000
Rolling, depressed	3,500

Values greater than 10,000 were excluded from these averages, as they were for the comparable existing barrier averages in a previous section (not included in this text). In all categories, the existing barrier and future barrier averages are comparable.

New Jersey

Priority Rating Index for Type II projects

New Jersey Department of Transportation (NJDOT) sent a research report titled, *A Procedure for Processing Highway Noise Complaints* (35) which details an eighty-four step procedure for handling noise complaints, including prioritization. NJDOT developed the priority rating index (PRI) as a comprehensive method of prioritizing requests for noise abatement from communities throughout the state. This system provides a method of processing complaints from citizens in an fair manner by equating three major factors that include: population (weighted with a factor for land use sensitivity), the magnitude of noise impact (degree of annoyance and energy content), and the duration of noise impact (number of years people have been exposed to high traffic noise levels).

Ohio

Type II Retrofit Barrier Program

As a result of legislative action (HB-201) it is imperative to prioritize retrofit (Type II) noise abatement projects in the State of Ohio. Ohio's Type II Retrofit Noise Barrier Program is designed to provide noise relief for those who have experienced the most noise for the longest period of time. The Noise Abatement Priority Index or NAPI does not address feasibility or economic reasonableness, it just prioritizes according to the set criteria.

$$NAPI = T (N1 \times D + N2 \times D/2 + N3 \times D/4)$$

T = Current average daily traffic
N = Number of residential units within a certain distance of the highway
D = Duration factor to weigh the length of time of the impact

Texas

Determining Noise Impacts
Determination of noise impact created by a proposed project is assessed after existing noise levels are measured or computer-modeled (using STAMINA) and the design-year levels are modeled. Land-use categories that the models represent have already been determined.

Determining noise impact is a two-step process. Step one involves determining whether the Noise Abatement Criteria (NAC) have been approached or exceeded in either the existing year or design year. This is a simple procedure involving a comparison of the present and proposed noise levels with the NAC. The second step involves determining the amount of increase between present-year and design-year noise levels.

If noise levels approach or exceed the NAC or there is more than a 10 dBA increase between existing-year and design-year noise levels, a substantial noise impact exists and mitigation must be considered. If the NAC are not approached or exceeded then mitigation is not required. If the projected noise levels increase more than 10 dBA or the NAC are exceeded then mitigation must be considered.

Mitigating Noise Levels
23 CFR Part 772 **requires** that five noise abatement measures be considered for highway noise abatement. Each measure must be considered and discussed in the environmental document. This discussion should include the feasibility and cost-effectiveness of each measure. Feasibility is the ability to lower the noise levels an average of 5 dBA for first-row receivers. Reasonable equates with cost-effectiveness and is defined as costing no more than $25,000 for each first-row receiver benefitted. **An abatement measure should lower the noise level an average of 5 dBA and cost $25,000 or less per receiver along the right-of-way to be reasonable and feasible.** In some circumstances, this figure may be exceeded to provide mitigation for a second-row or offset receiver to benefit from noise mitigation. In these cases, the additional receiver(s) may be counted in determining the cost per receiver.

Situations may exist where a noise wall will lower noise levels by more than 5 dBA at some receivers. In these cases, cost effectiveness may be calculated by dividing the cost per receiver by the insertion loss achieved. Mitigation is considered cost-effective if the cost is less than or equal to $5,000 per dBA reduction.

The $25,000 per receiver or $5,000 per dBA reduction per receiver figure should be used in considering all forms of noise mitigation discussed in 23 CFR Part 772. The figures should not include the costs of additional right-of-way, utility adjustments, or access rights.

Utah

Policy

Utah's noise abatement policy was consistent with 23 CFR 772 (FHWA Noise Standards) and provides a means to address highway noise impacts and determine the conditions under which noise abatement may be approved. Utah has established Type I and Type II noise abatement policies that include definitions, applicability statements, noise impact determination, abatement objective and conditions, participation methods, and public involvement statements. The following excerpts are portions of the policy.

Type II Priority Formula. All Type II projects will be prioritized for funding purposes, according to the formula below. A "Priority Index (PI)", used to prioritize these projects, is based upon noise level and cost-effective noise reduction. The project with the highest PI has the highest priority.

$$PI = L + R$$

L = Predicted Leq for typical dwellings nearest the highway
R = Noise Reduction (dBA)

Noise Impact Determination. A traffic noise impact occurs, for purposes of this policy, when either of the following conditions occurs at a sensitive receiver (dwelling units < 1000 ft from ROW line).

1. The predicted traffic noise level approaches (is within 2 dBA of) or exceeds the Noise Abatement Criterion (NAC). Applies to Type I and Type II projects.
2. The predicted traffic noise level substantially exceeds (10 or more dBA) the existing noise level. Applies to Type I projects only.

Abatement Conditions. (A set of conditions must be met to be considered for abatement) Condition number three included the following formula for residential dwellings.

3. a. For residential dwellings: The cost per dwelling in the formula shown below should not exceed a limit tied to an index and published annually. The index relates to a 3-year average bid price of noise walls. The present limit (at the most recent revision date of this policy) is $ 12,000.

$$\text{Cost per dwelling} = C \div SD$$

C= total cost of abatement
D= Total number of impacted dwellings that will likely receive some noticeable benefit (3 dBA or more) out to a distance not to exceed 1000 feet from the highway right-of-way.
S= Severity factor-an average weight applied to the number of effected dwellings, related to the amount of noise impact. For Type II projects S=1.

TABLE OF SEVERITY FACTORS - S (applicable only to Type I projects)				
Does predicted noise level approach or exceed the NAC?	Increase in Noise Level Predicted --- Existing			
	0 - 9	10 - 19	20 - 29	30
Yes	1	2	3	4
No	*	1	2	3
* Impact Severity = 0, so abatement is not considered.				

Wisconsin

Noise Barrier Study

As with a number of transportation agencies, Wisconsin has evaluated other states and their methods of prioritizing projects in order to develop a ranking process. The *Wisconsin Noise Barrier Study: Summary Report* (19) contains Wisconsin's approach to ranking projects. Factors considered were sound level energy (Energy), traffic exposure, age of residences, and cost per residence per decibel of noise reduction. The following is from the report:

Sound Level Energy. The energy level (E) is a unit-less number defined by the following equation:

$$E = 10^{dBA/10}$$

where dBA is the Leq sound level modified at each receptor. The average energy level (E) for a barrier is defined by the following equation:

$$E = \sum_{I=1}^{N} (10^{dBAi/10} x RESi) / \sum_{I=1}^{N} RESi$$

where N is the number of receptors modeled for the barrier, dBA is L_{eq} sound level at the ith receptor and RES is the number of residences for the ith receptor.

Traffic Exposure. The traffic exposure factor (TF) was used to account for the duration of sound exposure at the residential areas along the freeway in any given 24-hour period as a function of average daily traffic and the Level of Service-C capacity of the freeway. The traffic factor is expressed as:

$$\mathbf{TF = ADT/24xLOSC}$$

where ADT is the average daily traffic as published by the Department and Level of Service - C is the Level of Service - C traffic service volume determined for each freeway segment as one of the tasks of this study. The TF was developed so that if a freeway segment operated at optimum volume and speed for an entire day, every day of the year, the TF would be equal to one.

Age Factor. The age factor (AF) for a residential area is the age of a residence in terms of the age of the adjacent freeway segment. The age factor (AF) is expressed as:

$$\mathbf{AF = \sum((SY\text{-}RESi) \times RESi)/\sum RESi}$$

where SY is study year(1989), RES is the representative year of construction for the ith residence (if the RES is older that the abutting freeway, the RESY equals the opening year of abutting freeway) and RES is the number of residences for the ith receptor.

Cost Effectiveness. The noise barrier cost effectiveness factor (CEF) was determined by dividing the estimated construction cost of each defined noise barrier by the number of abutting residences adjacent to the barrier. The equation is written as follows:

$$\mathbf{CEF=CC/\sum RESi/WIL}$$

where CC is the estimated barrier construction cost, RES is the number of abutting residences for the ith receptor, and WIL is a weighted insertion loss.

Barrier Factor Weighting. The Department then conducted an analysis to determine the relative weight of each factor. The Department determined that the majority of the weight should be given to those factors that define the severity of the freeway noise problem. Accordingly, the Department assigned the following weights to each of the four factors:

Sound Level (Energy)	=	50%
Traffic Exposure	=	25%
Residential Age	=	15%
Cost Effectiveness	=	10%
TOTAL	=	**100%**

The noise barrier ranking (R) is expressed as:

$$R = 0.5(E) + 0.25(TF) + 0.15(AF) + 0.10(CEF)$$

Noise Barrier Rankings. The ranking of each noise barrier relative to the other barriers was performed by normalizing each of the barrier factors using standard deviation techniques and summing all four factors with the appropriate weighting factors for each barrier to arrive at a score. The method is based upon standardizing each barrier factor around the mean. This technique required four steps; the first step converted the barrier factor to standard deviation units, the second step converted the standard deviation units to a standardized score, the third step applied the weighting factors and the fourth step summed the four scores. The standard deviation units (Z) were defined accordingly:

$$Zi=(Bfi-\mu)/\sigma$$

where Bf is the value of a barrier factor, μ is the mean of the barrier factors, and σ is the standard deviation of the barrier factors.

Zi was then converted into a standardized score (SSi) for each barrier factor using a standard published Z Table. The standardized scores were multiplied by 100. The final Department Ranking Equation is expressed as:

$$R=0.50(SSe) + 0.25(SSt) + 0.15(SSa) + 0.10(SSce)$$

where SS is the standardized score for each barrier factor with the subscripts e,t,a & ce representing sound level (energy), traffic exposure, age, and cost effectiveness respectively.

These barriers and scores were then sorted in descending order, highest barrier score first, to rank each barrier relative to the other barriers.

Local Government's Funding Role

The variations of funding resources for noise mitigation included a wide range of options. Of the states that responded to the survey, the majority will not provide financial assistance for noise abatement unless the local government has noise ordinances for development in noise prone corridors. Many of the local governments provide funding for Type II projects only. As an extreme example, one community in Michigan funded a noise wall project themselves rather than complying with federal and state requirements. In New

Mexico, a "visual mitigation" was accomplished with a noise wall funded with local money because it did not meet the minimum noise attenuation criteria.

If the cost per receiver maximum is exceeded and the agency wants to construct a noise wall, the local government or private party may pay the construction cost difference in Alaska, Utah, Virginia, and Wisconsin. Local funding in Maryland was set up through increased property tax assessments. Ohio has used a combination of funding sources. The city of Vandalia, Ohio built a noise wall through funding which was 80% FHWA, 10% City of Vandalia, and 10% property tax assessments. Maryland's transportation agency said that the local government(s) must contribute 10-20% for Type II abatement and in Missouri they provide 75% of the funding. Nevada and Oklahoma have matching funds programs for local government contributions.

Mitigation at airport facilities was considered by less than 15% of the surveyed agencies. New Jersey, New York, and Virginia reported limited cooperation for the development of such a process. Utah manages its noise at airport facilities through local government compatible zoning.

NOISE WALL MATERIAL SELECTION

Bid cost analysis

The researchers requested bid cost analysis information as a part of the survey. Various levels of completion for this section prevented an effective comparison of the data by the researchers. Wisconsin, Maryland, Michigan, California, Colorado, and Nevada provided comparable data that was summarized. On the average, these states spend 50 percent of their noise abatement costs on the *noise abatement system or materials*. Table D shows the percentage breakdown of each state's cost components including noise wall systems, foundations, landscape, labor, engineering, drainage, traffic control, and miscellaneous.

Table D: Bid Cost Analysis

	California	Colorado	Maryland	Michigan	Nevada	Wisconsin
Barrier system	60.0%	57.2%	51.0%	59.5%	25.0%	50.0%
Foundation	18.0%	8.2%	21.0%	16.0%	20.0%	10.0%
Engineering		12.7%		10.0%	15.0%	10.0%
Landscape	10.0%	1.0%	19.0%	5.7%		5.0%
Traffic Control	11.0%	3.2%	4.0%	0.7%		
Drainage	1.0%	7.0%	5.0%	2.0%		2.0%
Labor		10.6%			40.0%	23.0%
Misc.				6.0%		

The basic construction materials used for noise walls consist of concrete, earth, wood, brick or masonry units, metal, vegetation, mineral aggregates, plastic, glass, and composites of these materials. Each material has unique properties that make it suitable for specific noise abatement situations. These materials can be manufactured and constructed to produce walls of many shapes and sizes. The most commonly constructed noise wall is the thin wall, usually free-standing. Others include the trapezoid, wedge, trapezoid with wall, cylinder top wedge and double edge noise walls (15). Special design applications using T-top, Thnadner, arrow-top and slanted-top noise walls should be considered for their specific acoustical benefits (9).

Information concerning the material types, quantity, and percentage of all noise abatement measures was requested in the survey of practice. Once a state chooses to provide a noise wall, there are still many decisions that remain. There were several factors in the noise wall material selection process defined by the transportation agencies and previous research findings. The most frequently encountered factors in the literature and survey responses are included the following:

- Site geometry;
- right-of-way;
- traffic types and volumes;
- noise frequencies;
- single or parallel configuration;
- surface imnpedance;
- source height;
- structural integrity;
- maintenence; and
- durability;
- acoustical properties;
- suseptability to vandelism;
- community preferences;
- site compatability;
- perceived and actual effectiveness;
- extraneous noise sources;
- cost;
- safety, location relative to clear zone.

For some transportation agencies, using lowest cost or bid price as their only standard for selection simplified the material selection process. Because of this prioritization, the agencies' community involvement was reduced to little or no participation in design phases. Lowest cost criteria virtually eliminated citizen preferences and design aesthetic considerations from the decision-making process. Even with other selection criteria considered important, 33% of the states responding stated low cost as the most important component of noise wall material selection. Table E shows an analysis of selection criteria as ranked by the transportation agencies.

Table E: Selection Criteria for Noise Wall Materials

Criteria	Concrete	Berm	Wood	Metal	Brick/Masonry	Transparent	Wall/Berm	Proprietary	Plants
Cost	***	***	***	**	*	*	***	**	**
Maintenance	***	***	*	*	***	*	***	***	*
Aesthetics	*	***	**	**	***	***	***	***	***
Acoustics	***	***	*	*	***	**	***	***	*
Only Choice	***	*	*	*	**	*	*	*	*
Structural Qualities	***	*	*	*	***	*	*	**	*
R.O.W. Availability	***	*	***	***	***	***	**	***	*
Retrofit	***	*	***	***	***	***	**	***	*

Desirability of use based on survey results and literature review

***** High ** Moderate * Low**

Concrete

Concrete was the most widely used noise wall material because of its reasonable cost, low maintenance and durability, versatility of surface aesthetic treatments, and acoustical value. Transmission loss (in dBA) for 101.6 mm (4 in) thick concrete or concrete block is a minimum 32 (35) which is high as compared to other materials. Other benefits to using concrete included multiple construction techniques available such as precast, cast-in-place, or post and panel concrete. The states with over 61,000 linear meters (200,000 lf) of constructed concrete noise walls included California, Florida, Kentucky, New Jersey, Pennsylvania, and Virginia. New Mexico reported specifying concrete exclusively for their noise walls. Many versatile surface treatments were used and included the following treatments:

- horizontal and vertical striations;
- ashlar stone pattern;
- exposed aggregate;
- fluted;

- fractured fin;
- double raked or fuzzy texture; and
- pressed patterns such as brick, block, stone, graphics, etc.

Several of these surface treatments did not add to the initial construction cost, but they did make significant *visual* impacts on the surrounding community aesthetics. Use of local cultural symbols, color, and artform provided a form of expression for the enjoyment of the traveling public. Design flexibility, effectiveness, and low cost will maintain concrete as a popular choice for noise wall materials.

Earth Berms

Other research has found that public preference for earth berms in noise attenuation was equal to that of concrete. Public acceptance of berms was high due to their more natural, less imposing character. In comparison, the transportation agencies' responses showed that earth berms were rated second in their preference. An advantage to using berms for path control is the availability of soil from highway construction. Earth berms provide excellent attenuation by absorbing sound, especially when planted with dense vegetation (up to 6 dBA /30 m wide greater than grass cover) (20). Berms would be used more readily if their spatial requirements did not conflict with limited urban rights-of-way. For visual aesthetics, earth berms should be constructed with a 4:1 slope and a maximum 2:1 slope (36). Figure 3 shows an earth berm planted with native grasses, shrubs, and trees located between the highway and adjacent neighborhoods near Copenhagen, Denmark.

A variation on the use of berm alone is the combination of earth and wall. Noise walls and berms were often used together to reduce the total structure necessary to achieve the specified attenuation levels. The insertion loss of this combination of materials has been cited in the literature as being equal to or greater than a berm (14). This method can incorporate the visual and acoustical benefits of a berm within a more limited right-of-way than a berm alone (27). Figure 4 shows an example of Michigan's earth berm and noise wall constructed along the highway.

Wood

Wood was ranked third by the transportation agencies in acceptance and in its use as a noise wall material. Public acceptance of wood noise walls has been documented through previous research studies (8). Wooden materials used in noise wall construction varied depending upon regional and climatic factors. Timbers, planks, plywood, and glue laminate were the basic components used for noise walls. These components were generally used with concrete or metal supports. The acoustical properties of wood are less than more solid materials with a transmission loss between 18 and 23 dBA for 25.4 millimeters (1 in) thickness (36). Alaska and West Virginia exclusively use wood because of its low cost, ease of construction, natural aesthetic appeal, and ready availability. Colorado, Nebraska, Connecticut, Wisconsin and Georgia have used wooden walls more than any other type.

However, some of these same states are now recommending alternate materials with longer service life and less maintenance for noise wall materials. These recommendations stem from common problems associated with wood's physical characteristics including: shrinkage, deterioration, warpage, moisture content, quality control by contractors, and discoloration around fasteners. These characteristics negatively alter the acoustical performance and visual appeal of wood. Colorado has improved some of these problems by specifying higher quality wood, ring shank nails, lap-and-gap boards, and (4x4) rails for their standard noise wall specifications.

Brick or Masonry Units

Brick or masonry units are fourth in order of community acceptance and agencies' selection. As of 1988, over 265 kilometers (165 mi) of brick, masonry unit (slump block, cinder block, stone), or combination walls have been constructed. Advantages of brick or masonry units include its visual quality and an excellent transmission loss of 33 dBA. The effectiveness of sound-absorbing concrete units can be increased by the addition of fibrous materials, such as mineral wool or fiber glass in the interior spaces of the units (25). The use of unit construction has allowed the designer to incorporate indigenous materials and blend these imposing elements into the landscape. Rhythm and sequence may be accomplished by the number of methods for laying the units that produce a variety of patterns. Disadvantages include higher initial construction cost and replacement due to damages.

Metal (Steel)

Steel noise walls are widely used by transportation agencies most often in combination with wood, concrete, and earth berms. The transportation agencies ranked metal below brick or masonry units in preference. Advantages of metal include low cost, maintainability, and ease of construction. A transmission loss between 10 and 22 dBA has been observed. Disadvantages of steel noise walls include problems with vibration and their ineffectiveness within the low frequency ranges. These problems may prove steel is an undesirable material for some applications. For retrofit applications, aluminum and fibrous materials have been used because of their light weight and sound absorption properties.

Proprietary Noise Abatement Systems and Absorptive Treatments

As the number of Type II projects and parallel noise wall configurations has increased, the use of proprietary noise abatement systems and absorptive treatments has also become greater. Proprietary noise abatement systems often have an absorptive treatment included to reduce the incidence of multiple reflections. Generally, these systems are easy to install and provide attenuation levels that are adequate for transportation agency use. Many products have incorporated recycled materials, such as tire rubber, wood processing waste, and plastics into their manufacturing process. A list of proprietary noise abatement system products and frequently used materials can be found in Appendix E.

Colorado, Pennsylvania, and New Jersey reported the use of *Durisol®* as one of their absorptive noise walls. Ontario has used this product for approximately 50 percent of their walls and reported satisfactory results (see Figures 5 & 6). New Hampshire and Pennsylvania have used the Evergreen Wall. PennDOT noted the initial construction cost as the main disadvantage with the Evergreen Wall system. Indiana and Nevada were in the process of installing absorptive treatment walls. Tennessee (TennDOT) has used absorptive block on its I-440 and I-240 projects. Wisconsin engineers specify absorptive treatments for all new noise walls because of the increased acoustical benefits. Table F lists other proprietary noise abatement systems, agency reporting use, and associated comments after construction.

Table F: Proprietary Noise Abatement Systems and Related Experiences.

SYSTEM DESCRIPTION	STATE	COMMENTS		
		POSITIVE	NEGATIVE	OTHER
ARMCO Steel	Florida	Very effective		
	Virginia			No Comment
Cameo Metal Panels	Colorado		Very expensive, reflections of light and sound, panels easily blown out by snow plows, difficult to seal to structures.	
Durisol®	Colorado			Too early for results
	Indiana			Wall still under construction
	New Jersey			No Comment
	Ontario	Very satisfactory		
	Pennsylvania			No Comment
Evergreen Wall	New Hampshire		Difficulty keeping vegetation alive with harsh weather conditions	
	Pennsylvania		Very expensive	
Fan Wall	Florida	Excellent results		
	Maryland	Generally good results	Some foundation problems	
	New York		Foundation problems	
	Washington	Good attenuation, aesthetically pleasing		
Sierra Wall	Maryland		Erodability of surfaces on lower portion near roadway, stepping of panels.	
Sound Lok®	Maryland		Problems with durability of absorptive surfaces.	
Sound Zero	Pennsylvania			Too early for results
SOUNDTRAP®	Nevada			No Comment
Transparent System (unspecified)	Maryland		Clouded and cracked due to exposure to cold weather and snow storage against the panels.	

Seventy-four percent of the states responding had no experience with absorptive treatments. Fifteen percent of those using absorptive treatments reported no net increases in noise wall construction costs. Colorado, Nevada, and Tennessee experienced an increase in their noise wall costs. Virginia DOT said their costs were as low or lower than reflective noise walls. Some transportation agencies stated the perceived cost and questionable durability of absorptive treatments as their reason for non-use. Others commented that absorptive treatment effectiveness was overstated.

Most of the agencies that have used proprietary systems and absorptive treatments on noise walls have reported successful results. Transportation agencies were careful not to favor the use of any particular system in the survey responses. Most specifications were developed and written to meet fair bidding practice policies within each state. An internal product evaluation review process was reported to effectively eliminate unsatisfactory products. Typically, this review process addressed issues such as safety, durability, functionality, and cost effectiveness. Over the last ten years, product performance has become the favorable method to specify noise wall materials rather than by the product constituents (29). Florida's proposed noise abatement product review addressed most issues that concern transportation agencies in their product approval process and included the following criteria:

- Manufacturer's name and address including plant location(s);
- Product trade or brand name (as marketed);
- Structural design calculations for the range of noise wall heights to be used;
- Foundation design calculations for the range of noise wall heights to be used;
- Detailed drawings showing the entire noise wall system and all components;
- A general statement of material composition and method of production.;
- Test results for materials as required in these criteria;
- Detailed material specifications;
- Statement of quality engineering control program; and
- Other information pertinent to the design and performance of the noise wall system as applicable and not covered by these criteria.

Plastics and Glass

Since Maryland was the only state to report experience with a transparent noise wall material, information (from the survey) was limited. From the literature review there were three primary plastic or glass components used in noise wall construction: lexan, glass, and fiberglass. Lexan is a plastic (polycarbonate) product that has an insertion loss of 10 dBA and a transmission loss between 22 and 25 dBA (36), which is adequate for most applications. The transparent nature of this material lends itself to areas where noise, not view or light, needs to be obstructed. Maintenance may be an issue because polycarbonates are more susceptible to abrasion and discoloration than glass or acrylics (33). Glass and glass laminated products have desirable qualities that include resistance to chemicals, easy-cleaning, and durability (41). They may succumb to vandals more easily than plastics, but should be considered for maintaining viewsheds. Fiberglass has proven to be an effective sound absorbing material for highway use. Weather resistance, durability, and design flexibility make fiberglass a noteworthy noise wall material. Its application with expanded or perforated metal panels keeps the surface from direct contact with the weather. Depending upon the thickness and density of the bats and the testing frequencies, fiberglass has a noise reduction coefficient (NRC) between (0.59) and (0.99) (36).

Material Specifications

New products and construction techniques have required engineers to develop new specifications and design details since the 1981 NCHRP study. Responding states were divided on the use of standard or custom specifications for noise wall design. Most have a standard specification for at least one aspect of noise wall design, i.e., standard wooden fence noise wall, color selection. Custom designs are often site specific details created for projects by those states using them. The Caltrans Action Program recommended developing "a standardized column/post/footing support system to adapt to a variety of panel-type materials"(29) to ease the burden of specification and detail development.

Retrofit or Existing Structure Noise Wall Materials

The placement of noise walls on existing structures was common with approximately 60 percent of the agencies responding to the survey. Of the materials cited, aluminum, metal absorptive, steel panels, wood, and transparent materials seemed best suited for this purpose. Their relative light weight and ease of construction and replacement made them versatile for retrofitting bridges, retaining walls in narrow rights-of-way, and center median placements. Problems encountered by Colorado DOT on their aluminum noise walls were from snow plows blowing out panels, sun glare from the smooth surfaces, and high construction costs ($538/square meter or $50/sf). Ontario used metal noise walls on structures and has set a maximum height of three meters (9.84 ft) for Type II, retrofit projects. As more states adopt Type II policies, the incidence of noise walls placed on structures will also increase.

Lighter weight wood, metals, and transparent panels are commonly used on bridge structures. Currently, Ohio DOT has allowed one hundred and two kilograms per 0.305 meters (225 lbs/lf) on existing structures. Massachusetts reported difficulty with transparent noise wall sections on an elevated section of I-93 built in the 1970's. The panels have become cloudy, yellowed, and cracked from weathering. Annual snow plowing and storage have accelerated the problem. Some panels reportedly cracked and fell onto the underpass.

Other Options

Less than half of the states responding to the survey used any sound masking or psychological barriers for mitigation of noise. Connecticut, Arizona, Colorado, Georgia, and Louisiana have used plant materials as a visual screening method to break the line of sight. Including landscape enhancements with a noise wall project was usually done to increase the aesthetic appeal of a proposed noise wall and not for additional acoustical benefits. Some research findings have suggested that dense vegetation can absorb and scatter about five dBA per thirty and one-half meters (5 dBA /100 ft) of distance (1). However, the depth and density of the plant materials needed to achieve an adequate amount of attenuation usually exceeds most available urban rights-of-way.

As a result of the public involvement process Kentucky, Michigan and Utah have used landscaping as an alternative for reducing noise levels. New Hampshire has given property owners the option of a noise wall or landscaping for residents that live close, 4.6 to 15.25 meters (15-50 ft), to a planned noise wall location. Several citizens have chosen landscaping instead of a structural noise wall in New Hampshire. Similarly, in Utah, subdivisions that qualified for a noise wall may choose to install landscape materials instead.

The Utah DOT has stipulated that the property owners receiving plant materials will also be responsible for maintenance. Wisconsin reported their intentions of experimenting with a live noise wall later in 1994. Among those states with live noise wall use, common comments included the agencies' perception that vegetation provided greater psychological benefits than acoustical attenuation.

MAINTENANCE

Structure maintenance costs for highway noise abatement systems can be broken into four major categories: susceptibility to graffiti, vehicle impact damage, snow maintenance related problems, and durability and weathering of noise walls. Smaller or less costly problems associated with maintaining narrow spaces left between the noise wall and right-of-way included litter accumulation and general landscape maintenance (weed control and mowing). Specific questions concerning these maintenance issues were asked. It should be noted that 23 out of 33 respondents with recent noise wall experience reported no known maintenance problems or no records have been kept. The following discussion summarizes the responses received.

Graffiti

Graffiti is an ever increasing problem for maintenance staff in urban highway corridors. The Michigan DOT spends 95 percent of its yearly five thousand ($5,000/yr) noise wall maintenance budget on graffiti removal with the majority spent in the Metro Detroit area. New York DOT considered graffiti a major problem. Utah averaged one hundred sixty dollars per square meter ($15/sf) on graffiti removal from noise walls. Wisconsin cited spending a meaningful portion of its annual $1,000 maintenance budget on graffiti removal and cleanup. They expressed a concern that their graffiti problems had increasingly consumed greater amounts of limited maintenance budgets and will continue to do so. New Mexico has experienced problems with graffiti but expected this cost as part of having a wall.

Several states have worked on reducing their graffiti costs by developing graffiti deterrents. Nevada established basic noise wall colors and keeps a supply of these colors to cover graffiti when it has appeared. Utah is experimenting with the use of plant materials to act as a physical obstacle for graffiti artists. Many state agencies have adopted the use of coarsely textured surfaces to deter offenders and anti-graffiti coatings to facilitate removal. The Colorado DOT noted their interest in employing "at-risk" youths for graffiti removal and currently are exploring the possibilities. Anyway, the graffiti problem will not likely go away.

Vehicle Impact

Vehicle impact has been kept to a minimum with the use of guard rails, concrete traffic barriers, and adherence to the FHWA standard 9.15 meter (30 ft) clear zone. Nevertheless, collisions do occur. Replacement of the damaged noise wall components was the most frequent method of repair. For wood, metal, or panel-type noise walls, this method of maintenance was the most cost effective. For other materials such as concrete, brick or masonry units, and glass, replacement was necessary but a costly item for limited maintenance budgets. Some states cited replacement problems with the manufacturer or supplier going out of business or unavailability of parts, especially with proprietary systems. Stockpiling materials has been tried as a solution, but other problems have occurred with theft and weathering of stored items. Colorado noted significant problems from wooden posts shearing off at ground level due to vehicle impact. CDOT quoted annual maintenance costs from vehicle impacts to be nine thousand dollars ($9,000) or 45 percent of its annual noise wall maintenance budget.

Snow Maintenance Related Problems

Repairs required by damage from snow removal and storage were reported by several colder climate areas. Problems included blown out panels, damage by errant snow plows, and snow storage on noise walls with an east-west orientation. Snow storage against walls also may cause an accelerated amount of deterioration. To control this problem, Utah enforced 3.66 meters (12 ft) height limits on walls close to the roadway so that the snow plows can blow snow over the top. Ontario engineers have avoided noise wall placement at the highway shoulder to reduce damages incurred by snow removal equipment. In Central Denver along I-70, the Colorado DOT set 3 meters (10 ft) height restrictions for noise walls with an East/West orientation. The height control was established to prevent road conditions that persist as icy, snow packed or wet within the winter shadow zone while the remainder of the highway is clear.

Durability and Weathering

Durability and weathering are more critical elements for noise walls with materials that are susceptible to environmental degradation. Concrete was thought to be the most durable material by states such as Florida (96% of noise walls are concrete) and Pennsylvania (86% are concrete). Metal that was protected by a weather protection coating made of polyvinyl lyden or other similar products did not have climatic weathering problems. Kentucky, Delaware, and Indiana reported no maintenance costs with metal noise walls due to weathering, only from impact damage. Three out of thirty-three survey responses considered wooden noise wall repair and replacement a major concern. Colorado and Wisconsin have each used wood for over 50 percent of their noise walls and spend most of their maintenance budgets on problems associated with wood.

Wood's inherent properties, such as short service life and low resistance to vandalism, were noted as major disadvantages for maintenance costs. Colorado DOT estimated 55 percent of their annual twenty thousand dollar budget, or eleven thousand dollars, was used for wooden noise wall maintenance. The Alaska DOT had problems with juveniles vandalizing wood noise walls to 'make nice skateboards'. In addition, residents have stolen wood components for home improvement projects. Similar incidences involving removal of boards for pedestrian access to the highway for carpooling were reported by Colorado. A few states reported a minimal amount of arson-related problems with their wooden noise walls.

Litter Accumulation

Litter accumulation was a problem reported by a few agencies. The area between the noise wall and right-of-way fencing was the most troublesome spot due to limited access. This problem has been controlled by removing the right-of-way fence or building on or near the right-of-way boundary. When removing fences for the construction process, Colorado noted difficulties that included obtaining temporary easement permits and resident pet control. CDOT has decided that this manner of handling fencing/noise wall at the right-of-way was not worth the effort for litter pickup. Other states concur that this is a difficult and time-consuming area to maintain.

General Landscape Maintenance

General landscape maintenance for the narrow rights-of-way left between a noise wall and the property owner's property was accomplished by individual property owners and community organizations.

Individual Citizen Assistance

Many states allow the adjacent property owners the option of using and maintaining this narrow strip of right-of-way. Depending upon the quantity of land to be maintained, citizens may permanently acquire the land or temporarily use it as their own. Highway planners noted that it was usually easier and less costly to let the property or homeowner assume ownership. In Maryland, if the wall was within 1.5 to 3 meters (5-10 ft) of the right-of-way, they recommended removal of the right-of-way fence. This would provide the residents with additional land for use and remove the maintenance burden from the state. However, this recommendation would occur dependent upon favorable agreement by all adjacent residents. In Missouri, it was assumed that the residents will maintain property up to the wall. New Jersey removes its right-of-way fencing unless the removal will create a safety hazard. Utah rarely has any area remaining after noise wall construction because of their design criteria. When land is leftover, the residents were given this area to use and maintain. For the Colorado DOT, it is against state statute to "give away" right-of-way, even though the area is usually 0.60-3 (2-10 ft) meters wide. In response to this, they have required their residents to obtain a *Landscape Permit* for the use and maintenance of this property. Appendix F contains a copy of Colorado's Landscape Permit.

Community Assistance

A few states reported maintenance done by civic organizations as a community service project. Colorado and Utah use the 'Adopt-a-Highway' program for cleaning portions of the noise wall corridor. Civic organizations who volunteer for this program became responsible for right-of-way maintenance along a designated 3.22 kilometers (2 mi) highway section. Generally these groups aided in litter pickup, graffiti removal, and landscape improvements.

AESTHETICS

Visual Quality

Noise walls make a strong impact on the visual quality of highway corridors. They become a major line element second to the roadway itself. Because of noise walls' visual impacts, careful attention should be given by the design team to wall aesthetics. Noise wall aesthetics means that scale, proportion, line, form, texture, and color and also acoustical or engineering considerations are addressed in the noise wall design. Designing aesthetic noise abatement systems for the urban environment requires the designer to visualize the noise wall from the corridor (high-speed) and from the adjacent property (static). In addition, the noise wall designer should consider the impacted residents' ideas of aesthetic acceptability. As compared to the 1981 NCHRP survey, American transportation agencies still reported insufficient data on the public's perception of aesthetically pleasing noise walls as a reference or guide. Generally, these agencies have dealt with noise wall aesthetics in the following manner:

- Design the most cost-effective walls to meet noise reduction function with little regard to public opinion or environmental surroundings (e.g., architecture form, color, line, or texture);
- Design the wall to perform function of noise reduction while blending it into the surrounding environment; or
- Design the wall as an artform (line, form, color, texture, and artistic expressions) within the context of its surroundings or the highway environment.

Transportation agencies have had trouble in meeting all of the public's demands for aesthetically pleasing noise walls within their financial means. Providing the public with a transportation system that is functional in the important transportation aspects such as safety, cost effectiveness, low maintenance, and environmental sensitivity is an ongoing challenge. Trends noted since the 1981 NCHRP survey suggested an increased awareness by transportation agencies and the public on the importance of noise wall aesthetics. Until 1981, Minnesota and Pennsylvania were the only two states that reported experience with aesthetic treatments in the NCHRP study. In the TTI study, four additional states (Florida, Colorado, Minnesota, and Arizona) reported including artform into several noise abatement projects because of public encouragement and approval. Results of the survey suggested that for noise wall design, aesthetic decisions were often related to favorable citizen participation during the project approval process. Decisions to implement noise walls were guided by state environmental policy, district or area planning regulations, and the citizen involvement process.

Environmental Requirements and Planning Regulations

The majority of noise mitigation was done for existing or proposed land development approved before the first public notification. Developments that occurred along highway corridors after public knowledge of highway improvements were usually not eligible for abatement. Colorado has approached their noise mitigation needs that encompass all parcels of land adjacent to the highway rights-of-way. If small parcels of undeveloped land exist within a proposed area for noise mitigation, they usually include these parcels in their environmental assessment.

Survey respondents said that the decision to construct a noise wall was made anytime during the environmental stage and sometimes after this stage. Typically, the decision to use noise walls was made the agencies during the final environmental assessment stage of a project's planning phase. Fifty-four percent of the states considered this the appropriate stage. Other states committed to wall construction during the design phase (preliminary or final). A few states, such as Kentucky, require acceptance by the affected residents at a public meeting before they will commit to noise wall construction.

Citizen Involvement Process

Public input has varied effects upon the design aesthetics and construction of the noise wall. Delaware and Florida have solicited public participation in the decision-making process for appropriate height, color, graphics, materials, and landscape planting. Ontario has limited its public participation to height, length, and color. One-fourth of the states considered little or no responses from the public for noise wall design approval. These states usually imposed these limitations due to restricted, preapproved noise wall designs or the "low bid" selection criteria. Of the states responding, 65 percent required a majority approval by the residents to construct a noise wall. Florida reported accommodating a minority group if they can provide a noise wall at a reasonable effort and expense. Connecticut has committed to installing a noise wall even if one resident wants it.

For several states, citizen involvement included renters and property owners in the decision-making process. Although TxDOT does not currently consider renters' opinion, the following states were reported to include renters: Alaska, Florida, Georgia, Iowa, Maryland, Nevada, New Mexico, Ohio, Oklahoma, Tennessee, Utah, Wisconsin, and Ontario. The remaining responding states considered property owners only, or did not have enough experience to comment. Colorado considered renters, but their opinions were not weighted the same as property owners.

Aesthetic Considerations

If the decision to construct a noise wall makes it through the initial citizen involvement process, the design team develops the schematic noise abatement measure proposals into a finished design solution. Often this process is benefitted through a continuing citizen involvement process to include surrounding citizens' preferences for surface treatments and color selection. Several states provided examples of aesthetic treatments as shown in the following figures.

The first series of photographs shows various types of noise wall construction installed in Michigan. Figure 7 is a mechanically stabilized earth wall with landscape enhancements on the freeway side. The next photograph, Figure 8, shows a precast concrete noise wall with 203.2 millimeters (8 in) thick panels and 2.44 meters (8 ft) post spacing. Integrally mixed color with the concrete did not prove to be visually pleasing because of the uneven color effect. The next photograph, Figure 9, shows a reinforced concrete block wall on a concrete base wall. Vegetation has been allowed to grow in front of the wall and adds visual interest to the long linear form. Light and dark earth-toned color bands also aid in relieving the structure's monotonous height. A Tedlar coated steel post and panel wall is shown in Figure 10. The landscape vegetation was preserved in this installation. Visually, the noise wall is unobtrusive from the motorists' viewpoint since the existing vegetation screens much of the constructed noise wall. Figure 11 was provided by Michigan to show their use of a brick wall placed on a concrete base wall. Much of the surrounding architecture have brick facades that helped this noise wall to blend into the community. Figure 12 shows the use of reinforced concrete block, 4" half-high units with founders finish. It is finished on top with a limestone cap. The appearance of this wall closely resembles brick and may be considered as a reasonable alternative.

Interesting examples were sent from the Florida DOT for their noise wall project on I-95 in Palm Beach County. The noise wall was constructed of concrete panels with cast-in-place concrete collars. Special graphic panels were located along the length of the wall. The graphics chosen were representative water fowl of this area and were selected by the local community. An architectural formed finish was used on the roadway side of the wall but not on the residential side of the wall. An anti-graffiti coating was used on this project as well. Figures 13 and 14 show examples of the wall graphics.

From the literature review, researchers found that many innovative aesthetic treatments have been used on noise walls in Europe. Many European countries have dealt with noise pollution for years. Their experiences with designing acoustically effective and visually appealing noise walls exceeds efforts by the Americans. Various examples of design details, often developed in response to citizens needs, were collected from Denmark, Holland, France, and Germany . These photographs are from Bendtsen and Schou's, *Noise Barriers: A Catalogue of Ideas(3)* and are being reproduced with permission from the authors.

Denmark

In Denmark, noise sluices have been constructed with noise absorbing sides to prevent undesirable reflections. The noise sluice provides openings in the wall for continuous pedestrian movement and cycle paths. One such wall is a corrugated concrete wall stained light reddish-brown and textured with a rough surface. Noise absorbers are in round, dark blue steel elements with small holes. In Søborg Hjovedgade near Copenhagen, a transparent noise wall was built to reduce the noise load inside the homes and in the open areas. The transportation agency constructed a transparent noise wall at the request of surrounding citizens to maintain their visual connection with "life on the street." Figure 15 shows a detail of the six meter (19.68 ft) reinforced glass and red wooden framed noise wall. The effect of the wall has been described as "sculptural" by creating a visual contribution both to garden and street scene.

Incorporating materials associated with the surrounding environment are important design criteria for the Danish. They have constructed many earth berms next to residential neighborhoods within their metropolitan areas. Along railways, noise abatement systems typically are constructed with steel to represent railway materials. Noise wall surface treatment is designed to match the facades of an adjacent housing project. The wall has the effect of inconspicuously merging with the project. In single family residential areas, the variety of fencing, architecture, and environment influences the design. Noise walls are designed to harmonize with the architecture of the residential areas to avoid appearing as an alien element in the community.

Holland

In Holland, Dutch legislation has set strict road traffic noise limits for new and existing (1988) roadways and homes. To meet these requirements, many measures have been initiated. These include noise mapping, traffic planning and regulation, noise wall construction, and installation of noise-reducing windows and facades. By the end of the eighties, approximately 35 percent of the annual transportation budget or DKK 80 million was being spent on noise screening. A similar annual amount was devoted to reducing noise from other sources such as industry, railways, and airports.

Since Holland will have a comprehensive noise abatement system within the next thirty years, design aesthetics are a vital component. They have established principle guidelines for the design of noise walls and earth embankments as follows: difference, variation, function as a landmark, and creation of varied experiences for motorists (3). Standard design details have been developed for noise walls that include the following:

- Special placement of colored posts and plexiglass panels on bridges;
- Location and design of service doors every 400 meters (1,312 lf);

- Recommended color combinations and height variations to avoid monotony, and
- Use of glass near residential areas to retain views (citizens desired visual connection to street life).

Architectural competitions, laboratory research findings, and residential concerns play an important role in deciding the most appropriate noise wall designs. For large projects, it is not uncommon for the Dutch to have architectural design competitions. During the planning phase, models of noise walls are constructed to evaluate the visual effect of an installation on its surroundings. Concurrent to these efforts, research is conducted in laboratories to assess how both motorists and local residents react to noise wall installations. Dutch residents have expressed their concerns to the transportation authorities about existing noise screens. These concerns include an appreciation for noise reduction but a disliking of the permanent "visual nuisance." It is not clear if these walls are a nuisance because they are ugly or because they separate the residents from street life activity.

Noise wall materials vary depending upon their location along the highway corridor, but low maintenance is always important. The Dutch require their noise abatement systems to last twenty years with the first ten years restricted to cleaning and repair of damage resulting from collisions, vandalism, etc. A material distribution is shown in Figure 16 that represents total percentages from the late 1980s. Special color coded pillars, glass panels, and wood are used to mark bridge structures. A retrofit noise abatement system on an existing bridge uses sound-absorbing perforated aluminum. The diagonal windows of plexiglass are placed at the underpasses to provide a visual break in the uniformity of the noise wall's horizontal element. This design is shown in Figure 17.

The A12 motorway in *The Hague* has a 2m (6.56 ft.) vertical glass noise wall. The wall consists of a concrete base, white painted steel profiles, and a transparent barrier made of two (6) millimeter (0.234 in) thick glass plates with a 3 millimeters (0.117 in) thick layer of transparent artificial material between them. As seen from the highway, it is reported that the noise wall seems very light and motorists have a clear view of the surroundings. As seen from nearby housing, the noise wall seems "natural and inconspicuous."

An unusual noise wall was constructed on the A28 motorway in Zeist. An eleven meter (36 ft) concrete overhang was built for considerable noise reduction. Behind the highway there are 1,600 apartments in sixteen-story blocks that were being subjected to considerable noise. To effectively achieve noise reduction on the upper floors, a large noise wall was necessary. Another unusual *rural* noise wall was made with live willow branches on the A15 motorway in Sliedrecht. The wall materials consisted of corrugated panels of 1 mm (0.039 in) corten steel, live willow branches of four different kinds, and posts of Creosoted wood. Both sides of the noise wall were planted with willow branches with approximately eighteen branches per meter. The wall is 1.5 to 2 m (4.9-6.5 ft) wide. Since live vegetation provides some of the noise attenuation (up to 22 dBA transmission loss for the metal part of the barrier), precautions were taken to prevent damage from occurring to the willows. A drainage system was established to separate salt water from reaching the roots of the willows and different species were planted to provide resistance from disease. Figures 18 shows an example of this type of noise abatement system.

France

In general, the French noise abatement systems are a dynamic visual component of the urban environment. Blending with the surrounding environment does not seem to be a design principle for them in available reviewed publications. Strong architectural forms, color, and line are frequently used. Several innovative solutions for noise attenuation have been installed such as the covering on the A6B motorway at Avenue Charles Gider. For two kilometers (1.24 mi) the highway is covered with an aluminum roof and partly of an experimental grille construction of vertical noise-absorbing panels. Figure 19 shows the installed *dreary* noise wall that later had the supporting beams painted blue at the request of the residents. Noise measurements at the site have proven that this solution works but it is "rather depressing" to view.

In densely populated cities such as Paris, portions of the roadway have had lids or covers placed over the highways. On the Boulevard Peripherique, seven kilometers (4.35 mi) of the thirty kilometer (18.63 mi) loop road around Paris have been covered with a massive concrete construction. The 'new' space created from this covering is used as an open space for the enjoyment of the citizens for uses such as football, park features, and other recreational activities. Other noise walls constructed on the Boulevard Peripherique are plexiglass with aluminum frames mounted on broad concrete bases. These noise walls have been described to have a sculptural effect and diverse reactions by the public. The three-dimensional grille construction and introduction of color produce an assertive or "overpowering" noise wall from the road experience. Residents who live in the apartments directly behind the wall refer to the intimate spaces created by the wall as "inspiring." Figures 20 shows a detail photograph of this noise wall construction.

Germany

In the literature review for Germany, there were several noise wall solutions worth mentioning. On Messe-Schnellweg south of Hanover, there is a green, aluminum paneled noise wall with red steel I-profiles and bricks with white coping at the ends of the wall. Figure 21 shows the architectural detailing with the brick portions of the noise wall. The aluminum sandwich elements are built up with mineral wool inside for noise absorption. The views from the motorists perspective is described as 'striking' concerning the red posts in contrast to the green aluminum color. From the buildings, the noise wall effect is noted as an 'alien' element in the landscape. But the planted vegetation is young and should eventually help soften the screen with maturity.

In contrast to the rural noise wall on Messe-Schnellweg, the aluminum noise wall in downtown Wunstorf was designed as an integral element within the surrounding community architecture. The wall materials used were brick, concrete, and glass which were traditionally used in this area. Figure 22 shows the brick pillars with glass 'windows' placed between them to preserve the residents' views or connections to street life. Another noise wall is described as a supported earth embankment built to establish a naturalistic planted barrier. Several experimental noise abatement systems have been installed to create the natural screen appearance on German highways. The general design of the noise walls consisted of large, round grey concrete pipes placed on top of each other and filled with earth. Noise walls over two to three meters (6.56-9.84 ft) are costly to construct since the entire wall is made of concrete pipes. However, the visually appealing appearance of the dense vegetation screen greatly affects the motorists.

Figure 3: Earth Berm Planted with Native Grass, Shrubs, and Trees located between Highway and Adjacent Neighborhood Near Copenhagen (Copyright Hans Bensten. Road Directorate Denmark Ministry of Transport Traffic Safety and Environment)

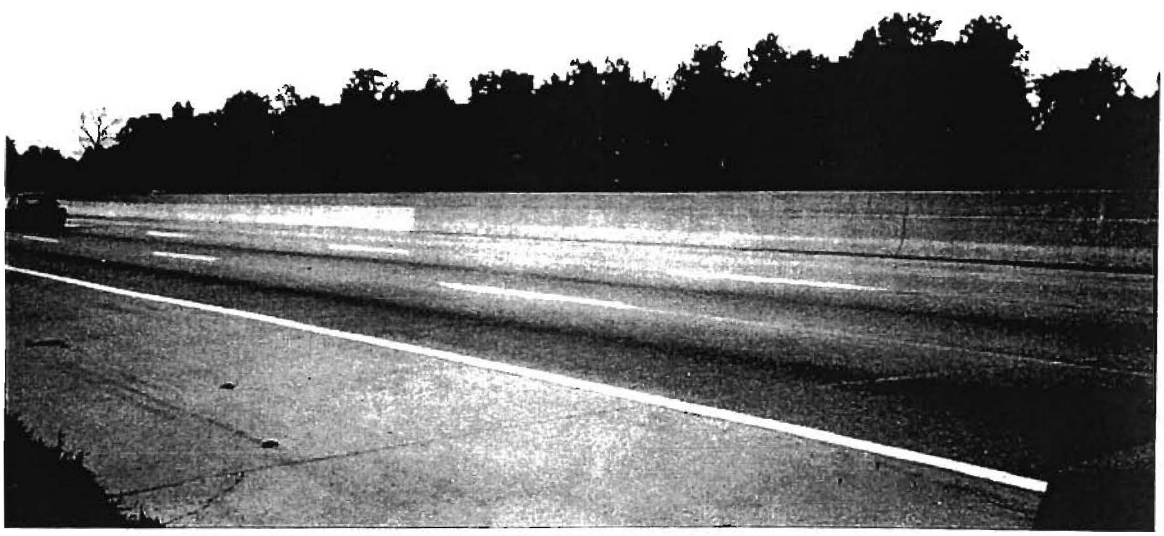

Figure 4: Earth Berm and Noise Wall along Highway (Michigan DOT)

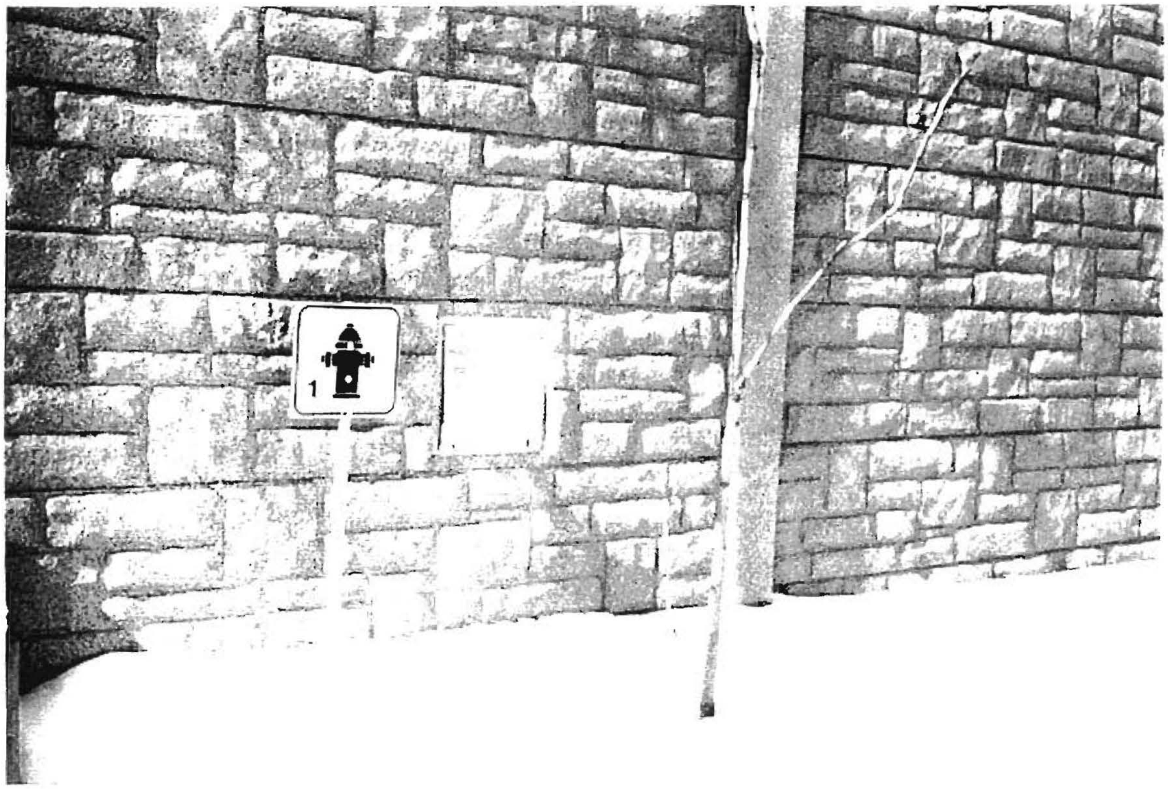

Figure 5: *Durisol*Ⓡ. Ontario. Canada

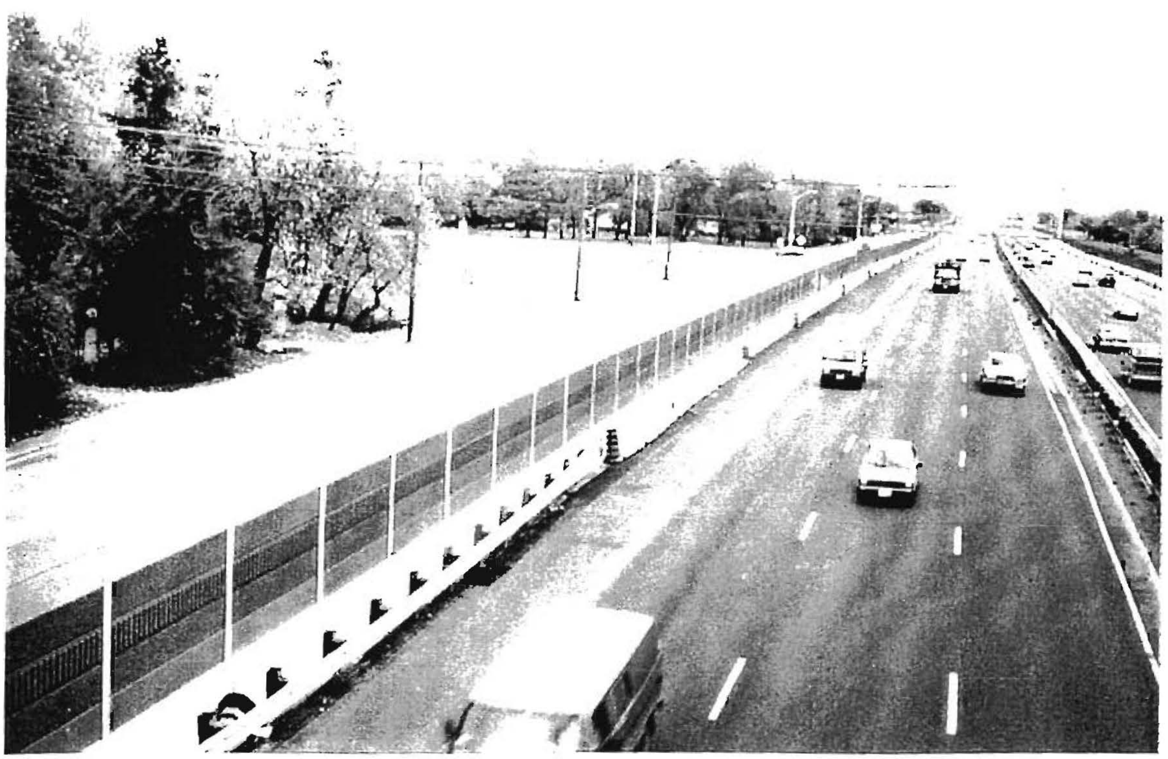

Figure 6: *Durisol*Ⓡ. Ontario. Canada

Figure 7: Mechanically Stabilized Earth (MSE) with Landscape Enhancments (Michigan DOT)

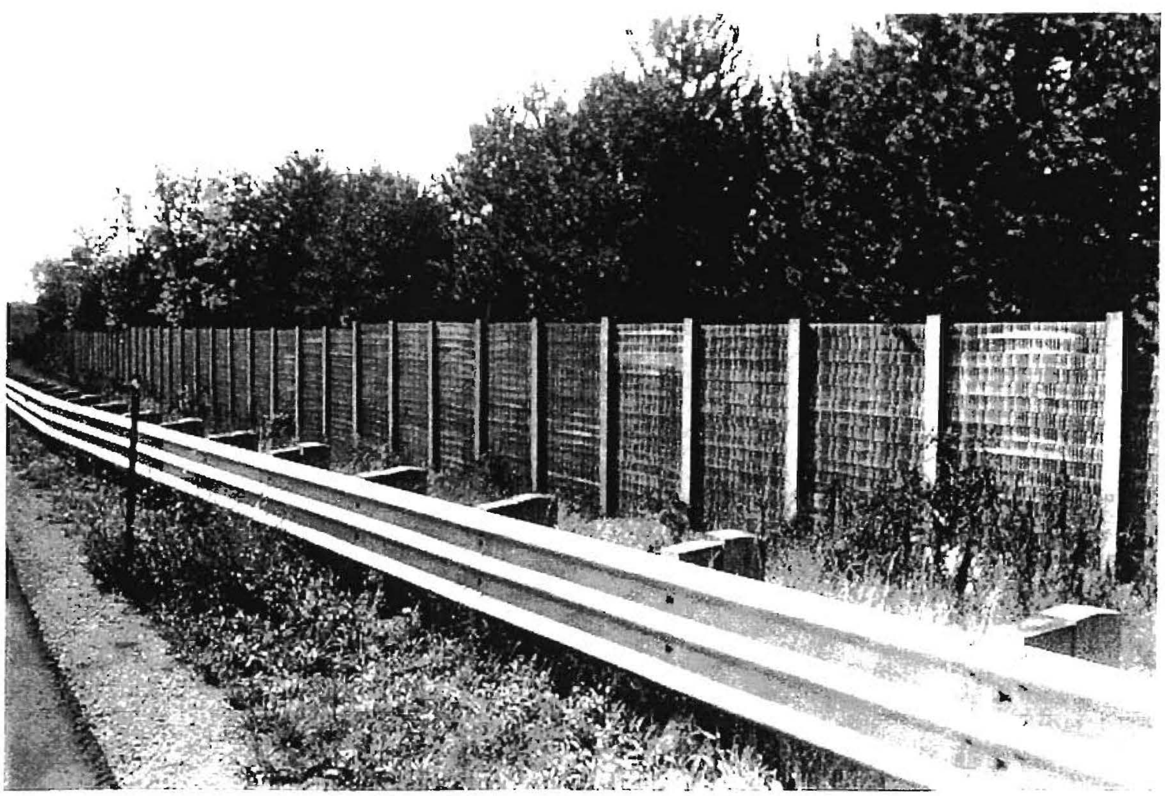

Figure 8: Precast Concrete with 203.2 mm (8 in.) Thick Panels and 2.44 m (8ft.) Post Spacing (Michigan DOT)

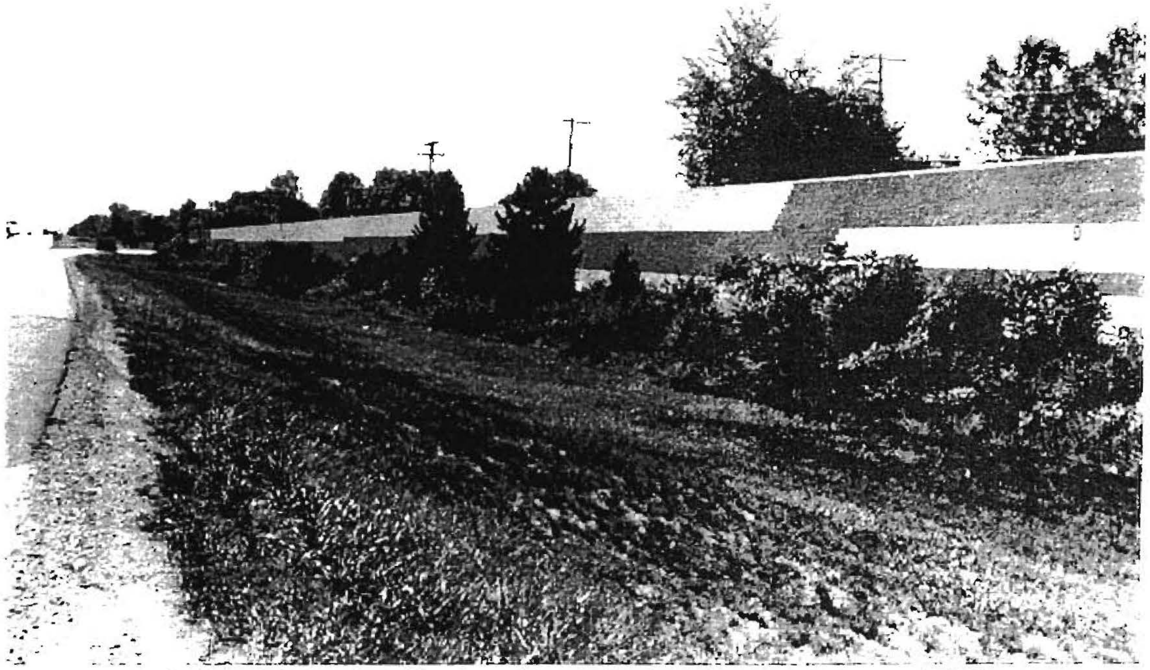
Figure 9: Reinforced Concrete Block on Concrete Base Wall (Michigan DOT)


Figure 10: Tedlar Coated Steel Post and Panel Wall (Michigan DOT)

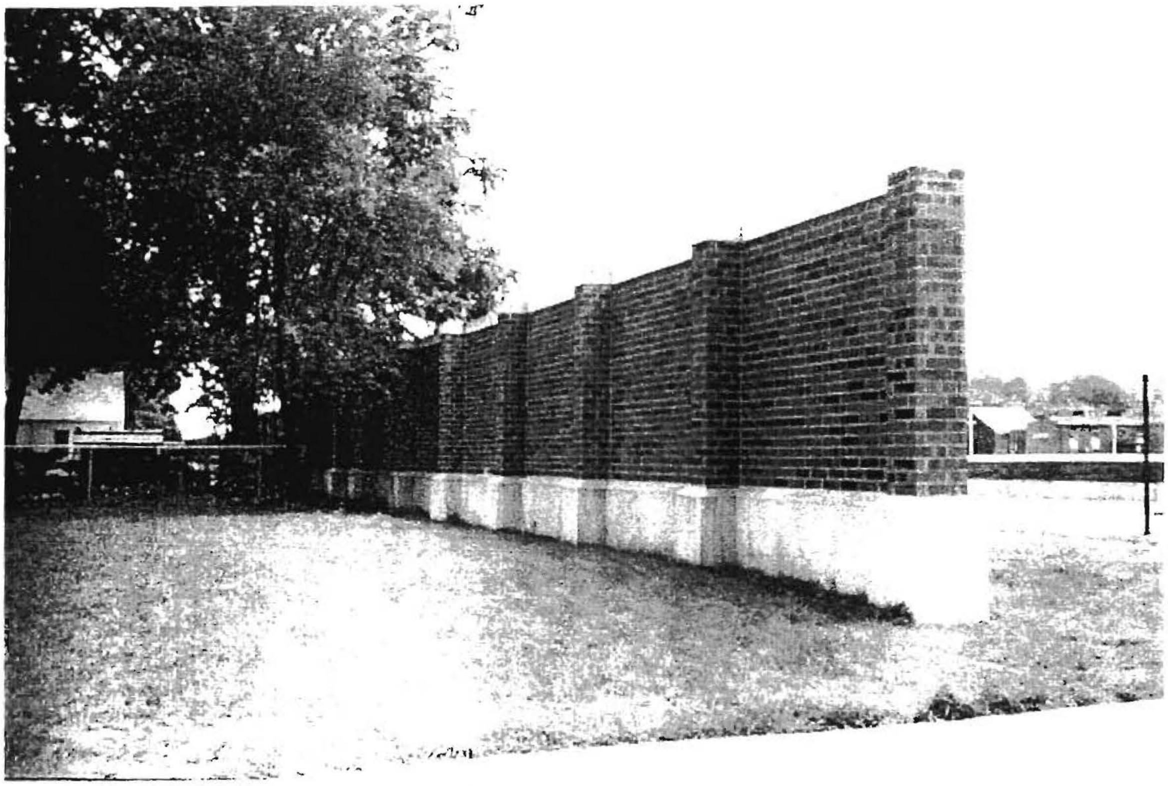

Figure 11: Brick Wall on Concrete Base Wall Complimenting Surrounding Brick Architecture (Michigan DOT)

Figure 12. Reinforced Concrete Block, 4" Half-high Units with Founders Finish and Limestone Cap (Michigan DOT)

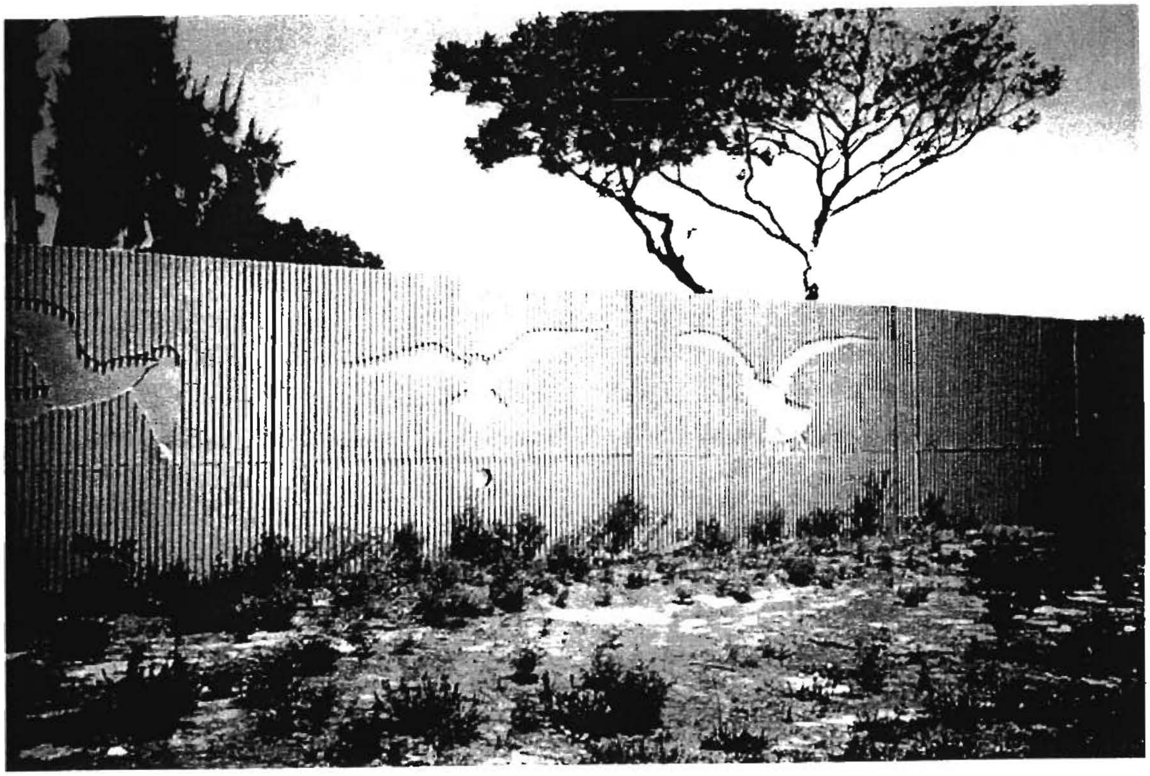

Figure 13: Noise Wall Graphics, I-95, Palm Beach County, Florida

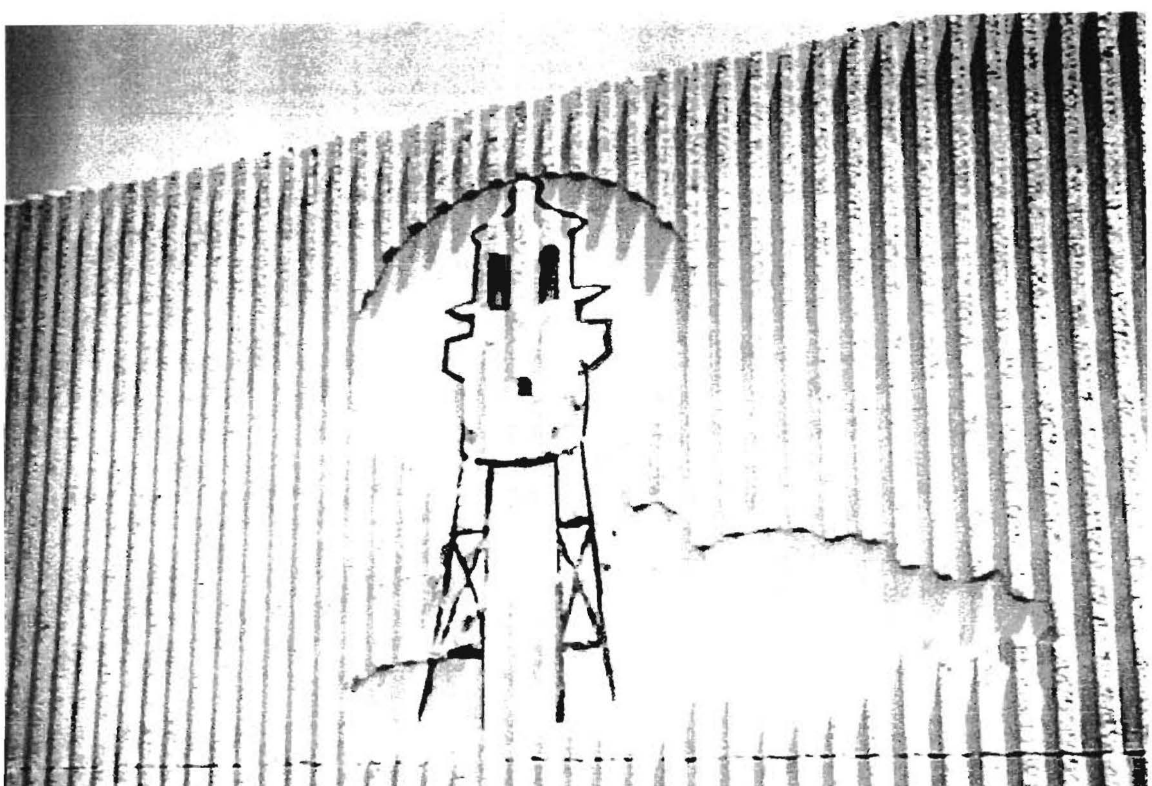

Figure 14: Noise Wall Graphics, I-95, Palm Beach County, Florida

Figure 15: Transparent Noise Barrier in Soborg Hjovedgade, Denmark, 6 m (19.68 ft.) Reinforced Glass Framed in Wood. (Copyright Hans Bendtsen. Road Directorate Denmark Ministry of Transport, Traffic Safety and Environment)

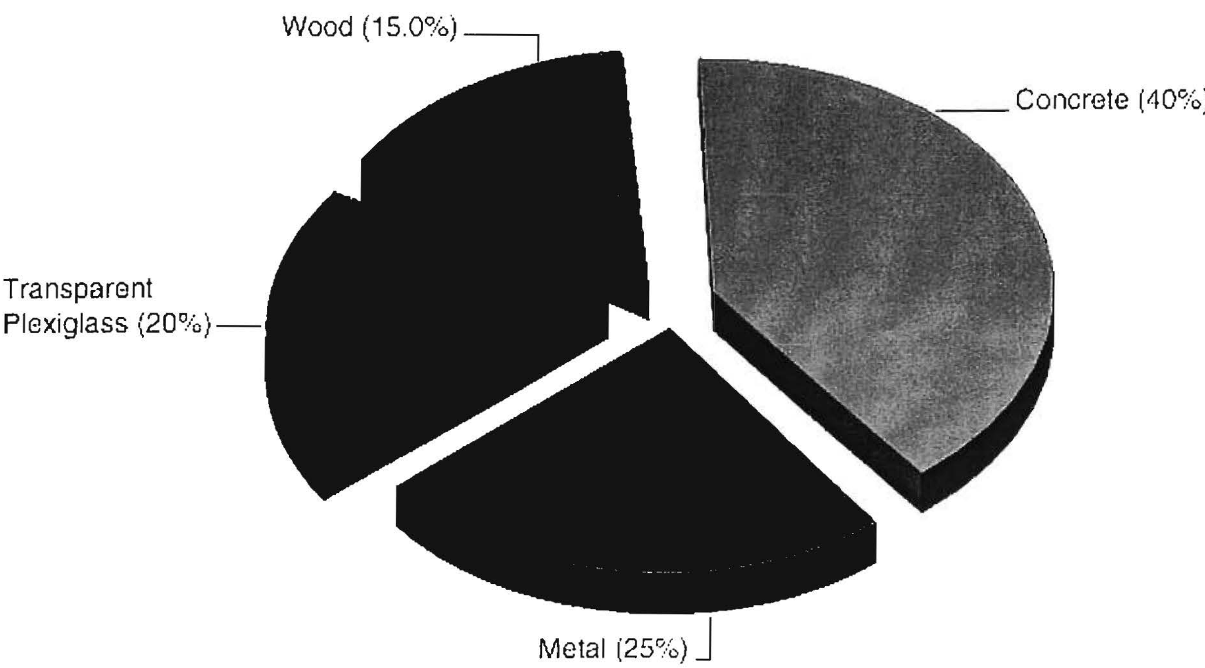

Figure 16: Holland's Material Distribution Analysis

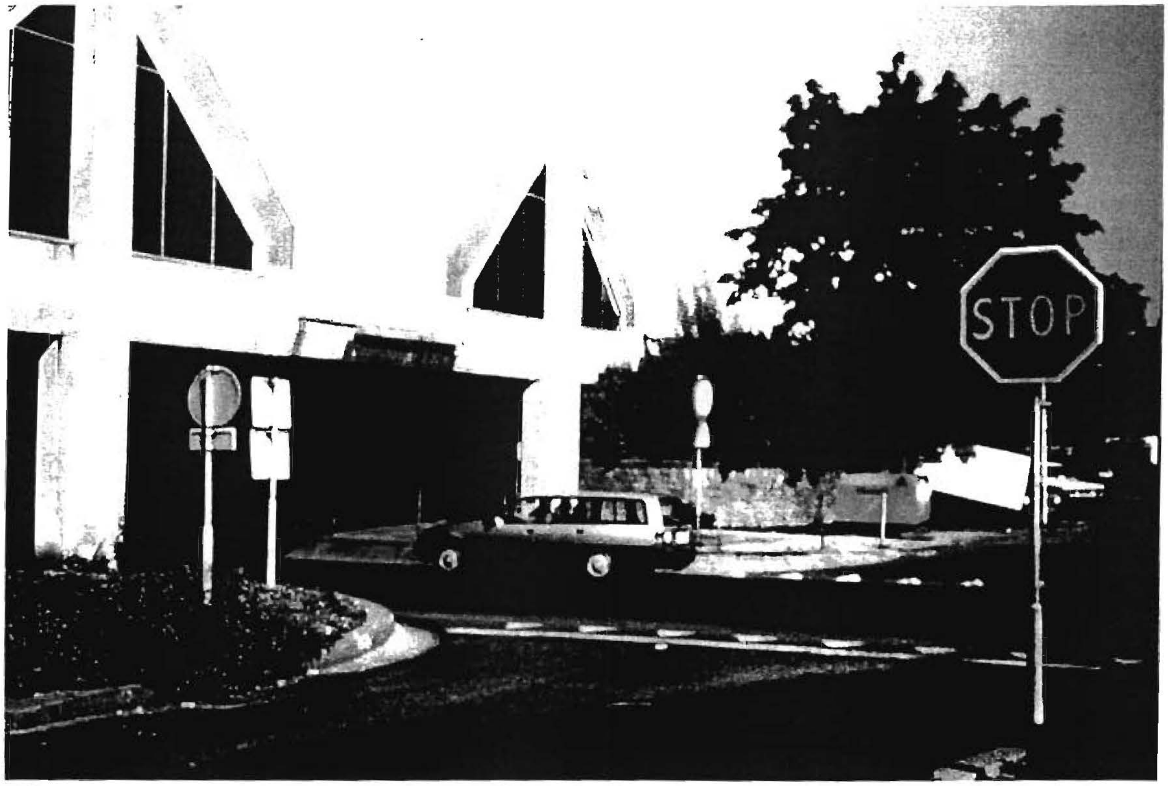

Figure 17: A Plexiglass Element on Bridge As Seen from the Housing Area (Copyright Hans Bendtsen. Road Directorate Denmark Ministry of Transport, Traffic Safety and Environment)

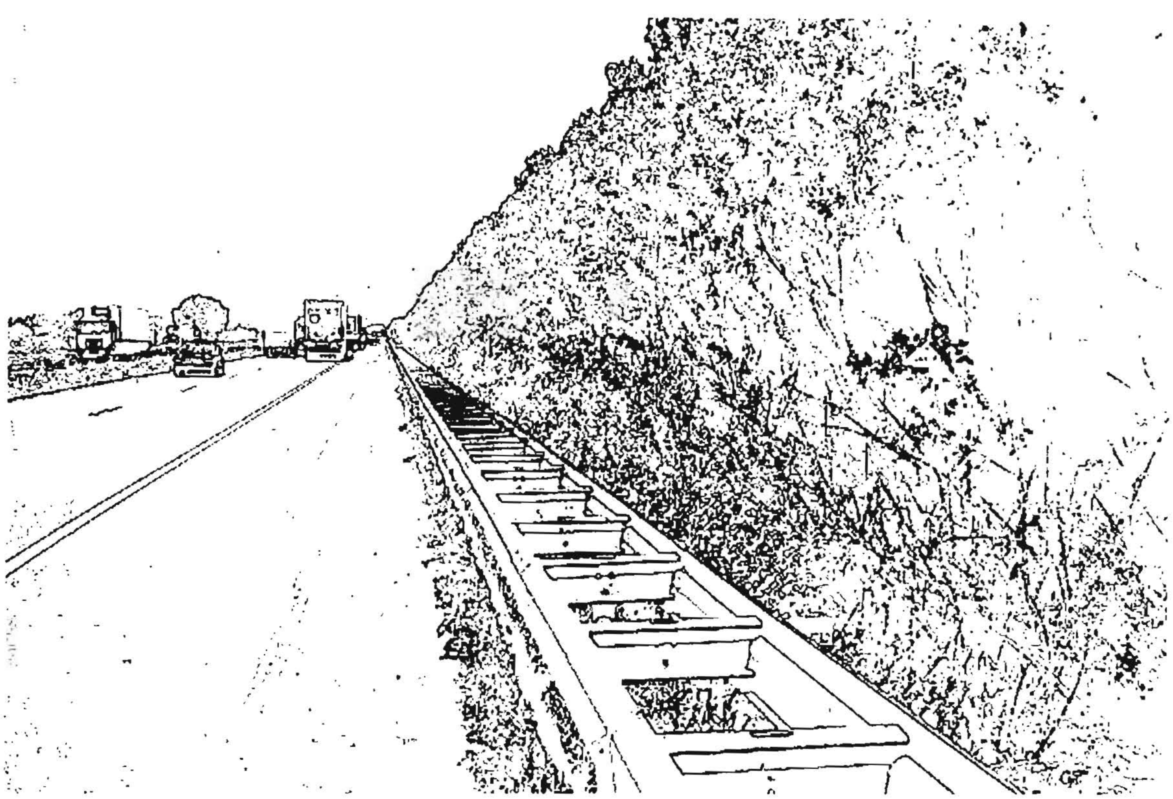
Figure 18: Live Willow Branch Noise Wall

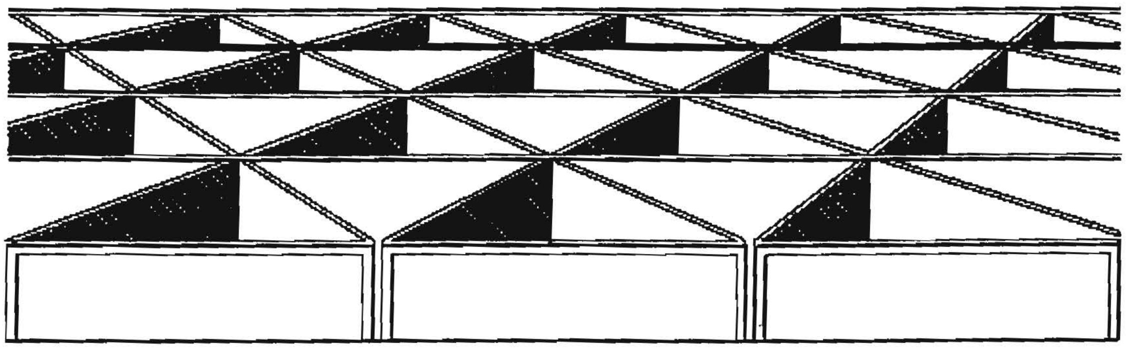

Figure 19: Aluminum Grille Roof Covering the A6B Motorway at Avenue Charles Gider in France

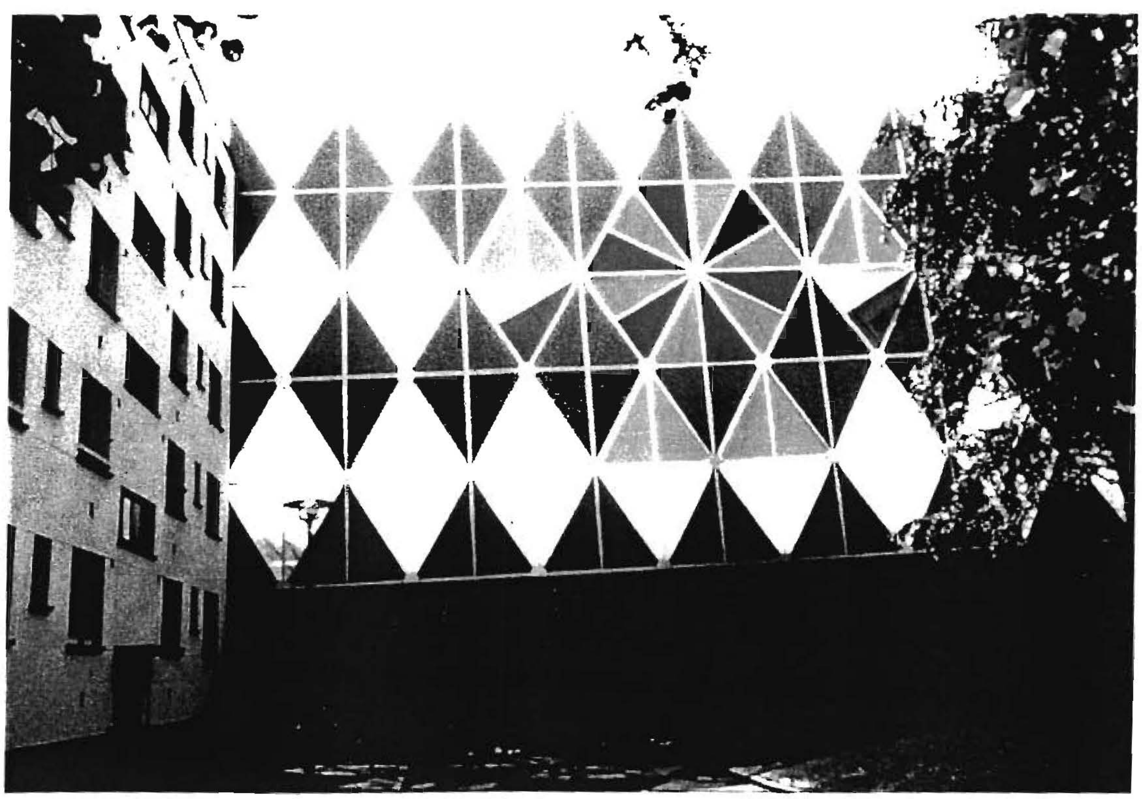

Figure 20: Three-Dimensional Grille Barrier on the Boulevard Peripherique in Paris, France (Copyright Hans Bendtsen. Road Directorate Denmark Ministry of Transport, Traffic Safety and Environment)

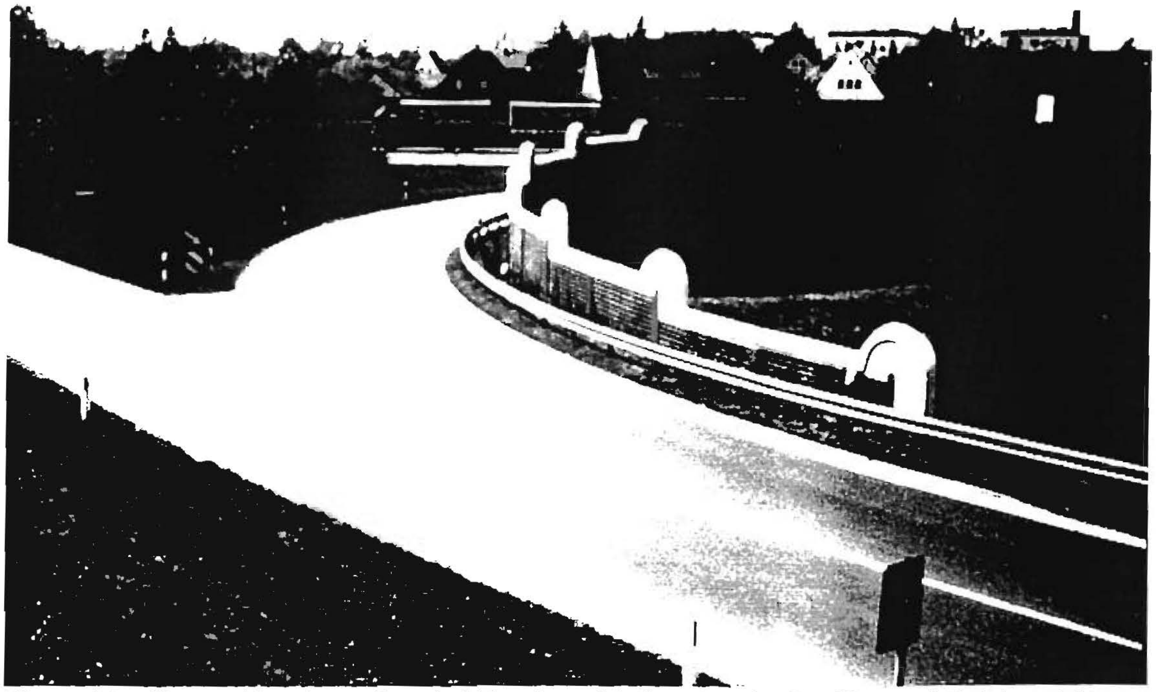

Figure 21: Green Aluminum Paneled Barrier with Red Steel I-Profiles and Bricks with White Coping in Messe-Schnellweg South of Hanover, Germany (Copyright Hans Bendtsen. Road Directorate Denmark Ministry of Transport, Traffic Safety and Environment)

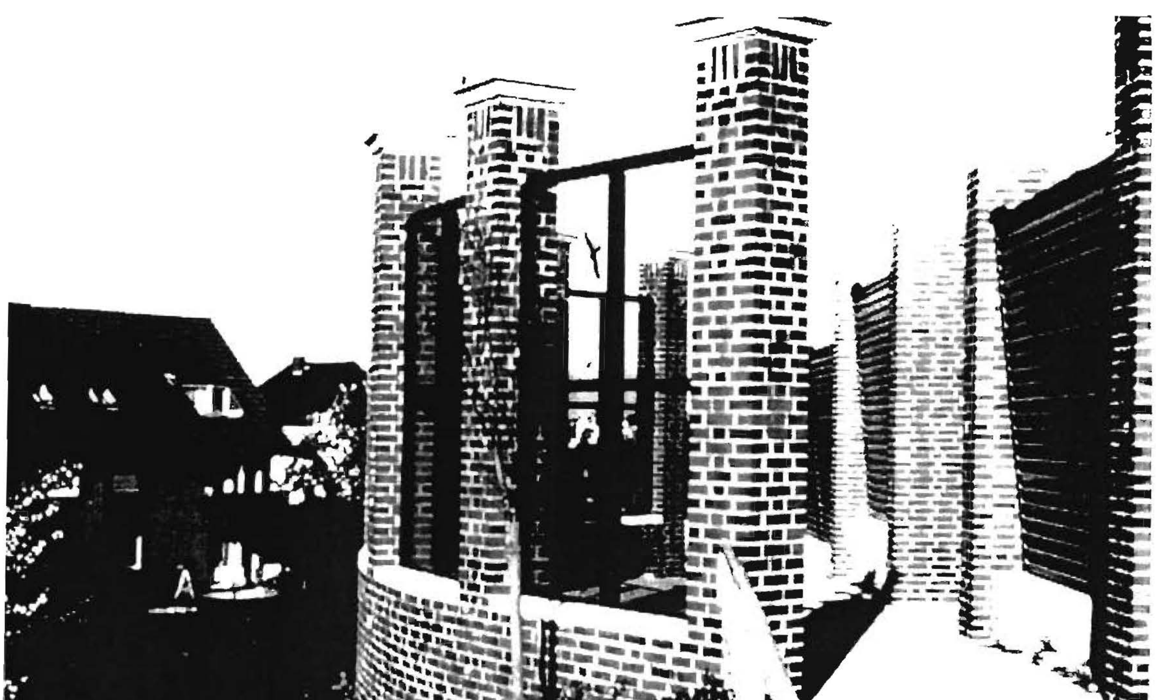

Figure 22: Brick Pillars with Glass "Windows" to Preserve Views and Connection to Street Life in Wunstorf, Germany (Copyright Hans Bendtsen. Road Directorate Denmark Ministry of Transport, Traffic Safety and Environment)

ACOUSTICAL CONSIDERATION IN DESIGN

Noise wall aesthetics is an important factor because of the potential for visual pollution, but acoustical effectiveness must be addressed early in the design process, as well. The primary issue in noise wall design is the attenuation achieved in terms of noise level reduction between the source and the receiver (or path control). Most noise walls have a 12 dBA level of attenuation with 10 dBA being considered acceptable throughout the literature. At 10 dBA attenuation, the loudness of noise at the receiver is reduced by approximately 50% and the acoustical energy by 90% (38). The range of noise wall materials have different performance characteristics or insertion losses that are figured for attenuation. Predicted noise level reduction after a noise wall has been installed must meet minimum insertion loss criteria established by the FHWA (5 dBA ΔIL minimum) and applicable state policies and guidelines. Insertion loss (ΔIL) defined as:

$$\Delta IL = L\ (before) - L\ (after)$$

where *L* (before) is the noise level (in dBA) before a noise wall is installed, and *L* (after) is the noise level after the noise wall is installed.

Since Δ*IL* is a function of diffraction, transmission loss, multiple reflections, shielding attenuation, and ground cover, (36) predicting a noise wall's performance depends upon many site specific factors. Numerical measurements of insertion loss, transmission loss, and sound absorption coefficients or noise reduction coefficients (NRC) may be accomplished whether the sound is transmitted, reflected, or diffracted from the source to the receiver. These concepts have been derived from mathematical models and demonstrated in the computer software shown in Table G. Literature reporting a combination of computer modeling and field evaluation, field testing, and synthesis studies have been useful in guiding the design of noise abatement systems.

Table G: Computer Software for the Analysis and Design of Noise Walls

COMPUTER SOFTWARE		
PROGRAM	**FUNCTION**	**REFERENCE**
BARRIER-X	Computes barrier reflection coefficients	*Analysis and Programs for Assessment of Absorptive and Tilted Barriers. Slutsky and Bertoni(37)*
BCR	Barrier Cost Reduction Program	*The Barrier Cost Reduction Program: A Tool to Reduce Highway Noise Barrier Costs. Anderson, Cuoco , Menge(2*
BOAP	Barrier Overlap Analysis Procedure	*Barrier Overlap Analysis Procedure. Lee, Slutsky Michlove and McColl (24)*
CHINA	An expert system for automated barrier design	*Using Microcomputers in Highway Noise Studies. Cohn, Bowlby and Waller (11)*
CROSECT	Highway Cross Section Analysis	*A Model to Calculate Traffic Noise Levels from Complex Cross Sections. Tobutt and Nelson (39)*
DIGIT-1	Reduces amount of time needed to encode	*Using Microcomputers in Highway Noise Studies. Cohn, Bowlby and Waller (11)*
ENM	Environmental Noise Model	*Wall Journal (29)*
HICNOM	Construction noise program	*Special Noise Barrier Applications. Cohn and Harris (9)*
IMAGE-3	Analysis and design of parallel barriers	*IMAGE-3: Computer-aided Design for Parallel Highway Noise Barriers. Bowlby and Cohn (7)*
IVTI	Interactive Visualization of Traffic Impacts	*Development of an Interactive Visualization Tool for the Effective Presentation of Traffic Impacts to Non-Experts. Prevedous, Bauer and Sykes (32)*
MICRO BRUIT	For prediction of traffic noise and noise barrier efficiency	*New Software for Prediction of Traffic Noise and Noise Barrier Efficiency. Paumier (28)*
MINNOISE and MINNOPT	Minnesota's version with modifications for heavy trucks	Minnesota Department of Transportation
NCAD	Three dimensional plotting	*Special Noise Barrier Applications. Cohn and Harris (9)*
NOISE CAD		
NOISE IV		Colorado Department of Highways
NOISE MAP		
REBAR	Parallel barrier analysis	*Special Noise Barrier Applications. Cohn and Harris (9)*
SNAP	Simplified Noise Analysis Program	*Highway Noise Barriers. Cohn (10)*
SOUND 23		Caltrans
STAMINA 2.0/OPTIMA		FHWA
STAMPLOT	For two-dimentinal plotting	*Special Noise Barrier Applications. Cohn and Harris (9)*
TPBP	Tilted Parallel Barrier Program	*Tilted Parallel Barrier Program: Application and Verification. Lee, Michlove and Slutsky (23)*
TrafficNoiseCAD	Uses Stamina 2.0 and AutoCAD graphics	*TrafficNoiseCAD-True Interactive Graphics for Traffic Noise Analysis and Design. Bowlby, Li, and Wayson (5)*
VUPLOT	Use to plot coordinate data in plan or profile view	*Enhancement of Highway Noise Modeling through Computer Graphics. Cohn, Casson and Bowlby (12)*

From the survey information, minimum acceptable insertion losses ranged from 5 dBA to 10 dBA. Table H shows the insertion loss values reported and the number of responding states that use these criteria.

Table H: Insertion Loss Goals and Corresponding Number of Agency Use

INSERTION LOSS GOALS	
ΔIL (dBA)	NUMBER OF STATES
5 minimum	12
7 minimum - 10 desirable	5
8 to 10	3
13 +	1

Diffraction

States typically used the FHWA computer program to analyze the amount of acoustical energy loss encountered when sound rays are required to travel over and around a wall or *diffraction*. From the survey, the most frequently used solution to minimize diffraction at noise wall ends was overlapping, as shown in Figure 23. However, an overlap of the ends of the noise wall at the mainlane and access ramp will produce multiple reflections between the noise walls that will eventually propagate into the adjacent vicinity (25). The multiple reflections caused by overlapping noise walls can be reduced by using an absorbent surface at the overlap as reported by the Ontario Ministry of Transportation. Figure 23 shows an example of this treatment also. The overlap distance has been manipulated in an attempt to minimize noise propagation. Indiana recommended an overlap distance of two times the opening width. Oregon recommended three times the opening width and Wisconsin reported four times.

Other effective solutions were wrap-around noise walls or wing walls and mini-barriers. Alaska has used the overlap method and mini-barriers. A few noted that there were no openings in their noise walls or walls were not constructed on unlimited access highways.

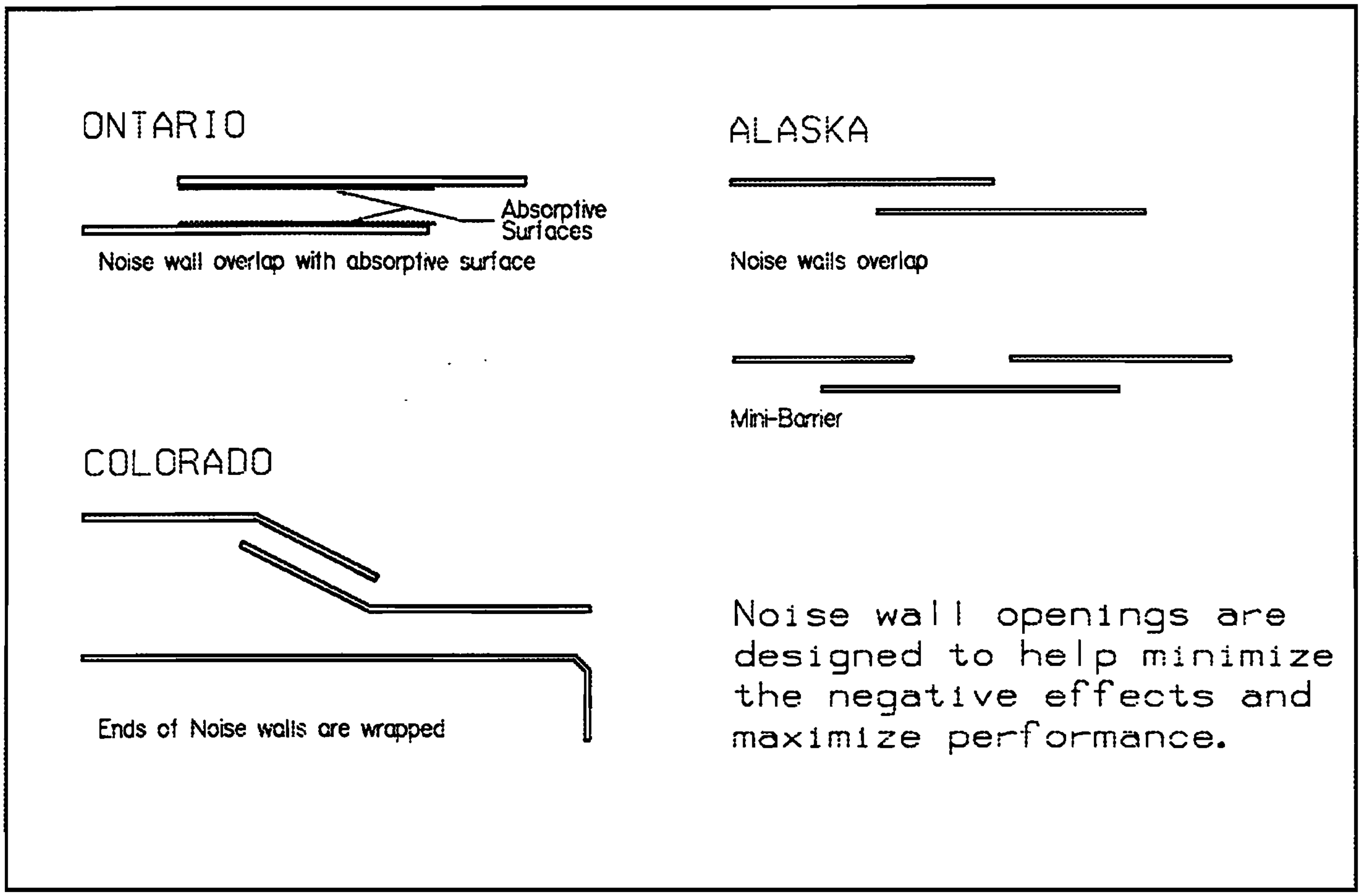

Figure 23: Design Applications to Minimize Diffraction and Multiple Reflections

Special design applications that required additional right-of-way often deterred designers from pursuing these options. Wrap around noise walls create a situation that often requires using private property for wall placement. Transportation agencies have allowed wall placement if an agreement is reached between the property owner and agency for construction and maintenance. According to TxDOT's current policy, noise wall wraps should be placed on "approved city or county property if easement and maintenance agreement can be implemented." Design solutions often conflict with safety parameters such as overlapping noise walls cause line of sight problems for maneuvering.

Highways with frontage road designs present unique acoustical problems as well. Most noise walls were placed between the mainlane and the frontage road (with little effort or need to provide mitigation of frontage road traffic noise) or at the right-of-way boundary. Placement at the right-of-way boundary created openings in the noise wall due to access to the frontage road. The acoustical benefits of this design were reportedly less than noise wall placement between the mainlane and frontage road.

Transmission loss

One element of a noise wall's effectiveness is gauged by the amount of sound able to *transmit* or pass through the wall to the receiver. Sound transmission loss (STL) minimum requirements were not reported by all of the responding states. Generally, for highway noise sources, the transmission loss of common wall materials increases with the weight of the material. Missouri's standards require noise wall materials to weigh at least 1.59 kilograms per 0.093 meters (3.5 lbs/sf) and provide at least 5 dBA reduction. Arizona's policy does not allow holes in the walls and required a material density of 1.82 kilograms per 0.093 meters (4.0 lbs/sf). Ten of the twelve states that reported an STL value required an overall rating of ≥ 20 dBA. Pennsylvania and Nevada reported STL values of ≥ 32 dBA.

Reflection

Many noise walls are designed to perform as reflective walls or to bounce the sound away from the receiver in a direction back to the source. In the case of tilted noise walls, the reflection angle is designed to avoid the receiver. This reflection becomes problematic and can affect wall performance when parallel noise walls exist or when retrofitting a highway facility creates a parallel configuration. The addition of a second reflective wall that is parallel to the existing wall can create multiple reflections that degrade the performance of the existing noise wall (17). This is known as insertion loss degradation. There is controversy among acoustical specialists as to the degree of degradation caused by multiple reflections. Insertion loss degradation is contingent upon several variables that include (6):

- Noise wall height;
- Sound absorbing capacity of the material used;
- Distance between the noise walls;
- Source location between noise walls;
- Receiver height above highway; and
- Receiver distance from closest noise wall.

A study done by Caltrans, on parallel reflective noise wall configurations along Route 99 in Sacramento, recommended maintaining a minimum width/average height ratio of 10:1. This ratio would avoid a significant reduction in performance due to multiple reflections. The study also noted that some site specific conditions may cause this ratio to be exceeded (16). Colorado has tried to place its parallel noise walls at least ninety-one and one-half meters (300 ft) apart, thereby reducing the effect produced by multiple reflections. CDOT has also used a centerline median absorptive noise abatement product, *Durisol®*, to reduce multiple reflections. Ontario has used an absorptive treatment when adequate right-of-way distance cannot be achieved. Wisconsin and Virginia reported the addition of an absorptive treatment on parallel noise wall configurations has become a standard.

Alternate methods of achieving desired acoustical benefits, especially with parallel noise walls, involve the use of a tilted wall. In Europe and a few states, noise walls have been tilted away from the source. Research has proven this to be an effective method of controlling multiple reflections (23). According to the survey responses, the most common angle of noise wall tilt was usually between six and ten degrees. New York DOT used this solution for multiple reflection, instead of an absorptive treatment. Arizona, New Jersey, Washington and Nevada have also used tilted noise walls. Measured noise reduction was reported from Nevada to be 15.2 dBA average attenuation.

A few states felt that the use of a coarsely textured noise wall surface would provide enough additional acoustical benefit that an additional surface treatment was not necessary. Another solution for multiple reflections was to increase the noise wall height. This may prove to be unacceptable to adjacent residents. Noise wall height is usually the variable in design that residents desire minimized.

Overall Noise Wall Effectiveness Ranking

The states were asked to rank the various noise wall types used in their state by acoustical effectiveness. Earth berms were viewed as the most effective noise reduction. Concrete and concrete/earth combination walls were ranked second. Metal, brick or masonry, and wood were rated below concrete and earth. Nevada was the only state to have a proprietary noise abatement system within the top three responses. Seven states gave all noise abatement system types used equal rankings based upon their experiences.

Alternate Solutions to Noise Walls

The participants were asked to provide information on the use of internal or external abatement methods (e.g., sound insulated windows, absorbent panels, etc.) instead of noise walls. 23 CFR 772 describes available options to transportation agencies when mitigation by the insulation of public use or nonprofit institutional structures is the most reasonable and effective method of noise abatement.

Installation of double glazed windows, insulation, and air conditioning for schools and other similar type public and private institutions had been done occasionally. Utah cited the use of glass block to replace windows on the first floor and installing double glazed windows on the second floor. UDOT policy does not provide alternate mitigation techniques for private homes. However, if a noise abatement solution cannot be achieved with a wall, then right-of-way damages may be paid to the affected parties. Florida's policy provided funding as part of right-of-way damages similar to UDOT. Of those responding, 70% have not experienced the use of any external or internal noise abatement of this manner.

PERCEIVED EFFECTIVENESS AND COMMUNITY INVOLVEMENT

The effectiveness of a noise wall can be figured out by actual acoustical measurement and by community opinion or *perceived effectiveness.* When asked if there was a relationship between aesthetics and perceived effectiveness, 15 out of 34 responded positively. Typically, transportation agencies gauge perceived effectiveness through the public involvement process. The traditional methods of public involvement included public hearings, special meetings on noise issues, informational mailings, surveys, and questionnaires.

Questionnaires

Of the states using questionnaires, the majority considered first row development routinely, second row receivers sometimes, and third row receivers rarely. Wisconsin's respondents must live within one hundred fifty-two meters (500 ft) of the proposed noise wall. Uncommonly, Oregon and Utah considered all impacted residents. Most of the transportation agencies reported including a questionnaire during the initial public hearings or meetings. Appendix G includes sample surveys used throughout the country.

Public Hearings and Meetings

The states were asked to describe methods of communicating proposed noise abatement measures to the public. Presentation techniques have improved with the development of computer technology. Tape recordings of current and proposed noise levels along with noise contour maps have been useful in demonstrating proposed abatement to the public. Representative noise wall samples or photographs of existing noise abatement projects have been used. Graphic representations such as sketches, renderings, and plan drawings were typically cited for public hearings and community meetings. However, most of these presentation techniques have remained in a two-dimensional form that does not accurately display the visual presence of most noise walls. Over one-third of the states reported that they had removed or modified a noise wall based upon public **reaction** once the wall was constructed. Problems not conveyed in the public involvement process included negative visual aesthetic effects (e.g., blocked views from street life or scenic features, modified views, etc.), scale of the noise wall, and unattractive surface finishes.

Noise walls that have blocked advertising or restricted business access or views have been removed, modified, or monetary settlements made to impacted parties by Michigan, New York, Nevada, Pennsylvania, Connecticut, Kentucky, and Virginia. Indiana is currently involved in the process of negotiation with affected parties. In contrast, Michigan has experienced opposition to noise wall construction from a local planning board, land conservancy, and non-adjoining property owners even with a majority favor of impacted citizens. New York, Georgia, Ohio, and Pennsylvania have all experienced lawsuits regarding noise walls. In response to litigation, Utah will not build directly in front of a commercial establishment. Arizona completes negotiation before building a noise wall to reduce the potential for post-construction difficulties. The research team found responses that indicated that the public is very interested in receiving noise level reduction but do not necessarily want noise walls as a permanent feature of their backyards. Wisconsin summed up this sentiment with a response of, "You can't win!"

Even with the problems associated with dealing with the public on these projects, most of the agencies felt that active public involvement is vital for successful noise mitigation. Colorado's comments included a lack of public sentiment for impacted residents. Other states, such as Connecticut, cited that the affected residents favor the construction of noise walls, but others view them as a "waste of the taxpayers' money." New York transportation agency has experienced similar sentiment from motorists who believe that noise walls are a waste of money while the surrounding residents do not.

The relationship between cost, aesthetics, and perceived effectiveness has different connotations depending upon which "side of the fence you're on." Utah stated there was a direct relationship between perceived effectiveness and aesthetics. From their experience, if the public perceived the wall to be visually appealing or acceptable, they were less likely to complain about deficient noise reduction. The State of Delaware has realized that aesthetics seemed more important to the residents, but they view acoustical effectiveness and cost with equal and justifiable importance. Many communities with no experience in noise mitigation have discounted cost, effectiveness, and attractiveness as secondary to the ability to mitigate for noise. Once they experienced the social and economic impacts associated with constructing noise walls, their enthusiasm fades.

Information obtained from the community involvement portion of the survey included citizens' preferences for aesthetic treatments. The treatments were related to aesthetic surface treatments (e.g., colors, texture, etc.), architectural details, and landscape enhancements. Problems regarding the aesthetic treatments included increased implementation costs and long-term maintenance costs. There was a hesitancy by some agencies to add landscape improvements to their noise wall construction projects, especially in states with water conservation problems.

According to Farnham's *Noise Barrier Design Guidelines* (13), citizen preference to include landscape plantings evolved from five basic concepts that included the following responses:

- Landscape plantings "soften" the appearance of a wall that is visually appealing to impacted residents;
- Vegetation makes the wall appear to "blend" into the surrounding community;
- Plantings modify the scale of the wall so that it is not "intrusive";
- Landscape enhancements accentuate the strong horizontal or vertical lines present in noise walls; and
- Landscape plantings create focal points or frame views depending upon which side of the wall you're viewing.

Including architectural detailing and establishing color themes were reported by a few states for aesthetic enhancements used in the community involvement process. Colorado has assigned a color scheme and architectural treatment to each corridor in the Denver Metro area. CDOT made efforts to incorporate neighborhood cultural aspects into the residential side of the noise wall in one community. As noted by CDOT, providing visual continuity throughout a project corridor was the most important aesthetic principles to achieve. The Ohio DOT concurred with this recommendation.

The unfortunate discovery or conclusion of this information was the effort taken to communicate the proposed noise abatement measure design to the impacted residents. The quality of visual information presented in an understandable format to the people who will eventually live with these noise walls in their backyards was poor. From the highway side of these projects, few design teams considered the appearance or influence the noise walls' presence will have on the highway environment. If an aesthetic treatment were used on the highway facade, the residential side usually received no aesthetic improvements. Noise wall planning and design for acoustical effectiveness and community aesthetic acceptance should be complete for motorists and property owners throughout the highway corridor.

CONSTRUCTION

Construction-related problems have always been present in the history of highway noise wall construction. This phenomenon is not uncommon to construction projects with stringent tolerances, complex sites constraints, and architectural features not usually constructed in the rights-of-way. Quality control, whether in installation or materials, continues to be a primary problem in comparison to the 1981 NCHRP synthesis. The following table summarizes the most frequently encountered responses from the TTI survey.

Table I: Construction Problems Encountered by Survey Participants

PROBLEMS ENCOUNTERED	STATE
Lack of adequate design details and specifications for new types of walls	Colorado
Lack of knowledge by construction personnel of the physics of sound	Colorado
Lack of knowledge by contractors on noise wall installation	Colorado
Inaccurate soil analysis	Colorado, Connecticut, Virginia
Unforeseen excavation surprises-concrete pieces, boulders, rocks, etc.	Connecticut
Utility location above and below ground	Florida, Indiana, Ontario
Uniformity of concrete color tints or wood stains	Connecticut
Stains in aggregate bleeding to the finished concrete	Michigan
Discoloration around fasteners on wooden walls	Colorado, Connecticut
Foundation settlement or erosion	Florida, Maryland, Michigan, New Jersey, New York, Tennessee
Drainage under walls creating degradation of foundations	Florida, Michigan
Moisture content or quality of wood being consistent with specifications	Colorado, Michigan
Stepping of panels	Maryland
Disagreement with contractors over payments	New Hampshire
Any of the above creating cost overruns	Many states

Wisconsin has resolved many of its construction-related problems by adopting the use of design-build contractors. By using a design-build contractor, noise wall design and construction liability is shifted to the contractor. Foundations seem to give contractors and highway maintenance personnel alike a great deal of difficulty. Florida has resolved some of its foundation problems by using a cast-in-place auger pile. Maryland's Fanwall foundation problems were handled by reconstruction and resetting the panels.

CONCLUSIONS

Since the 1981 NCHRP Synthesis of practice, there has been a steady increase in the public's awareness for environmental issues such as noise abatement. With the implementation of the Intermodal Surface Transportation Efficiency Act in 1992 (ISTEA), transportation agencies are further challenged to provide a *quality* highway system for the public. Path control solutions such as noise wall systems introduce a visually strong element into highway corridors. Therefore, an unsightly noise wall appearance increases the risk of public scrutiny for visual pollution even if the noise attenuation may be acceptable.

Transportation agencies have used minimal resources to gauge public perception of proposed noise abatement projects. Through research and development efforts, transportation agencies should pursue the use of better communication tools to present more realistic graphical or computer generated models (with audio) and the capability to select various noise wall materials in an interactive environment. The computer technology exists but has not been used to measure public perception or design noise walls.

Related to noise wall material selection and public preference is the number of available systems approved by most transportation agencies. Most agencies have a limited palette of approved materials for noise wall material selection that skews the agencies' perception of public consensus. In the research team's opinion, transportation agencies would gain a better understanding for acceptable design if the public were given a wider range of selection options that included color, shape, and architectural features. European counterparts have developed comprehensive noise wall programs, included residential concerns in the design process, and introduced aesthetic amenities and vegetation on a broader scale than in the United States. The apparent success of their noise abatement system management and planning done on a corridor basis should prevail as a guide for American transportation agencies to follow.

Additional innovative, cost-effective foundation and noise wall designs and specifications are necessary to meet the surveyed agencies needs. From the survey information, several projects were noted to have been postponed, some indefinitely, or stopped due to insufficient funding. In contrast, the need to construct Type I and Type II noise walls has grown since the early eighties and will continue to do so. Testing and approval programs need to be developed for new products, innovative noise wall designs, and existing proprietary noise abatement systems. Collectively, transportation agencies, private industry, and institutional research programs should work together to advance the available knowledge in noise research.

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APPENDIX A

SURVEY OF PRACTICE

HIGHWAY NOISE ABATEMENT SURVEY OF PRACTICE

I. BARRIER MATERIAL AND TYPE

A. DATA - Please provide approximate figures

MATERIAL	LINEAR FT. (Statewide)	PERCENTAGE OF ALL BARRIERS IN STATE
1. Concrete		
2. Wood		
3. Metal		
4. Berm		
5. Concrete/Berm		
6. Wood/Berm		
7. Metal/Berm		
8. Transparent Material		
9. Patented Systems		
10. Other (specify)		

B. QUESTIONS

1. Define the Criteria used in material selection.
2. Rank order the listing in A. above in terms of community acceptance and selection.
3. (If one is used) Describe your multi-disciplinary team used in material selection.
4. How is the community consulted in the material selection process?
5. Are barrier types and materials custom-designed or included in standard specifications?
6. Describe and evaluate any experience with patented systems.
7. What methods and types of concrete finishes have been used?
8. Describe any experience of barrier-on-structure.
9. Describe any experience with absorptive treatments?
10. Describe any experiences with sound-masking in lieu of noise barriers (i.e. plant walls).

II. COSTS

A. DATA - Please provide approximate figures (for each barrier type or a representative sample).

	$/FT.^{2}	PERCENTAGE
1. Engineering		
2. Materials		
3. Foundation		
4. Labor		
5. Drainage		
6. Landscaping		
7. Additional right-of-way acquisition		
8. Other		

B. QUESTIONS

1. Please provide any average annual maintenance cost figures that you have.
2. How have bid costs compared to actual construction costs?
3. Benefit/Cost Analysis (If one is used)
   a. Fully define inputs considered
   b. Does FHWA (Div.) require B/C justification for projects?
4. Define criteria used when evaluating cost/FT² of wall, cost/receiver protected, etc. (i.e., when is a wall too expensive?).
5. What is the local government's role in funding noise abatement projects?
6. Describe any experience with community cost-sharing.
7. If absorptive treatment has been used, what % has it added to in-place costs?
8. Have the in-place costs for patented barrier systems been relatively consistent with manufacturers?
9. Noise barriers at airport facilities - is there FHWA/FAA cooperation? cost sharing? coordination of two different modeling techniques?

III. DESIGN DETAILS

A. DATA - Please provide any design detail standards or guidelines, if available. Also, provide examples of barrier design plans from a representative sample of projects.

B. QUESTIONS

1. At what stage in the process is a firm decision made to construct a barrier?
2. Does the community have any input into design details?
3. What is your solution when a minority of adjacent property owners want a noise wall? How do you reach a consensus? Do renters have a voice in the decision-making process?
4. What procedures are used, if any, to discourage the favoring of a patented barrier system?
5. What criteria are used in height and length determination?
6. Do highway planners view noise mitigation by the corridor (adjacent land use) when determining where noise walls should be placed? or do planners respond when new similar development occurs?
7. Define, if applicable, criteria for
   a. seismic
   b. post imbedment
   c. wind load (is AASHTO sign spec used?)
8. Describe any special designs used to reduce reflections.

IV. ACOUSTICAL DESIGN

A. DATA - Please provide any formal or informal department specifications for:

1. ΔIL - Insertion loss
2. STL - Sound Transmission Loss
3. Barrier justification (ΔL_{10} or ΔL_{eq} with project)

B. QUESTIONS

1. Is noise pollution level (NPL), Noise Abatement Criteria (NAC), or any other measure of intrusiveness, ever used?
2. What prediction model is used in barrier analysis? (STAMINA 2.0, SNAP, OPTIMA,etc.) Is road surface noise introduced into the traffic noise prediction model?
3. Does your model use the national reference energy mean emission level (L_{OEi}), or have you generated your own?
4. What source height is used in barrier analysis?
5. Do you always design for the highest or most critical receptors?
6. Rank in order the various barrier types utilized in your state in terms of overall acoustical effectiveness.
7. Describe any solutions to the problem of diffraction around required openings.
8. Describe solutions, if applicable, to frontage road design.
   a. Where are the noise barriers placed?
   b. How effective are the barriers?
9. Describe your experiences with barriers on both sides of a highway.
   a. Have multiple reflections been a problem?
   b. Have you experienced insertion loss degradation with parallel barriers?
   c. How has reflection been handled?
   d. Have absorptive materials been used as a solution on one or both sides? if so, what type and how effective was that solution?
10. Describe experiences, if any, using internal or external noise abatement materials (i.e., sound insulated windows, absorbent panels, etc.) on existing structures in lieu of noise barriers.

V. MEASURED NOISE REDUCTION

A. DATA - For those barriers where such date exists, please provide the calculated IL and the measured IL. Attempt to explain those situations where significant differences exist.

B. QUESTIONS
1. Fully describe the procedures used in Before/After (IL) measurement analysis, including utilized, and descriptor (L_{10} or L_{eq}).
2. Where behind the barrier is the After microphone placed?
3. During IL analysis how are changes in traffic mix an volume, ground cover, and weather accounted for?

VI. PERCEIVED EFFECTIVENESS

A. DATA - Please provide samples of social survey forms and questionnaires that have been used on barrier projects in your state. Also provide summarized tabulations of responses where they exist.

B. QUESTIONS
1. Are Before/After surveys usually performed in your state?
2. What methods of survey have been used? (i.e., questionnaire, door-to-door telephone, mailing, etc.)
3. How deep into the community does the social survey data base usually extend? (1st row, 2nd row, etc.)
4. Rank the barrier types in terms of community acceptance.
5. Have your surveys sighted specific correlations between perceived effectiveness and -
   a. Before L_{10} or L_{eq}
   b. IL
   c. aesthetics/landscaping
   d. barrier type/material
   e. initiation of community involvement process
   f. Other
6. Has a lawsuit ever resulted from a barrier implementation?
7. What special problems have been encountered in social surveying?
8. Do you have any documented driver reaction?
9. Does the public consider the barriers necessary?
   a. Cost v. perceived effectiveness
   b. Cost v. aesthetics
   c. Perceived effectiveness v. aesthetics

VII. COMMUNITY INVOLVEMENT

QUESTIONS
1. In general, is the public interested in noise abatement?
2. At what stage in the project life does community involvement begin?
3. At what point does community involvement benefit the project? early in the process or later?
4. Describe the techniques used in community involvement concerning barriers.
5. If formal or informal meetings are held, how well are they attended and what types of aids are used (sketches, renderings, slides, computer simulations, etc)?
6. To what extent does community involvement input affect decision-making or barriers?
7. Have any completed barriers ever been taken down? (If so, why?)
8. Have you had problems resulting from barriers blocking advertising?
9. Fully describe the process for Type II project initiation and implementation.

VIII. CONSTRUCTION

QUESTIONS
1. What problems and solutions have been encountered in barrier construction and/or contractor relations?
2. Have you had any particular foundation problems?
3. For Type II projects, what is the typical construction period?
4. If a *No Type II* policy exists, how do you implement this? What is public reaction to this policy?
5. For Type I projects, are barriers installed early for construction noise abatement?
6. For Type I projects, are barriers ever let as separate contracts?
7. Have barriers ever been constructed not contiguous to existing right-of-way? Describe.
8. How is staged construction handled? are the barriers constructed with the beginning phase or at completion?

IX. MAINTENANCE

A. DATA - Please provide any quantitative information available comparing maintenance costs for the various barrier types.

B. QUESTIONS

1. Describe the typical maintenance problems and solutions that have been encountered.
2. Is the maintenance staff consulted prior to or during barrier design?
3. Are ROW fences used behind barriers? have these created problems?
4. Is property behind the barrier given to the adjacent landowners to maintain?
5. Have you solicited the assistance of community civic organizations in maintaining a portion of the barrier and adjacent corridor?
6. To what extent have these been problems?
   a. graffiti
   b. litter accumulation
   c. snow removal or storage
   d. mowing
   e. paint removal (sand blasting particulates)
7. Describe any experience with vehicle impact.
8. Describe access points for maintenance operations.

X. PRIORITY FOR TYPE II PROJECTS

QUESTIONS

1. Fully describe and define your state's priority rating system.
   If one exists, include all input parameters.
2. Is the system responsive to:
   a. individual or group complaints
   b. local government influences
   c. political pressure of any kind
3. Is "number of complaints" a valid input parameter?
4. How often is the system updated?
5. Has the public ever argued, formally or informally, concerning the system or rating?
6. Has the system or rating ever been involved in litigation?

XI. AESTHETICS

A. DATA - Where it exists, please provide cost data for aesthetic treatment by barrier project and type. Also provide typical landscaping plans.

B. QUESTIONS

1. Rank the order of the various barrier types concerning their aesthetic acceptability.
2. Describe the process used to satisfy the public concerning aesthetics.
3. Are landscape architects and/or other design professionals involved in the aesthetic treatment design?
4. What is the correlation between aesthetics and
   a. perceived effectiveness
   b. acoustic effectiveness
5. Describe specific media reaction to the aesthetic impact of the barrier.
6. Describe (and provide pictures of) any experiences with graphics, murals, or planter designs on barriers.
7. Have there been any reports of driver distractions?
8. Is there a concerted effort to design with aesthetics as an important element incorporating art, architecture, and local or regional culture? a continuity of materials or style?

XII. SAFETY

QUESTIONS

1. Describe any safety problems encountered.
2. Describe all safety features routinely designed into barrier projects.
3. Is sight distance ever a problem in barrier placement?
4. Describe access points for fire and safety vehicles.
5. What kind of shielding is provided inside the 30' clear zone?
6. Has the "breakaway" concept ever been used in lieu of guardrails?
7. Is "tunnel effect" ever a problem for drivers?
8. Have there been any vandalism problems besides graffiti?
9. Has vandalism been a problem where barriers have reduced visibility or police access? is the community concerned about security behind the barriers?

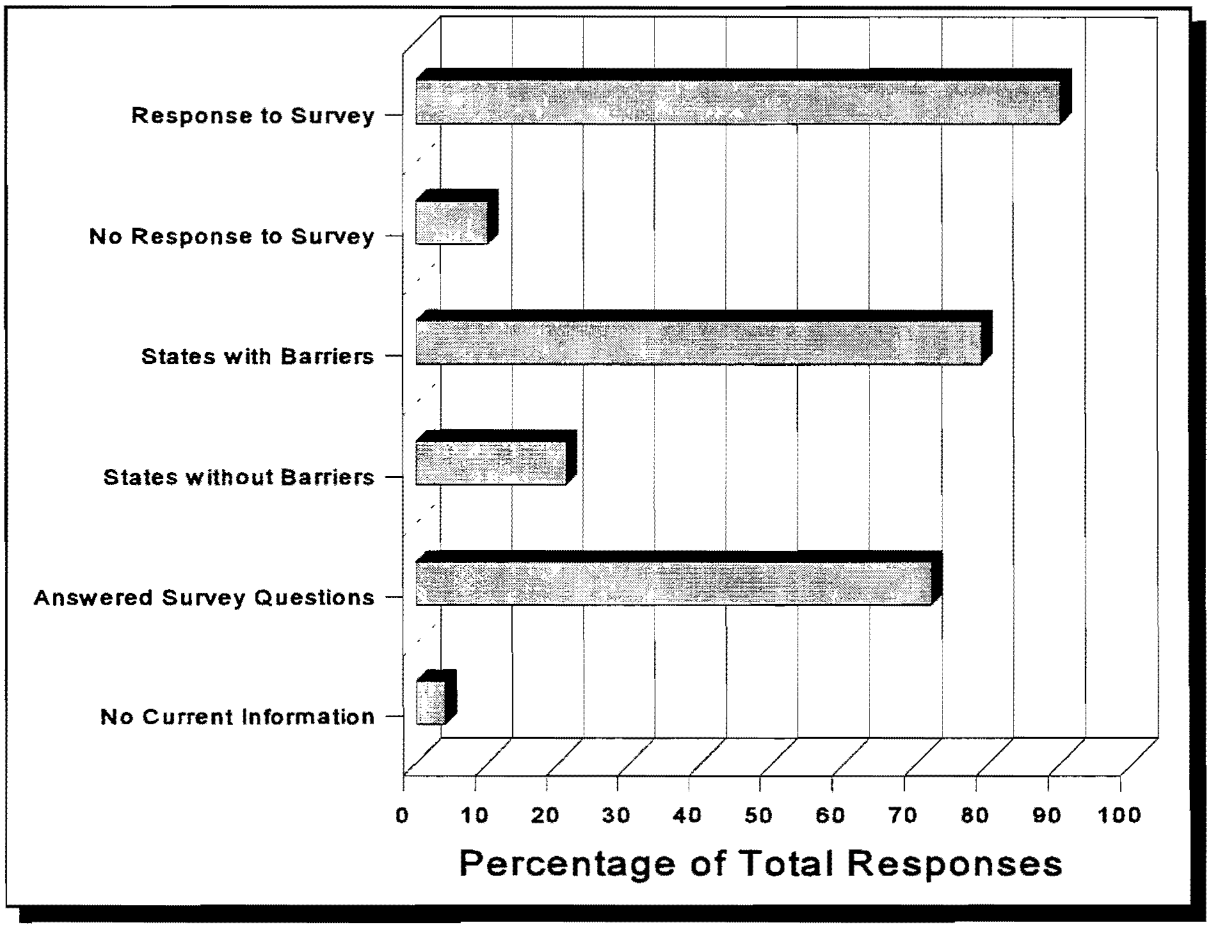
APPENDIX B

NOISE ABATEMENT SURVEY OF PRACTICE RESPONSES

SURVEY PARTICIPANTS

MATERIALS BY STATE

NOISE ABATEMENT SURVEY OF PRACTICE RESPONSES



COMPARISON OF STATES WITH MOST NOISE WALLS, 1981 and 1994

STATES WITH MOST LINEAR METERS OF NOISE WALLS			
STATE	**1981* LINEAR METERS**	**STATE**	**1994 LINEAR METERS**
CALIFORNIA	101,009	CALIFORNIA	391,166**
MINNESOTA	56,969	KENTUCKY	120,052
COLORADO	28,529	MINNESOTA	119,462
VIRGINIA	19,599	NEW JERSEY	100,600
OREGON	15,269	VIRGINIA	76,108
ARIZONA	15,154	NEW YORK	73,057
WASHINGTON	8,359	COLORADO	71,805
MASSACHUSETTS	8,068	PENNSYLVANIA	71,701
CONNECTICUT	6,541	MICHIGAN	60,535

Source: **Highway Noise Barriers(10)*
**1989

STATE	DESCRIPTION	METERS	PERCENTAGE	COST($/SF)
Alabama	No Barriers			
Alaska	Wood Berm		99.90 0.10	10.00
Arizona	Concrete Berm Concrete/Berm Metal/Berm	11,409 14,030 6,609 160	35.00 44.00 20.50 0.50	
Arkansas	2 Barriers, built 1970's, no information			
California	No Response to Survey			
Colorado	Cast-in-place Wood Metal Berm Concrete/Berm Wood/Berm *Durisol*® Block Precast Berm/Wood/Metal Wood/Metal Wood/Block Wood/Concrete	390 39,523 398 1669 5390 6302 189 968 1674 4768 6410 3266 857	0.50 54.80 0.60 2.30 7.50 8.80 0.30 1.30 2.30 6.60 9.30 4.50 1.20	
Connecticut	Concrete Wood Concrete/Berm Wood/Berm Masonry Block		1.00 95.00 2.00 1.00 1.00	9.00 - 11.00
Delaware	Metal Berm	305 610	33.00 67.00	
Florida	Concrete Metal Berm Proprietary System	34,339 90 410 4027	96.00 2.00 2.00 9.00	
Georgia	Wood Metal/Berm		75.00 25.00	
Hawaii	No Response to Survey			
Idaho	No Barriers			
Illinois	No Response to Survey			
Indiana	Wood Proprietary System	5490		13.50 - 24.50
Iowa	Concrete Wood Metal Berm Concrete/Berm Wood/Berm	1068 305 2959 1891 244 214	16.00 5.00 44.00 28.00 4.00 3.00	8.00 - 15.00
Kansas	No Barriers			
Kentucky	Concrete Metal Brick/Masonry	74,844 20,107 25,061	62.00 17.00 21.00	

STATE	DESCRIPTION	METERS	PERCENTAGE	COST ($/SF)
Louisiana	Concrete	1525	17.20	
	Wood	915	10.30	
	Metal	2135	24.00	
	Berm	915	10.30	
	Concrete/Berm	1525	17.20	
	Plastic	1830	21.00	
Maine	Berm 1975, none since			
Maryland	Concrete	11,459	23.70	
	Wood	3303	6.80	
	Berm	946	2.00	
	Concrete/Berm	885	1.80	
	Wood/Berm	763	1.60	
	Metal/Berm	458	0.90	
	Transparent	133	0.30	
	Proprietary System (Conc..)	29,375	60.70	
	GFRC	1050	2.20	
Massachusetts	Post and Panel			
	Wood			
	Concrete/Berm - Fanwall	4053		
	Wood/Berm	3111		
	Transparent - Lexan	488		
	Steel/Berm			
Michigan	Concrete			
	Precast	26.30		
	Cast-in-place	1.90		
	Block	14.20		
	Wood	2.40		
	Composite			
	Glue laminated			
	Post & Plank			
	Berm	4.50		
	Concrete Block/Berm	4.50		
	Metal/Berm	0.90		
	Brick	13.60		
	Brick/Berm	1.50		
	Brick/Concrete	13.60		
	Brick/Concrete Block	2.60		
	Concrete/Metal	5.00		
	Concrete	1.90		
	Block/Wood/Berm/Deck-	4.60		
	Concrete/Earth	1.60		
		1.00		
Minnesota	No Information			
Mississippi	No Barriers			
Missouri	Precast Concrete	1024	59.21	13.89
	Wood	264	15.28	6.69
	Wood on Retaining Wall	441	25.51	17.50
Montana	No Barriers			
Nebraska	Wood	444	75.00	
	Proprietary- *Durisol®*	150	25.00	
Nevada	Block	12,139	80.00	
	Metal	1229	8.00	
	Berm	720	4.00	
	Proprietary-Soundtrap	305	2.00	
	Planks filled with recycled tire rubber	1016	6.00	

STATE	DESCRIPTION	METERS	PERCENTAGE	COST ($/SF)
New Hampshire	Berm Proprietary - Evergreen Wall	1281 519	70.00 30.00	
New Jersey	Concrete Wood Metal Berm Concrete/Berm Proprietary -Fanwall	80,627 11,201 2265 641 1159 4708	60.00 20.00 5.00 5.00 5.00 5.00	
New Mexico	Concrete	6100	100.00	
New York	Concrete Wood Berm Concrete/Berm Wood/Berm Proprietary -Fanwall Plywood	30,269 19,113 7265 3123 11,476 1470 341	41.00 26.00 10.00 4.00 16.00 2.00 1.00	
North Carolina	Concrete Precast & Post and Panel Masonry Wood	22,546		
North Dakota	No Barriers			
Ohio	Concrete Wood Metal Metal/Berm Wood/Fiberglass	24,237 8266 10,712 244 805	55.00 19.00 24.00 0.50 1.50	9.00 - 11.00
Oklahoma	No Information			
Oregon	No Information			
Pennsylvania	Concrete Wood Metal Berm	61,905 2143 712 6933	86.00 3.00 1.00 10.00	
Rhode Island	No Barriers			
South Carolina	Metal Metal/Berm	4758 4575	51.00 49.00	
South Dakota	No Barriers			
Tennessee	Concrete Metal Berm	19,825 8235 Negligible	71.00 29.00	
Texas	No Response to Survey			
Utah	Trees Concrete Berm Concrete/Berm Stucco Masonry Block Depressed Highway Jersey Barrier	420 26,513 752 244 1054 271 5948 946	1.00 73.00 2.00 1.00 4.00 16.00 3.00	

STATE	DESCRIPTION	METERS	PERCENTAGE	COST ($/SF)
Vermont	No Barriers			
Virginia	Concrete	61,927	81.00	
	Wood	3426	5.00	
	Metal	4155	5.00	
	Concrete/Berm	1506	2.00	
	Wood/Berm	1933	3.00	
	Metal/Berm	3160	4.00	
Washington	Concrete	23,251	47.00	12.00 @ R.O.W.
	Wood	805	<2.00	15.00 @ Shoulder
	Masonry Block	1288	<3.00	
	Berm	16,748	34.00	
	Concrete/Berm	3704	7.00	
	Masonry Block/Berm	1127	<3.00	
	Proprietary	4831	(10.00)	
	Other	227		
West Virginia	Wood Post and Plank	146	100.00	17.00 $132,820 total
Wisconsin	Concrete	6279	37.00	
	Wood	8742	51.00	
	Metal	1587	9.00	
	Concrete/Metal	476	3.00	
Wyoming	No Barriers			
Puerto Rico	No Response to Survey			
Ontario, Canada	Concrete	4234	4.00	
	Wood	711	0.60	
	Metal	51,234	48.30	
	Berm	850	0.80	
	Proprietary - *Durisol*®	47,256	44.60	
	Absorptive Steel	1756	1.70	

MATERIAL	LINEAR METERS	LINEAR FEET	MILES
CONCRETE	345,022.67	1,131,221.90	214.25
Cast-in-Place	1,233.54	5,028.00	0.95
Precast	18,243.58	59,815.00	11.33
Post & Panel			
WOOD	79,412.85	260,370.00	49.31
Plywood	340.99	1,118.00	0.21
Composite	113.77	373.00	0.07
Glue Laminated	288.22	944.00	0.18
Post & Plank	1,187.37	3,893.00	0.74
METAL	91,019.93	298,426.00	56.52
Absorptive Steel	1,755.58	5,756.00	1,09
BERM	138,759.10	127,079.00	24.07
CONCRETE/BERM	18,007.20	59,040.00	11.18
WOOD/BERM	20,687.24	67,827.00	12.85
METAL/BERM	3,777.12	12,384.00	2.34
TRANSPARENT	620.98	2,036.00	0.39
PROPRIETARY	4,051.01	13,202.00	2.50
Concrete	29,375.16	96,312.00	18.24
Durisol®	47,595.25	156,050.00	29.55
GFRC	1,050.12	3,443.00	0.65
Fanwall	1,470.10	4,820.00	0.91
SOUNDTRAP®	305.00	1,000.00	0.19
OTHER			
Block	23,960.50	70,559.00	13.36
Masonry Block	270.84	888.00	0.17
Brick	8,030.35	26,329.00	4.99
Brick/Masonry	25,060.78	82,166.50	15.56
Brick/Berm	879.93	2,885.00	0.55
Brick/Concrete	8,050.78	26,396.00	5.00
Brick/Concrete Block	1,536.90	5,039.00	0.95

MATERIAL	LINEAR METERS	LINEAR FEET	MILES
Brick/Wood	2,960.03	9,705.00	1.84
Berm/Wood/Metal	4,767.76	15,632.00	2.96
Wood/Metal	6,410.19	21,017.00	3.98
Wood/Block	3,266.25	10,709.00	2.03
Wood/Concrete	857.36	2,811.00	0.53
Concrete Block/Berm	2,595.55	8,510.00	1.61
Concrete/Concrete Block	1,091.29	3,578.00	0.68
Concrete/Metal	2,691.02	8,823.00	1.67
Block/Wood/Berm/Deck-Concrete/Earth	567.61	1,861.00	0.35
Planks Filled with Recycled Tire Rubber	1,018.09	3,330.00	0.63
Trees	419.99	1,377.00	0.26
Depressed Highway	5,947.50	19,500.00	3.96
Stucco	1,053.78	3,455.00	0.65
Jersey Barrier on Fill	945.50	3,100.00	0.59
Wood on Retaining Wall	441.03	1,446.00	0.27
TOTALS	**804,729.78**	**2,638,458.30**	**499.71**

APPENDIX C

23 CFR 772
TITLE 23 CODE OF FEDERAL REGULATIONS
PART 772

SUBCHAPTER H - RIGHT-OF-WAY AND ENVIRONMENT

PART 772 - PROCEDURES FOR ABATEMENT OF HIGHWAY TRAFFIC NOISE AND CONSTRUCTION NOISE

Authority: 23 U.S.C. 109(h), 109(i); 42 U.S.C. 4331, 4332; 49 CFR 1.48(b).

Source: 47 FR 29654, July 8, 1982; 47 FR 33956, Aug. 5, 1982, unless otherwise noted.

Sec. 772.1 Purpose.

To provide procedures for noise studies and noise abatement measures to help protect the public health and welfare, to supply noise abatement criteria, and to establish requirements for information to be given to local officials for use in the planning and design of highways approved pursuant to Title 23, United States Code (U.S.C.).

Sec. 772.3 Noise standards.

The highway traffic noise prediction requirements, noise analyses, noise abatement criteria, and requirements for informing local officials in this regulation constitute the noise standards mandated by 23 U.S.C. 109(i). All highway projects which are developed in conformance with this regulation shall be deemed to be in conformance with the Federal Highway Administration (FHWA) noise standards.

Sec. 772.5 Definitions.

(a) Design year. The future year used to estimate the probable traffic volume for which a highway is designed. A time, 10 to 20 years, from the start of construction is usually used.

(b) Existing noise levels. The noise, resulting from the natural and mechanical sources and human activity, considered to be usually present in a particular area.

(c) L_{10}. The sound level that is exceeded 10 percent of the time (the 90th percentile) for the period under consideration.

(d) $L_{10}(h)$. The hourly value of L_{10}.

(e) Leq - the equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same time period.

(f) Leq(h). The hourly value of Leq.

(g) Traffic noise impacts. Impacts which occur when the predicted traffic noise levels approach or exceed the noise abatement criteria (Table 1), or when the predicted traffic noise levels substantially exceed the existing noise levels.

(h) Type I projects. A proposed Federal or Federal-aid highway project for the construction of a highway on new location or the physical alteration of an existing highway which significantly changes either the horizonal or vertical alignment or increases the number of through-traffic lanes.

(i) Type II projects. A proposed Federal or Federal-aid highway project for noise abatement on an existing highway.

Sec. 772.7 Applicability.

(a) Type I projects. This regulation applies to all Type I projects unless it is specifically indicated that a section applies only to Type II projects.

(b) Type II projects. The development and implementation of Type II projects are not mandatory requirements of 23 U.S.C. 109(i) and are, therefore, not required by this regulation. When Type II projects are proposed for Federal-aid highway participation at the option of the highway agency, the provisions of Secs. 772.9(c), 772.13, and 772.19 of this regulation shall apply.

Sec. 772.9 Analysis of traffic noise impacts and abatement measures.

(a) The highway agency shall determine and analyze expected traffic noise impacts and alternative noise abatement measures to mitigate these impacts, giving weight to the benefits and cost of abatement, and to the overall social, economic and environmental effects.

(b) The traffic noise analysis shall include the following for each alternative under detailed study:

(1) Identification of existing activities, developed lands, and undeveloped lands for which development is planned, designed and programmed, which may be affected by noise from the highway;

(2) Prediction of traffic noise levels;

(3) Determination of existing noise levels;

(4) Determination of traffic noise impacts; and

(5) Examination and evaluation of alternative noise abatement measures for reducing or eliminating the noise impacts.

(c) Highway agencies proposing to use Federal-aid highway funds for Type II projects shall perform a noise analysis of sufficient scope to provide information needed to make the determination required by Sec. 772.13(a) of this chapter.

Sec. 772.11 Noise abatement.

(a) In determining and abating traffic noise impacts, primary consideration is to be given to exterior areas. Abatement will usually be necessary only where frequent human use occurs and a lowered noise level would be of benefit.

(b) In those situations where there are no exterior activities to be affected by the traffic noise, or where the exterior activities are far from or physically shielded from the roadway in a manner that prevents an impact on exterior activities, the interior criterion shall be used as the basis of determining noise impacts.

(c) If a noise impact is identified, the abatement measures listed in Sec. 772.13(c) of this chapter must be considered.

(d) When noise abatement measures are being considered, every reasonable effort shall be made to obtain substantial noise reductions.

(e) Before adoption of a final environmental impact statement or finding of no significant impact, the highway agency shall identify:

(1) Noise abatement measures which are reasonable and feasible and which are likely to be incorporated in the project, and

(2) Noise impacts for which no apparent solution is available.

(f) The views of the impacted residents will be a major consideration in reaching a decision on the reasonableness of abatement measures to be provided.

(g) The plans and specifications will not be approved by FHWA unless those noise abatement measures which are reasonable and feasible are incorporated into the plans and specifications to reduce or eliminate the noise impact on existing activities, developed lands, or undeveloped lands for which development is planned, designed, and programmed.

Sec. 772.13 Federal participation.

(a) Federal funds may be used for noise abatement measures where:

(1) A traffic noise impact has been identified,

(2) The noise abatement measures will reduce the traffic noise impact, and

(3) The overall noise abatement benefits are determined to outweigh the overall adverse social, economic, and environmental effects and the costs of the noise abatement measures.

(b) For Type II projects, noise abatement measures will not normally be approved for those activities and land uses which come into existence after May 14, 1976. However, noise abatement measures may be approved for activities and land uses which come into existence after May 14, 1976, provided local authorities have taken measures to exercise land use control over the remaining undeveloped lands adjacent to highways in the local jurisdiction to prevent further development of incompatible activities.

(c) The noise abatement measures listed below may be incorporated in Type I and Type II projects to reduce traffic noise impacts. The costs of such measures may be included in Federal-aid participating project costs with the Federal share being the same as that for the system on which the project is located, except that Interstate construction funds may only participate in Type I projects.

(1) Traffic management measures (e.g., traffic control devices and signing for prohibition of certain vehicle types, time-use restrictions for certain vehicle types, modified speed limits, and exclusive land designations).

(2) Alteration of horizontal and vertical alignments.

(3) Acquisition of property rights (either in fee or lesser interest) for construction of noise barriers.

(4) Construction of noise barriers (including landscaping for aesthetic purposes) whether within or outside the highway right-of-way. Interstate construction funds may not participate in landscaping.

(5) Acquisition of real property or interests therein (predominantly unimproved property) to serve as a buffer zone to preempt development which would be adversely impacted by traffic noise. This measure may be included in Type I projects only.

(6) Noise insulation of public use or nonprofit institutional structures.

(d) There may be situations where (1) severe traffic noise impacts exist or are expected, and (2) the abatement measures listed above are physically infeasible or economically unreasonable. In these instances, noise abatement measures other than those listed in Sec. 772.13(c) of this chapter may be proposed for Types I and II projects by the highway agency and approved by the Regional Federal Highway Administrator on a case-by-case basis when the conditions of Sec. 772.13(a) of this chapter have been met.

Sec. 772.15 Information for local officials.

In an effort to prevent future traffic noise impacts on currently undeveloped lands, highway agencies shall inform local officials within whose jurisdiction the highway project is located of the following:

(a) The best estimation of future noise levels (for various distances from the highway improvement) for both developed and undeveloped lands or properties in the immediate vicinity of the project,

(b) Information that may be useful to local communities to protect future land development from becoming incompatible with anticipated highway noise levels, and

(c) Eligibility for Federal-aid participation for Type II projects as described in Sec. 772.13(b) of this chapter.

Sec. 772.17 Traffic noise prediction.

(a) Any traffic noise prediction method is approved for use in any noise analysis required by this regulation if it generally meets the following two conditions:

(1) The methodology is consistent with the methodology in the FHWA Highway Traffic Noise Prediction Model (Report No. FHWA-RD-77-108)

(2) The prediction method uses noise emission levels obtained from one of the following:

(i) National Reference Energy Mean Emission Levels as a Function of Speed (Appendix A).

(ii) Determination of reference energy mean emission levels in Sound Procedures for Measuring Highway Noise: Final Report, DP-45-1R.

(b) In predicting noise levels and assessing noise impacts, traffic characteristics which will yield the worst hourly traffic noise impact on a regular basis for the design year shall be used.

Sec. 772.19 Construction noise.

The following general steps are to be performed for all Types I and II projects:

---

* These documents are available for inspection and copying as prescribed in 49 CFR Part 7, Appendix D.

(a) Identify land uses or activities which may be affected by noise from construction of the project. The identification is to be performed during the project development studies.

(b) Determine the measures which are needed in the plans and specifications to minimize or eliminate adverse construction noise impacts to the community. This determination shall include a weighing of the benefits achieved and the overall adverse social, economic and environmental effects and the costs of the abatement measures.

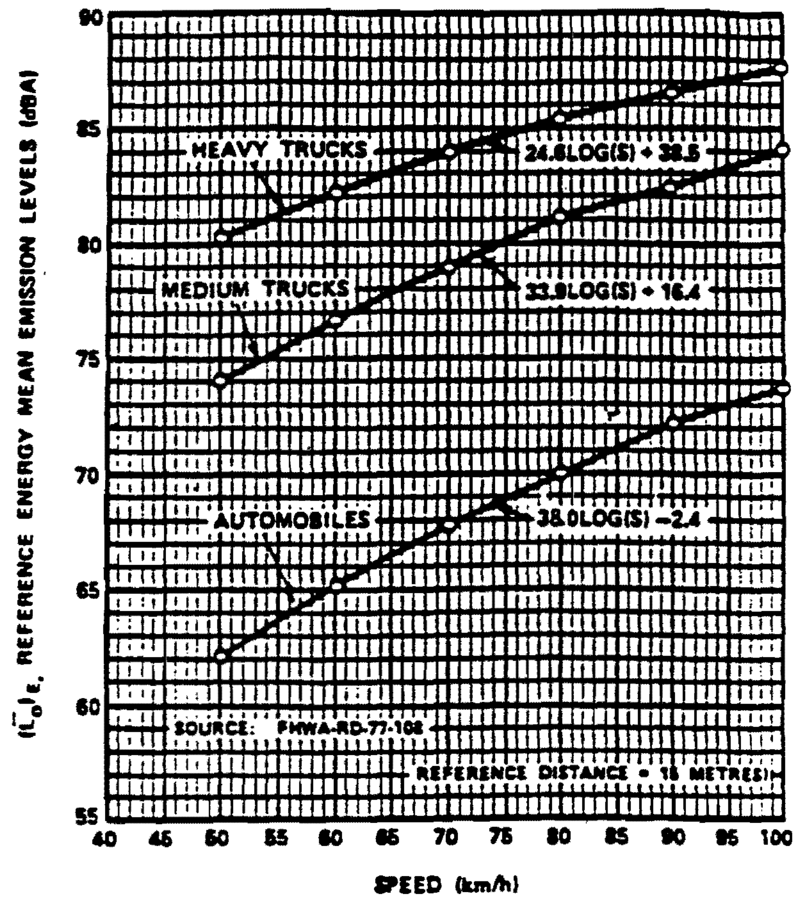
(c) Incorporate the needed abatement measures in the plans and specifications.

NOISE LEVEL CRITERIA

ACTIVITY CATEGORY	Leq (h)* (dBA)	DESCRIPTION OF ACTIVITY CATEGORY
A	57 Exterior	Lands on which serenity and quiet are of extraordinary significance and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 Exterior	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 Exterior	Developed lands, properties, or activities not included in Categories A or B above.
D	———	Undeveloped lands.
E	52 Interior	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

*"Leq" means the equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same period. For purposes of measuring or predicting noise levels, a receptor is assumed to be at ear height, located five feet above ground surface.
"Leq(h)" means the hourly value of Leq.
Use of interior noise levels shall be limited to situations where exterior noise levels are not acceptable.

History: Cr. Register, August, 1989, No. 404, eff. 9-1-89.



LEGEND:

1. AUTOMOBILES: ALL VEHICLES WITH TWO AXLES AND FOUR WHEELS.
2. MEDIUM TRUCKS: ALL VEHICLES WITH TWO AXLES AND SIX WHEELS.
3. HEAVY TRUCKS: ALL VEHICLES WITH THREE OR MORE AXLES.

National Reference Energy Mean Emission Levels as a Function of Speed

APPENDIX D

NOISE ABATEMENT RECOMMENDATION CHECKLISTS

Alaska Department of Transportation and Public Facilities
Colorado Department of Transportation
Utah Department of Transportation
Wisconsin Department of Transportation

ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
NOISE BARRIER RECOMMENDATION CHECKLIST

Project Name:
Project No: Preparer:

Receiver Name/Description :

1. Does a noise impact exist or is one predicted to occur in the Design Year? Yes ___ No ____ If no, then noise abatement is not recommended. Proceed to decision segment of form.

2. Is the receiver a use typically defined within Land Use Category A and/or B in the FHWA noise abatement criteria? Yes____ No___. If no, then no noise abatement is recommended. Proceed to decision segment of form.

3. Is the receiver in a "mixed" area of development where both noise sensitive and non-sensitive uses occur? Yes___ No___. If yes, then no noise abatement is recommended. Proceed to decision segment of form.

4. Are there local zoning or ordinances to control the new development of noise sensitive land uses adjacent transportation corridors? Yes ___ No ___ If no, has the local government provided written assurance that it will implement measures to prohibit the development of non-sensitive land uses within and adjacent to those sensitive land uses being considered for noise abatement? Yes___ No___. If no, then noise abatement is not recommended. Proceed to decision segment of form.

5. Can effective noise barriers be constructed which provide a minimum 5 dBA reduction in noise without creating a hazard to users and residents, and interfering with operations and maintenance of the highway facility? Yes___ No____. If no, barriers are not feasible and are not recommended at this site. Proceed to decision segment of this form. If yes, then continue filling in the form to determine the reasonableness of abatement measures.

REASONABLENESS DETERMINATION

Reasonableness Factors	YES High	YES Low	NO High	NO Low
(a) Cost/Residence	_____	___	_____	___
(b) Residents' Desires	_____	___	_____	___
(c) Development vs. Timing	_____	___	_____	___

(d) Development existence	____	____	____	____
(e) Build Level 65 dBA	____	____	____	____
(f) Build Level 5 dBA greater than existing	____	____	____	____
(g) Build level 3 dBA	____	____	____	____

ADDITIONAL CONCERNS:

DECISION

Are Barriers feasible? Yes ____ No ____

Are Barriers reasonable? Yes ____ No ____

REASONS FOR DECISION:

NOISE ABATEMENT WORKSHEET FOR DETERMINATION OF FEASIBILITY AND REASONABLENESS

COLORADO DEPARTMENT OF HIGHWAYS

FEASIBILITY

	YES	NO
Can a continuous noise barrier be constructed?	_____	_____
Can a 5 dB(A) noise reduction be achieved by constructing a noise barrier?	_____	_____
Can a 5 dB(A) noise reduction be achieved by insulation of the receiver? (Normally limited to public and non-profit buildings)	_____	_____
Are there any fatal flaw safety or maintenance issues involving the proposed noise barrier?	_____	_____

REASONABLENESS

REASONABLENESS FACTORS

	VERY REASONABLE	REASONABLE	MARGINALLY REASONABLE	UNREASONAB:
1. Build level 66 dB(A)	_____	_____	_____	_____
2. Build level 5 dB(A) greater than existing	_____	_____	_____	_____
3. Cost/receiver/decibel	_____	_____	_____	_____
4. Impacted persons' desires	_____	_____	_____	_____
5. Development vs. highway timing	_____	_____	_____	_____
6. Development existence	_____	_____	_____	_____
7. Development type	_____	_____	_____	_____
8. Land use control implementation	_____	_____	_____	_____

9. **INSULATION CONSIDERATION:**

a. Does this project have noise impacts to public or non-profit buildings? YES____ NO____

b. Are normal noise abatement measures physically infeasible or economically unreasonable? YES____ NO____

If the answer to b. is YES, then:

1. Is private residential property affected by a 30 dB(A) or more noise level increase? YES____ NO____

2. Are private residences impacted by 75 dB(A) or more? YES____ NO____

10. **ADDITIONAL CONSIDERATIONS:**

DECISION

Are noise mitigation measures feasible? Yes____ No_____

Are noise mitigation measures reasonable? Yes____ No_____

DECISION JUSTIFICATION:

PRELIMINARY ENVIRONMENTAL REVIEW

UTAH DEPARTMENT OF TRANSPORTATION

Project Name ______________________________ Date________

Project No. ______________________________

Project Concept ____

____

____

Potential areas impacted by project (i.e. access roads, borrow sites, etc.) __________

____

____

____

Will the following environmental factors affect project design concept?

Yes___No___ Cultural and Paleontological Resources

Yes___No___ Threatened or Endangered Species

Yes___No___ Noise

Yes___No___ Water Pollution, Wetlands, Floodplains, Stream Encroachments

Yes___No___ Hazardous Waste

Yes___No___ Prime, Unique or Local Important Farmland

Yes___No___ Air Quality

Yes___No___ Relocations

Yes___No___ Land Use/Urban Policy

Yes___No___ Section 4(f) or Section 6(f) Properties

Yes___No___ Wild/Scenic Rivers

Yes___No___ Visual

Yes___No___ Socioeconomic

Yes___No___ Natural Resources

Yes___No___ Construction

Yes___No___ Energy

Yes___No___ Geology/Soils

Yes___No___ Ecology

If "Yes" to any of above explain potential significance of environmental resources which may affect project concept with estimated mitigation costs and estimated time frame for mitigation. Attach additional sheets, technical reports, maps, sketches, and/or drawings as necessary.

____
____
____
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____
____
____
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____
____

Probable Environmental Classification (I, II, or III)______________________________

Approved:______________________________________

Lawrence G. Kirby, P.E.,
District Two Environmental Engineer

Environmental Division comments (attach additional sheets, etc. as necessary):

____
____
____
____
____
____
____

Approved:______________________________________

Dave Berg, P.E.
Engineer for Environment

WISCONSIN DEPARTMENT OF TRANSPORTATION
REQUEST FOR RETROFIT NOISE BARRIER PROJECT

ALL ITEMS MUST BE SUBMITTED BY THE APPLICATION DEADLINE.

1. APPLICANT(S)

   A. Municipality: ____________________

   B. Contact: ____________________

   C. Street/P.O. Box: ____________________

   D. City & Zip: ____________________

   E. Phone: ____________________

2. REQUESTED BARRIER LOCATION

   Route: ____________________

   From: ____________________

   To: ____________________

   Side: ____________________

   Barrier Number: ____________________
   (from Noise Study)

3. CERTIFICATION

   To the best of my knowledge and belief, the information submitted herein is true and correct and the document has been duly authorized for submittal by the governing agency.

____________________ ____________________
Signature of applicant or authorized agent. Date

____
Title

4. DOCUMENTATION OF LAND USE CONTROLS

In order for the requested barrier to be eligible for funding the local unit of government must provide documentation of land use controls which encourage noise compatible land uses. These controls should apply to land adjacent to freeways or expressways, and should reasonably eliminate the need for state-funded noise barriers in highway rights-of-way adjacent to future developments. The documentation could be in the form of zoning ordinances, land use plans, or local planning policies. If no land use controls currently exist this application shall be considered a committment to enact such controls prior to final design of the requested barrier.

5. LOCAL COST SHARING PARTICIPATION

If the requested barrier cost exceeds $30,000/abutting residence local cost sharing will be necessary. Submittal of this application shall be considered a committment by the local municipality to pay for all costs exceeding $30,000/abutting residence. Barrier projects which exceed this cost are not eligible for consideration unless the local municipality agrees to cover all costs exceeding the $30,000 limit.

6. RESOLUTION OF SUPPORT

The local government shall furnish the department with a formal resolution supporting the proposed noise barrier project, and cost sharing agreement (if necessary). Submittal of this application is considered a statement of general support for the requested noise barrier project.

7. GUARANTY

If preliminary

APPENDIX E

NOISE ABATEMENT SYSTEM PRODUCT INFORMATION
NOISE WALL MATERIALS AND PRODUCTS

NOISE ABATEMENT SYSTEM PRODUCT INFORMATION

* **SOUNDCORE®** - Extruded prestressed hollow-core concrete plank. Made of high strength zero slump concrete with reinforcement strands.

***TIMBAWALL** - Pre-fabricated timber noise barrier panels. Reduces transmission and reflection.

***BOWMANS REFLECTIVE METAL SOUND BARRIER** - Reflective sound barrier system (metal) of galvanized steel panels, painted with polyvinyl lyden.

***WOODCRETE/BRICKCRETE®** - Precast concrete posts and interlocking panels with caps, manufactured with a wood grain and brick texture.

***K-X® PANELS** - Wood concrete sound absorbing panels set in steel or concrete H beams.

***KENTUCKY RAIL CONCRETE FENCE** - Fencing material of 50% sand, 50% 3/8" gravel and 5 sack cement (The above are from the D-10 product review).

ACOUSTA-WALL® - by Nabco Glazed Products, sound absorbing masonry units with resonating cavity

Acrylite 237® - Weather resistant, non-yellowing, lightweight, chemical resistant, break-resistant transparent sheet, STC of 32 dB for 12.7 mm (0.500 in.) thick sheet, and 34 dB for 19.1 mm (0.750 in.) thick sheet.

ARMCO STEEL

astra-glaze® - by Nabco Glazed Products sound absorbing masonry unit with resonating cavity

CAMEO - double layer aluminum with honeycomb material between.

C-Loc - non corrosive, paint free, pollution resistant, environmentally safe and aesthetically pleasing corrugated PVC sheet material; outer skin is exterior grade vinyl, ultraviolet light resistant; interior is made of recycled and virgin plastics, uses horizontal supports (walers).

Carsonite® SOUND BARRIER - Lightweight pre-assembled panels; uses up to 250,000 pounds of recycled scrap tires per barrier mile; STC of 36; 50 year life cycle; graffiti resistant.

COMPOSITE - RECYWALL, recycled plastic w/ compost and organic waste material with crushed glass.

CONCRETE IMPRESSIONS, INC. - A process by which precast concrete is impressed with a pattern. These patterns can be custom designed.

DIFFUSORBLOX - The first load bearing diffusing and absorbing concrete masonry unit

***Durisol*®** - Wood particle concrete, durable, molded into any shape, light weight, non-combustible and sound absorptive.

FANWALL

FASWALL - insulating wall forms for reinforced concrete made from recycled wood products.

Green Walls - combination of living, organic and inorganic materials: The Sandbag System, polyproylene bags filled with soil mix with bare-root shrubs or grass clumps planted in between the stacked bags; Soil Blanket Concept, soil covered with a soil-stabilizing structural fabric and planted or hydroseeded on a vertical structure; Mesh Retaining Wall, a supported chainlink fence, backfilled with soil and the face planted with sod or other appropriate plant materials.

monowall™ - By Pickett Wall System, monolithic, one-piece panel-and-post modular wall system.

NOISHIELD® - galvanized expanded steel or aluminum panel over fiber bats with a solid steel back.

PLYWALL - Post and Panel permanent engineered wood barrier system, maintenance free, permanent coloration, UV resistant with CCA preservative.

***"RecyWall"*®, Green, Living Sound Barrier Walls**-100% recycled materials, stacked planter system

POLYMER (TIMBREX) - Wood/Polymer Composite, recycled wood and plastic, Mobil Chemical Co.

SIERRA WALL - from Smith-Midland Corp. 4" thick, steel reinforced concrete with an integral column, joined by tongue in groove connection.

Sound Fighter® SYSTEM NOISE CONTROL WALLS - high density, polyethylene elements which are stacked to desired height. Units locked into place at each end by steel columns. Hollow interior is filled according to intended use, i.e. mineral wool, gypsum board, concrete, etc. Can be installed as a temporary unit and reused.

SOUND ZERO

Sound-Lok® - An absorptive treatment(Smith-Midland Corp.) Noise reduction coefficient .65+, colored to client, cast to new structure or applied to existing concrete, form lined finishes available

Sound Off®-Composition layered wall consisting of Tedlar(a protective polymer surface), polyester resin, fiberglass and plywood. Has TL of 32.

SOUNDBLOX - by The Proudfoot Company

the scott system® - Elastometric form liners for concrete construction used to create textures and graphics in concrete.

A & M PLANTENER - Concrete planter wall. Can be planted on one or both sides. Excess water discharged at back of wall.**

BASALT AG - Lava (scoria) concrete longitudinal panels set onto reinforced concrete supporting columns. Fully sound absorbent due to specially textured surface.**

BETONWERK WESER-EMS (BWE) - Precast glass-fiber concrete units placed between reinforced concrete columns. Cross-sectional shape of panel may be varied for interest. Sound absorbing mineral-fiber mats fill the cavity of the panels.**

BETONWARENFABRIK THEODOR BREE (Abi) - Trough-shaped concrete units dry stacked one on top of the other on a strip foundation. Units can be staggered to provide planting niches on both sides.**

DABAU - Dry stacked angle-shaped precast concrete units of various lengths and comprising outward and inward sloping aprons and height spacing brackets for obtaining different vertical stepped arrangements. This is set on a strip foundation. Planting niches result from the stepped wall.**

DYCKERHOFF & WIDMANN - Honeycomb grid of rectangular openings filled with specially textured slab-type concrete sound absorbing lining which can be omitted and the unit filled for planting.**

EBENESEER BETONWERKE - A space lattice structure of precast reinforced concrete filled with compost and planted. Requires no foundation. Permeable to water at base.**

ESKOO-FLORWAND - Precast concrete blocks laid in an open or closed pattern. Fully absorbent when open spaces are planted.**

ETERNIT - Asbestos cement units connected at their third span joints by aluminum tubes.**

FULGURIT - Sound reflecting barrier of asbestos cement hollow sections inserted one on top of the other between flanges of wide-flange columns. Available in light and dark grey. Can be painted.**

GRUNKORN BETONWERK - Fully absorbent multi-layer panels in which the load-bearing layers are of ordinary lightweight concrete. Absorbent mineral-fiber layer between concrete layers.**

POLYKLET - Large precast blocks with front face of perforated clay slab with downward-sloping holes. A glass-fiber mat fills the blocks. Can be set between reinforced concrete columns.**

KUNZ GMBH & CO. - Precast reinforced concrete on a foundation of bored piles surmounted by socket-type footings. Two types available, type Z and folded plate.**

LECA/LAIS - Lightweight concrete block with expanded clay aggregates and characterized by intergranular porosity (of the no-fines type) for sound absorption. Can be produced in any length of height.**

LOFFELSTEIN WALL -Concrete "spoon blocks" are dry stacked, filled with soil and planted.**

SILENZITON - Precast concrete units have their center of gravity near the center of the base allowing it to be placed on the sub-grade near the site boundary edge with little earthmoving. The parabolically curved wall reflects sound.**

MULLER-MARI - Precast concrete is highly polished on the road side and is set in raised footings.**

POROSIT-BETONWERKE - Prismatic units made of no-fines concrete, square in plan and comprising cylindrical cavities. The cavities are cover with concrete caps which can be made into visual designs by various color selection. The cavities can also be planted.**

ROCHELL BETONELEMENTE KG - Reinforced concrete panels inserted into slots in A-frame trestles of the same material.**

EVERGREEN GMBH - Ladder-shaped reinforced concrete units are filled with soil and planted. The soil provides the dead weight of the structure. Use of soil from excavating can be used.**

SuK - Large concrete units with a sound absorbing material on the face. The same company produces a small box-shaped unit also.**

STEWING-BETON-UND FERTIGTEILWERK - Structural panel of lightweight concrete with a sound absorbing panel of no-fines lightweight concrete. The units overlap to produce a scale-like configuration.**

TRASSWERKE MEURIN -The units are of pumice and lava-slag lightweight concrete which has a structural layer and a sound absorbing layer. The structural layer is of dense-textured lightweight concrete and the absorbing layer is of lightweight concrete of the no-fines type. These are mounted on columns.**

TUBAWALL - Units are made of lightweight concrete with expanded shale aggregate. No foundation is required for the dry stacked wall. The bottom units should be filled with concrete.**

ZUBLIN AG - This system can be constructed as both sound absorbing and reflecting. They are flat structures composed of ribbed reinforced concrete panels with an absorbent facing and a reverberation cavity. The panels are bolted to reinforced columns which are installed in advance in recesses formed in bored piles. There is a complimenting curved panel**

Clay foam

Concrete and expanded clay aggregates

Concrete and expanded shale

Concrete and fiberglass

Concrete and mineral wool

Concrete and pumice, lava-slag

Concrete and wood fiber

Double layer steel - front panel has 15% of area perforated, mineral rock wool inside

Expanded minerals

Flow resistant films of metal or plastic, 2 mil. thick, 20 holes/sq. in., 8 mil. dia. holes

MSE- Mechanically Stabilized Earth

Perforated steel or aluminum over fiber bats with solid back.

Resonant cavities

Soil - berms

Vegetation

Vermiculite aggregate

Wood fiber board with dead air space

* TxDOT approved systems
** Dietsch, Von Wolfgang. 1980. *Noise Barriers with Concrete Components.* Betonwerk Und Fertigteil-Technik. Vol. 46, No. 1 (Jan): 37-43.

APPENDIX F

COLORADO DEPARTMENT OF TRANSPORTATION LANDSCAPE PERMIT

COLORADO - LANDSCAPE PERMIT

6/09/88 DJH

THE COLORADO DEPARTMENT OF HIGHWAYS, UPON APPLICATION TO THE DEPARTMENT, IS WILLING TO GRANT A LANDSCAPE PERMIT TO AN ADJACENT PROPERTY OWNER IN WHICH THE ADJACENT OWNER IS PERMITTED USE AND MAINTENANCE OF THE LAND BETWEEN THE STATE HIGHWAY RIGHT-OF-WAY LINE (PROPERTY LINE) AND THE SOUND BARRIER FENCE, UNDER THE FOLLOWING CONDITIONS:

1. THE COLORADO DEPARTMENT OF HIGHWAYS SHALL RETAIN TITLE TO THIS LAND.

2. THE DEPARTMENT RESERVES THE RIGHT TO ENTER THIS AREA VIA THE YARD OF THE ADJACENT PROPERTY TO MAINTAIN THE SOUND BARRIER FENCE. ANY UTILITY COMPANIES PRESENTLY OCCUPYING THIS LAND SHALL ALSO CONTINUE USING THIS PROPERTY AND WILL BE ALLOWED ACCESS BY THE ADJACENT OWNERS TO MAINTAIN THEIR FACILITIES.

3. ADJACENT PROPERTY OWNERS WILL BE ALLOWED TO EXTEND THEIR FENCES TOWARD AND IMMEDIATELY ADJACENT TO, BUT NOT CONNECTING WITH THE SOUND BARRIER FENCE. IN FACT, NOTHING WILL BE PERMITTED TO BE ATTACHED TO THE SOUND BARRIER FENCE.

4. THE ADJACENT PROPERTY OWNERS SHALL NOT ERECT ANY BUILDING OR PERMANENT STRUCTURE ON THIS LAND. SPRINKLER SYSTEMS WOULD BE ALLOWED AT THE RISK OF THE REMOVAL LATER SHOULD THE LAND BE NEEDED FOR HIGHWAY PURPOSES.

5. NO EARTHWORK SHALL BE POSITIONED AGAINST THE SOUND BARRIER FENCE BY THE ADJACENT OWNER.

6. TO AVOID DAMAGE TO UTILITY LINES AND THE SOUND BARRIER FENCE, NO TREES SHALL BE PLANTED IN THIS AREA. THE RISK OF PLANTING SHRUBBERY IS THAT IT COULD BE REMOVED TO GAIN ACCESS TO UTILITY LINES, OR FUTURE GROWTH COULD DAMAGE THE FENCE. GRASS, FLOWERS, OR VINES WOULD BE ALLOWED.

7. CARE SHOULD BE EXERCISED TO PERPETUATE EXISTING PROPERTY PINS ALONG THE REAR PROPERTY LINES (HIGHWAY RIGHT-OF-WAY LINE).

8. EACH APPLICATION WILL BE CONSIDERED ON ITS OWN MERIT, AND THE DEPARTMENT RETAINS THE RIGHT OF NON-ACCEPTANCE.

9. THE HIGHWAY DEPARTMENT SHALL BE HELD HARMLESS, AND NOT BE LIABLE FOR ANY DAMAGE OR PROPERTY LOSS AS A RESULT OF GRANTING THIS PERMISSION.

APPENDIX G

COMMUNITY PARTICIPATION

Iowa Department of Transportation
Florida Department of Transportation
Maryland State Highway Administration
Kentucky Department of Transportation

Figure 9-A. Post-construction questionnaire.

Citizen Comments

Planning and Research Division,
Office of Project Planning (515) 296-1225

I-235 Noise Barrier, Easton Boulevard-Guthrie Avenue
Post Construction Survey - E. 22nd Street & Searle Street Residents

September, 1980

Dear Resident:

Please take a few minutes to answer the following questions concerning the effects of the I-235 Noise Barrier. This information will be of great value to us in assessing its effectiveness and the advisability of future projects of this nature. Please be assured that your individual responses to these questions will remain strictly confidential and will be used only as a part of the overall analysis of community response.

After completing this two page questionnaire simply fold together along the dotted lines on the back of the second page, fasten with staple or tape and put in mail - no postage required.

Please enter your name and address <u>or</u> indicate the location of your home.

Name ______________________

Address ______________________

1. In your judgement how has the noise barrier affected these highway related problems? If you think it has affected other problems, please indicate and mark the appropriate space.

	worsened the problem	no effect	slightly reduced the problem	greatly reduced the problem
highway dust & dirt	1	4(8)[11]	4(4)	13(6)[6]
headlight glare		3(6)[10]	2(3)	15(10)[7]
litter from vehicles	1	2(8)[9]	4(3)[1]	15(9)[7]
highway noise	1 [1]	3(3)[5]	12(5)[3]	8(11)[10]
vibration from road	1	9(9)[7]	6(3)[2]	5(6)[7]
fumes from the road	1(1)	2(5)[8]	7(3)[4]	8(9)[6]
other? privacy		[2]		1 [1]

Figure 9-B. Post-construction questionnaire.

2. How has the barrier affected you during the following activities?

	activity more difficult	no effect	activity less difficult	activity much less difficult
conversation indoors		10(10)[9]	4(3)[2]	7(5)[5]
conversation outdoors	1	1(6)[8]	12(7)[1]	7(6)[8]
use of telephone		11(11)[10]	5(2)[2]	5(5)[3]
watching television	1	9(8)[9]	6(5)[2]	5(5)[4]
relaxing indoors	[1]	6(7)[8]	7(6)[3]	9(5)[3]
relaxing outdoors	2 [1]	2(5)[7]	12(8)	6(5)[9]
sleeping	2(2)[1]	3(5)[8]	7(6)[1]	10(6)[7]
getting fresh air through open windows	1(3)	6(6)[7]	8(4)[1]	4(6)[7]

3. What effect do you think the noise barrier has had on the traffic noise you hear while you are at home?

	considerable reduction	moderate reduction	slight reduction	no effect	slight increase	moderate increase	considerable increase
outdoors	8(9)[7]	4(3)[3]	8(5)[1]	(4)[7]	1(1)		1
indoors	7(7)[9]	6(1)[1]	5(6)	1(4)[6]	1(1)[1]	1	

4. What effect do you feel the barrier has had on the general appearance of this residential area?

considerable improvement	moderate improvement	slight improvement	no effect	slight deterioration	moderate deterioration	considerable deterioration
8(5)[4]	3(1)	7(5)[2]	3(3)[7]	2 [2]	(3)[2]	1(2)[1]

5. What effect do you feel the noise barrier will have on your property value?

considerable increase	moderate increase	slight increase	no effect	slight decrease	moderate decrease	considerable decrease
3(3)[1]	3(3)[3]	8(1)[1]	4(10)[10]	2(1)[2]	[1]	2(1)

6. Please offer any comments or suggestions relative to the noise barrier project which may be of help to us in considering the application of noise barriers along other sections of Interstate highway.

Your response to this survey is greatly appreciated.

Sincerely,

Robert H. Given
Deputy Director

RHG:RR:kel

St. Petersburg Opinion Survey Questionnaire
State Job No. 15190-3466

Case No.____   Date of Interview__________

Introduction: Hello - I'm an interviewer from the Florida Department of Transportation. We are doing a study of some of the people's attitudes about I-175 which is being built through this area of St. Petersburg.

Reason for no interview (if appropriate): Vacant___ No qualified adults___ Refused___
Not at home___ Other__________

Name__________

Address__________ Sex___ Age___ Family Income: 0 - $4,999 ___
5,000 - 9,999 ___
Race___ Respondents position in family heirarchy__________ 10,000 - 14,999 ___
15,000 - 19,999 ___
1. How long in St. Petersburg? ___ 2. At this address? ___ 20,000 - over ___

3. Do you think I-175 will help solve traffic congestion? Yes ___ No ___ No difference___ Don't Know ___

4. Do you feel the Interstate has affected your neighborhood? Yes ___ No ___ Don't Know___
If yes, how?__________

5. Is noise presently a problem in your neighborhood? Yes ___ No ___ Don't know ___
If yes, what types of noise and how does it affect you? __________

6. Do you feel that traffic noise is a major urban problem? Yes ___ No ___ Don't Know___

7. Are you aware that a wall is being built along different sections of I-175 to reduce traffic noise? Yes ___ No ___ If yes, how did you find out about it? __________

8. Do you think an outside wall along a highway will reduce traffic noise?
Yes ___ No ___ Not Sure ___

9. Do you think tax money should be spend to reduce traffic noise? Yes ___ No ___
Don't Know ___

10. Have you ever been contacted by FDOT personnel at any time regarding the Interstate?
Yes ___ No ___ If yes, when and why? __________

Comments:

St. Petersburg Follow-up Survey Questionnaire
State Job No. 15190-3466

Case No. ___ Date of interview ___________

Introduction: Hello - I'm an interviewer from the Florida Department of Transportation and we are conducting a follow-up survey regarding your feelings about noise abatement along I-175 which is being built through St. Petersburg.

Reason for no interview (if appropriate): Vacant ___ No one home ___ Refused ___
Moved ___ Other ___________

Name ___________ Address ___________

Age ___ Race ___ Sex ___

1. Does noise in your neighborhood bother you? Yes ___ No ___ If yes, what types?
____
2. Does car and truck noise from I-175 bother you? Yes ___ No ___
3. Do you feel the noise wall along I-175 reduces traffic noise:
Quite a bit ___ Somewhat ___ Not at all ___ Don't know ___
4. Is it important to you that noise from I-175 be reduced? Yes ___ No ___ Don't know ___
5. Do you consider the noise wall along I-175 to be good or bad for your neighborhood?
Good ___ Bad ___ Don't know ___
6. Do you feel the noise wall along I-175 has affected your neighborhood in any way?
Yes ___ No ___ Don't know ___ If yes, how? ___________
7. Do you feel the noise wall along I-175 looks: OK ___ Pretty ___ Ugly ___ Other ___
8. Do you think a noise wall should be pleasant to look at? Yes ___ No ___ Don't know ___
9. Do you feel the noise wall along I-175 should or could be made better looking?
Yes ___ No ___ Don't know ___ If yes, how? ___________
10. Do you think that you or anyone else in your neighborhood has any influence on whether the noise wall was built or not? Yes ___ No ___ Don't know ___ If yes, how? ___________
____
11. Would you like to see the noise wall removed? Yes ___ No ___ Don't know ___
If yes, why? ___________
12. Do you feel you should have been asked about the noise wall before it was built?
Yes ___ No ___ Don't know ___ Why? ___________

Comments:

MARYLAND STATE HIGHWAY ADMINISTRATION
NOISE BARRIER QUESTIONNAIRE
PERRING PARKWAY TO HARFORD ROAD

1. How long have you lived at your present address? ______Years

2. Prior to the construction of the noise barrier, how severe was the noise problem? (check one)
______very severe ______somewhat severe ______not severe

3. What effect has the noise barrier had in reducing traffic noise levels at your residence? (check one)
_____Excellent _____Good _____Fair _____Poor _____None

4. Has the noise barrier made your outdoor space more useable?
______YES ______NO

5. Do you feel that the noise barrier was a worthwhile project?
______YES ______NO

6. What is your opinion regarding the overall attractiveness of the noise barrier?
______Attractive ______Good ______Fair ______Poor

7. What do you like best about the noise barrier project?

____

____

8. What do you like least about the noise barrier project?

____

____

9. Did you encounter any problems during the construction phase of the noise barrier project? Please explain.

____

____

10. Did you attend the community meeting(s) held for the noise barrier project:
______YES ______NO

11. Do you feel anything was changed or omitted from the project from that which was mentioned at the community meeting? (If you attended)

____

____

12. What do you feel should or could have been done to make this a better project?

____

____

13. Please provide any other thoughts you may have regarding this noise barrier project on the back of this page.

TRANSPORTATION RESEARCH PROGRAM

UNIVERSITY OF KENTUCKY

EFFECTIVENESS OF TRAFFIC NOISE BARRIERS QUESTIONNAIRE

Please complete and return this questionnaire in the enclosed self-addressed, postage-paid envelope. Thank you for your cooperation.

---

1. How long have you lived at this address? ____Years ____Months

   What is your street address: ____________________

2. How many persons live at this residence? ________

3. Do you own your residence, or do you rent? ___Own ___Rent

4. How would you describe your neighborhood before and after construction of I 471 and the accompanying traffic noise barriers?

	Before Construction (Check one)	After Construction (Check one)
Very quiet	_____	_____
Quiet	_____	_____
A little noisy	_____	_____
Noisy	_____	_____
Very Noisy	_____	_____

5. Are you aware that a noise barrier, which was constructed at the same time as I 471, stands between your residence and the interstate? ____Yes ____No

   (If you answered "No" to the above question, please stop here and return the questionnaire; if you answered "Yes", please continue).

6. How did you learn about the noise barrier?

__________Television/Radio
__________Newspaper
__________Public hearing notice
__________Letter from a political representative
__________Observed construction of barrier
__________Other____________________

7. How do you feel that the presence of a noise barrier has affected these highway-related problems compared to the situation where no noise barrier was present?

	Worse	No Effect	Slight Improvement	Significant Improvement	No Opinion
Highway dust and dirt	____	____	____	____	____
Headlight glare	____	____	____	____	____
Litter from vehicles	____	____	____	____	____
Highway noise	____	____	____	____	____
Road vibration	____	____	____	____	____
Road fumes	____	____	____	____	____
Privacy	____	____	____	____	____
Other ____	____	____	____	____	____

8. How do you feel that the presence of a noise barrier affects the following activities compared to the situation where no noise barrier was present?

	More Difficult	No Effect	Less Difficult	Significantly Less Difficult	No Opinion
Conversation indoors	____	____	____	____	____
Conversation outdoors	____	____	____	____	____
Telephone use	____	____	____	____	____
Relaxing indoors	____	____	____	____	____
Relaxing outdoors	____	____	____	____	____
Sleeping	____	____	____	____	____
Leaving windows open	____	____	____	____	____
Other ____	____	____	____	____	____

9. Indicate if you feel that the noise barrier has created any of the following disadvantages:

	Yes	No	No Opinion
Creates closed-in feeling	_____	_____	_____
Hurts area environment	_____	_____	_____
Limits or restricts view	_____	_____	_____
Requires more yard maintenance	_____	_____	_____
Visual eyesore; unsightly	_____	_____	_____
Other_________________	_____	_____	_____

10. How do you feel about the appearance of the barrier?

_____Attractive _____OK _____Unsightly

11. Compared to having no noise barrier at all, how effective do you feel the noise barrier has been in reducing the traffic noise?

_____Very Effective _____Somewhat Effective _____No Effect

12. How do you feel the presence of the noise barrier has affected the value of your property?

_____Decreased Significantly _____Decreased Somewhat _____No Effect _____Increased Somewhat

13. If the noise barrier had not been built, do you feel that you would use your yard more, less, or the same amount?

_____More _____Less _____Same Amount

14. How do you feel about the noise barrier in general?

_____Like _____Dislike _____No Opinion

Please feel free to submit any further comments about the noise barrier here. Thank you. Your help is sincerely appreciated.

____
____
____
____
____
____
____