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SYNTHESIS OF HIGHWAY PRACTICE **87**

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest to roadside designers, environmental specialists, and others concerned with the mitigation of excessive highway noise. The experiences of highway agencies in the use of noise barriers are reviewed, and recommendations are offered for reducing the cost of barriers.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Most state highway agencies have installed noise barriers along their highways using systems of various design and materials. Their experiences are presented in this report of the Transportation Research Board; and design details, social impacts, and operational elements are evaluated.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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HIGHWAY NOISE BARRIERS

SUMMARY

Many people in the United States live quite close to high-volume, high-speed highways and thus are exposed to high noise levels. To mitigate excessive noise from highways, it is often necessary to construct a noise barrier—a device with sufficient mass and configuration to provide transmission loss and diffraction of noise propagating from a highway to a receptor. By December 31, 1980, 31 states had constructed 189 mi (304 km) of noise barriers made of wood, metal, concrete, earth, or some combination of these materials.

The principal criterion used to determine height and length of a barrier is the Federal Highway Administration (FHWA) design noise levels, although several states use other criteria, such as the requirement that the line of sight between source and receiver be broken. Most states will not install a noise barrier unless it will result in a noise reduction of at least 10 dBA, although some use 5 dBA as the minimum deduction. Most states use the FHWA model for highway noise prediction, and two-thirds of the states design for the most critical receptor.

The ultimate test of the effectiveness of a noise barrier is its impact on residents and motorists. Most states use systematic procedures to obtain community involvement including public hearings, special meetings on noise issues, mailings, interviews, and questionnaires. Questionnaires are commonly used for social surveying to determine the perceived effectiveness of a barrier. The perceived effectiveness is often more influenced by the aesthetics and landscaping of a barrier than by the acoustical performance.

Maintenance problems with barriers include difficulty with mowing close to barriers, litter accumulation, graffiti, and vandalism. A barrier placed inside of a right-of-way fence creates a "dead space" that is virtually inaccessible for maintenance. Solutions to this problem include doors in the barriers or overlapping sections of barriers to allow access, or deeding the area behind the barrier to the abutting property owners.

Several states have developed priority rating systems for installing noise barriers on existing highways. These systems enable the states to quantitatively order noise abatement needs so that the most serious are addressed first. In general, a formula is used that includes the number of dwelling units protected, the existing noise level, the expected noise reduction, and the cost of the barrier.

One recommendation of this synthesis is that states seek innovative ways to reduce the mass of barriers (and therefore cost) while maintaining noise-reduction capability. A cost-reduction methodology should be used to minimize the area of barrier needed. Also the structural and foundation design criteria should be reexamined for possible modification in order to reduce the bulk and mass of the typical wall.

CHAPTER ONE

INTRODUCTION

Efforts to abate the impacts of highway noise are in the embryonic stage compared to the long-standing national commitment to the highway program. Nevertheless much progress has been made in the last decade.

This synthesis report summarizes progress on one aspect of highway noise abatement: barriers. It gives quantitative and qualitative perspectives of the design construction, maintenance, and impacts of the barriers that have been built to mitigate excessive highway noise.

DEFINITIONS

Some of the terms used in this synthesis are defined below.

Barrier. A noise abatement device with a mass and geometric configuration sufficient to provide transmission loss and diffraction of noise propagating from a highway to a receptor.

Barrier attenuation. A reduction in noise level resulting from diffraction.

Barrier insertion loss. The difference in noise level at a given receptor due to the insertion of a barrier. Insertion loss is the effect of diffraction, transmission loss, and ground-cover effects.

Berm. A barrier in the form of a trapezoidal or triangular-shaped earthen mound, usually covered with some form of vegetation.

Design noise levels. The noise levels established by FHPM 7-7-3 for various activities or land uses, representing the upper limit of acceptable traffic noise conditions. They are a mitigation criterion; i.e., when exceeded, mitigation must be considered. Typical design noise levels for residences, churches, and schools are L_{eq} of 67 dBA (exterior) and L_{eq} of 52 dBA (interior).

FHPM 7-7-3. The official Federal Highway Administration (FHWA) regulation concerning highway noise, "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (*Federal Aid Highway Program Manual*, Volume 7, Chapter 7, Section 3).

FHWA Model. The currently accepted methodology for predicting highway traffic noise levels. The model is given in Report FHWA-RD-77-108, *FHWA Highway Traffic Noise Prediction Model* (*1*).

L_{eq}. The equivalent steady-state sound level that, in a stated period of time, contains the same acoustic energy as the time-varying sound level. Unless otherwise noted, the time period used in this report is 1 hr.

L_{10}. The sound level that is exceeded 10 percent of the time (the 90th percentile) for the period under consideration (1 hr. in this report). This value is an indicator of both the magnitude and frequency of occurrence of the loudest noise events.

Noise impact. The net effect of a highway project on the acoustic environment adjacent to the highway. A change of 5 dBA or less is usually considered negligible, whereas a change of 15 dBA or more is usually considered severe (*2*). The severity of the noise impact also depends on the relationship between the "after" levels and the design noise levels.

Noise level. The sound level that is obtained through use of A-weighting characteristics specified by the American National Standards Institute (ANSI) Standard S1.4-1971. The unit of measurement is the decibel (dB), commonly referred to as dBA when A-weighting is used.

Receptor. Any sensitive receiver of highway noise, such as a residence, a cluster of residences, a school, a church, a park, etc.

SNAP 1.0. The Simplified Noise Analysis Program 1.0, which is the simple computer program (*3*) of the FHWA Model. The updated version of SNAP 1.0 is referred to as SNAP 1.1.

STAMINA 1.0. The Standard Method in Noise Analysis 1.0, which is the complex computer program version (*4*) of the FHWA Model.

Type IA and IB Projects. A highway construction or reconstruction project, which may include noise barriers. Type IA projects have partial or full control of access; Type IB projects have no access control.

Type II Project. A project for the purpose of retrofitting an existing highway with noise-abatement features.

Wall. A noise barrier that is a thin, vertical structure made of concrete, wood, metal, or other material.

THE HIGHWAY NOISE PROBLEM

The federal-aid highway system has expanded rapidly in recent years, and now includes more than 40,000 mi (64,000 km) of Interstate highways. Much of this mileage, as well as that of other systems, is located within the metropolitan areas of the nation. The result is that many Americans live quite close to high-volume, high-speed highways, and thus a great number of people are exposed to high noise levels. Many other people reside in corridors that may one day see new highways constructed; without proper planning and design for noise abatement, these people may also be exposed to excessive noise levels.

The U.S. Environmental Protection Agency estimates that more than 90 million people are presently exposed to excessive highway noise levels (*5*). This situation naturally produces many opportunities for noise-control projects. The

New York State Department of Transportation, for example, has recently completed a study that identified 93 sites for noise-abatement treatment on the Interstate System alone (6). A 1981 FHWA report (7) estimates that 1,800 mi (3 000 km) of existing U.S. highways are in need of "retrofit" treatment for noise abatement. Based on past experience, this could represent a potential cost of more than $480 million (in 1980 dollars).

All federal-aid highway construction projects must comply with the requirements of FHPM 7-7-3. Many times it is necessary to include noise abatement treatment in order to comply with these requirements. The FHWA (7) estimates that nearly $200 million in barriers will be needed for noise abatement in the completion of the Interstate program. Many additional dollars will also be spent for noise abatement on the primary, secondary, and urban systems.

In many areas of the nation, particularly in the West, private developers are also constructing highway noise barriers. Although no estimate is available detailing the current inventory of privately constructed barriers or the future potential, both must be considered significant.

Taken collectively, it is possible that $1 to 2 billion will be invested to mitigate highway noise in the United States.

SOLUTION OPTIONS

For situations where a noise study indicates a traffic noise impact that can be reduced by abatement measures, FHPM 7-7-3 lists five measures for which federal funding participation is normally available:

1. Traffic management procedures.
2. Alterations of horizontal and vertical alignments.
3. Acquisition of property rights (either in fee or lesser interest) for installation or construction of noise-abatement barriers or devices.
4. Installation or construction of noise barriers or devices (including landscaping for aesthetic purposes), whether within or outside the highway right-of-way.
5. Acquisition of property to serve as a buffer zone to preempt development that would be adversely affected by noise.

This report concentrates on the installation and/or construction of noise barriers, which is the abatement measure most commonly used.

CONCEPT OF NOISE REDUCTION BY A BARRIER

Total noise reduction by a barrier is commonly referred to as insertion loss. Simply defined, insertion loss is the difference in sound level before and after a barrier is placed next to a highway.

Insertion loss has five components (8).:

1. Barrier attenuation due to the diffraction of sound waves over and around a barrier placed in the line-of-sight plane between the source and receiver.
2. Transmission loss of sound *through* the barrier.
3. Reductions in barrier attenuation resulting from multiple reflections caused by double barriers.
4. Shielding attenuation from other barriers between the source and the receiver.
5. Loss of excess attenuation already received from soft ground cover.

These concepts are discussed in more detail in Appendix A. For more complete analyses, see Barry and Reagan (1) and a report by the FHWA (7).

SYNTHESIS METHODOLOGY

In order to collect data and synthesize experience on noise barriers, two surveys of state highway agencies were undertaken. The first of these surveys, distributed in February 1980, was designed to obtain quantified information, such as number of projects, type, cost, physical dimensions, people protected, and year constructed. The second survey, distributed in August 1980, was sent only to those states that had constructed noise barriers, in order to gain insight into their experiences (see Appendix B). Twenty-seven of the 31 states that were surveyed responded.

The second survey sought information in 12 different areas:

1. Barrier materials and types
2. Costs
3. Design details
4. Acoustical design
5. Measured noise reduction
6. Perceived effectiveness
7. Community involvement
8. Construction
9. Maintenance
10. Priority systems for retrofit projects
11. Aesthetics
12. Safety

The surveys were supplemented with field visits in August 1980 to five states active in barrier design and construction (Arizona, California, Colorado, Oregon, and Washington).

SUMMARY OF FINDINGS

By the end of 1980, more than 189 mi (304 km) of noise barriers had been constructed in 31 states and Puerto Rico; 20 states and Puerto Rico had constructed more than one barrier (Appendix B). Through 1980, 85 percent of the barriers had been constructed in nine states (Table 1). The metropolitan areas with the most extensive barrier programs are Los Angeles and Minneapolis-St. Paul (Table 2).

Most barriers in the United States are constructed of wood, metal, concrete, earth (berm), or some combination of these materials. For the nation as a whole, the total lengths and costs of the various types of barriers are given in Table 3.

TABLE 1

STATES WITH THE MOST NOISE BARRIERS

State	Length ft	m	Number of Barrier Projects
California	331,394	101,009	116
Minnesota	186,906	56,969	27
Colorado	93,600	28,529	22
Virginia	64,300	19,599	30
Oregon	50,095	15,269	41
Arizona	49,718	15,154	8
Washington	27,425	8,359	24
Massachusetts	26,470	8,068	18
Connecticut	21,460	6,541	14

TABLE 2

METROPOLITAN AREAS HAVING THE MOST NOISE BARRIERS

Metropolitan Area	Length ft	m
Los Angeles, Calif.[a]	252,533	76,972
Minneapolis-St. Paul, Minn.	186,906	56,969
Denver, Colo.	69,885	21,301
Phoenix, Ariz.	49,193	14,994
Portland, Ore.	45,469	13,859
Washington, D. C.	42,083	12,827

[a]Most of the barrier length reported for the Los Angeles area is for the Type II retrofit program.

Existing federal legislation allows funds to be used for voluntarily "retrofitting" existing highways with noise barriers. Eleven states have responded to this opportunity by developing priority rating systems that objectively rank potential projects (see Chapter 5).

DETAILED REPORTING OF FINDINGS

Appendix C contains the detailed information gathered from the first survey. In total, more than 370 barriers were reported in response to that survey.

Chapters 2–5 of this synthesis reflect the information concerning state experience, as reported in the second survey. The survey areas have been clustered into four groups reflecting similar characteristics:

Chapter Title	*Survey Areas*
2. Design Details	III. Design Details IV. Acoustical Design V. Measured Noise Reduction
3. Social Impacts	VI. Perceived Effectiveness VII. Community Involvement XI. Aesthetics
4. Operational Elements	VIII. Construction IX. Maintenance XII. Safety
5. Priority Rating Systems for Type II Retrofit Projects	X. Type II Projects

In reviewing these chapters, it may be helpful to refer to Appendix B.

TABLE 3

MATERIALS USED IN NOISE BARRIERS

Barrier Type	Length ft	m	Cost in 1980 Dollars
Concrete	464,475	141,572	48,600,000
Combination	232,759	70,945	33,500,000
Wood	157,746	48,081	16,600,000
Earth Berm	128,711	39,231	5,900,000
Metal	14,298	4,358	2,000,000
Other	2,474	754	500,000
Total	1,000,463	304,941	107,100,000

CHAPTER TWO

DESIGN DETAILS

Design details concerning noise barriers include information from two broad categories: structural details and acoustical details. Areas III, IV, and V of the survey form (Appendix B) contain the questions relevant to these categories.

Only a few states, notably California and Minnesota, have had a large number of barriers in place for 5 or more years (see Appendix D). Thus most states do not have design standards for noise barriers as part of their standard drawings and specifications. Instead, the common practice is to develop a "custom" set of drawings and specifications for each project. Selected examples of California and Minnesota standards are included in Appendix D.

There is great variation among the states as to when a firm decision is made to construct a barrier. This is because there is really no *best* time within the project development process for committing to noise abatement. It is advantageous, for example, to wait as late as possible, so that all relevant input can be obtained, including precise availability of funds. However, it is often necessary to commit early, so that barrier requirements can be most efficiently integrated into the roadway plans.

Of the states responding to the questionnaire, most indicated that final decisions for Type I projects are made early in the design phase, shortly after approval of the final environmental impact statement. Several states defer the decisions until after all public hearing input is obtained, whereas a few wait until roadway plans and specifications are completed. For Type II projects, the decision is usually made after all the public input is gathered.

Principal decision-makers in the process are, in most cases, high-level engineering administrators functioning as part of a team. Typically, these administrators include the chief design engineer, chief planning engineer, and chief environmental engineer. They are often assisted by the district engineer and the local FHWA division office. In New Jersey, local elected officials are also accorded a role in the decision. Three states (Illinois, Minnesota, and Texas) report that the decision is made totally at the district office level.

Nearly three-fourths of the 27 states responding allow some form of community involvement in design issues, primarily through the public-hearing process. In Iowa and Pennsylvania, input is sought specifically concerning such items as material selection, landscaping, and aesthetics.

Most states do not encourage or discourage the use of proprietary barrier systems, and generally allow such systems at least to be bid as an alternative. Several states, as typified by Virginia, require that proprietary systems be reviewed and formally approved by a standing committee. These committees are usually interdisciplinary in nature, with members from the environmental, design, construction, and maintenance functions of the state highway agency.

SIZE, LOCATION, AND STRUCTURAL DETAILS

With respect to the quantitative aspects of barrier design, the states are quite consistent in that the *principal* criterion for height and length determination is meeting the FHPM 7-7-3 design noise levels (DNL). Within that general framework, however, there are wide variations. Texas, for example, has a policy calling for a 5 dBA insertion loss as a minimum, irrespective of the DNL. Many states also require that, in addition to meeting the DNL, the line of sight between source and receiver be broken. In Connecticut, the height of the source is assigned the value of 15 ft (4.6 m); in Missouri, the height is 10 ft (3 m); and in Florida, 8 ft (2.4 m). These heights are used only for line-of-sight checks; they are not used to calculate barrier attenuation. Missouri also requires that a wall be at least 1 ft (0.3 m) higher than the line-of-sight breakpoint, whereas Oregon recommends 2 ft (0.6 m).

In terms of barrier length, Michigan requires that a barrier extend a distance beyond the last receptor equal to 4 times the perpendicular distance from the receptor to the barrier. However, in Virginia, this distance need be only 2 to 3 times the perpendicular distance.

It should be noted that most of these somewhat arbitrary criteria will be unnecessary as the states move to full implementation of the STAMINA/OPTIMA Barrier Cost Reduction (BCR) package (*9*). This will allow each barrier to be optimized in its height, length, and cost so as to most efficiently meet the DNL. It has been estimated that cost savings of nearly 50 percent are possible with a BCR-type approach (*9*).

Two states, Maryland and Washington, report additional criteria for height and length selection—aesthetics and overall cost effectiveness. Inclusion of these criteria could result in an appropriate compromise for insertion loss goals.

Only California uses seismic criteria for the design of barriers (Appendix D). There is no consensus among the states for post embedment because each barrier is different. Iowa uses a criterion of 10,000 lb (44 kN) applied 3 ft (0.9 m) above the ground line when crash rails are used. Michigan simply requires embedment below the frost line.

Almost every state reports using the AASHTO sign specifications (*10*) for wind loading. Thus the design wind speed is usually between 70 and 100 mph (113 and 161 km/h), depending on location. Several states, in particular Nevada and California, have recently begun utilizing less stringent criteria, such as the Uniform Building Code (UBC), in order to reduce barrier mass. This area of structural design criteria is one where much potential exists to optimize barrier cost and still provide adequate noise protection.

Occasionally, barrier effectiveness can be optimized by placing part or all of the barrier at a location that is not contiguous to the highway right-of-way (ROW). In most cases, however, this is not done because of constraints in state highway laws, which usually limit ROW purchase for "highway purposes" only. This limitation can be reasonably met when barriers increase ROW width by slight amounts, but not when barriers are placed on new and separated, i.e. non-contiguous, strips. Only Minnesota reports purchase of separate ROW for a barrier project, which was a Type II retrofit. The closest that most states come to building barriers off the normal highway ROW is in a cost-effective end treatment. In this case, the barrier would "wrap around" the receptors and become almost perpendicular to the highway; this would necessitate the purchase of ROW outside that normally used for the highway.

ACOUSTICAL DETAILS

Within those state highway agencies more experienced in noise barrier design and construction, individual policies, both informal and formal, reflecting engineering judgment have evolved to serve as guidelines for noise-abatement projects. Many states appear to be heading in the same general direction.

For example, one-half of those states responding to the survey have adopted a minimum insertion loss (IL) criterion as a threshold for barrier decision-making. The most commonly used criterion is an IL of 10 dBA, although several have adopted criteria as low as 5 dBA for IL. In the latter case, all barriers will be designed to provide an insertion loss of *at least* 5 dBA, even if less is needed to satisfy FHWA guidelines.

Nearly three-fourths of the 27 responding states do not have specifications for barrier sound transmission loss (TL), usually because it is assumed that a wall of sufficient mass to withstand wind loads will naturally reduce transmitted sound to at least 10 dBA below the level of diffracted sound at any receiver. Six states require the amplitude of each one-third octave band from the noise spectrum of a typical heavy truck at 55 mph (89 km/h) to be reduced sufficiently so that the total TL is 20–23 dBA. (Virginia specifies 15 dBA.)

When asked what change in noise level would necessitate barrier construction regardless of FHWA DNL criteria, most of the 27 responding states indicated a general unwillingness to provide barriers unless the DNL were exceeded. Many agree, however, that a 10–15 dBA increase over existing levels is significantly serious to warrant a thorough barrier feasibility study.

In accordance with federal direction, every state responding uses either L_{10} or L_{eq} (or both) as descriptors in defining highway noise impacts. In addition, Louisiana, Minnesota, and Nevada sometimes use the descriptor noise pollution level (NPL) as a measure of the intrusiveness of highway noise. New Jersey also uses the NPL, although only to help set priorities for potential projects for its Type II retrofit system.

Again because of federal direction, most of the 27 responding states either use or are planning to implement the FHWA Model for highway noise prediction. Eighty percent, in fact, already use the STAMINA 1.0 version of the FHWA Model. Several others use the SNAP 1.0 and 1.1 versions. Arizona and Nevada use the hand-held calculator version, although Arizona will shortly be implementing STAMINA. New Jersey uses the TSC MOD 04 program (*12*) as well as STAMINA; and Florida and Wisconsin use methods given in *NCHRP Report 117* (*2*) and *NCHRP Report 144* (*13*), properly modified to incorporate the requirements of FHPM 7-7-3.

One of the strengths of the FHWA Model is its flexibility in modifying the national reference energy mean emission levels for automobiles, medium trucks, and heavy trucks. FHWA currently requires that these national values be used *unless* the state highway agency makes modifications through the application of standard measurement procedures. Ninety percent of the 27 responding states have thus far chosen to use the national values, which were developed after an extensive measurement program conducted in four states: Colorado, Florida, North Carolina, and Washington. Florida has chosen to use only those data gathered in its own state for emission-level development. In addition, New Jersey has developed its own emission levels, and Michigan is currently in the process of doing so.

In calculations for barrier attenuation due to diffraction, the FHWA Model assigns source heights of 0.0 ft (0.0 m), 2.3 ft (0.7 m), and 8.0 ft (2.4 m) for automobiles, medium trucks, and heavy trucks, respectively. Most responding states have incorporated these source heights into their modeling schemes without modification. However, several states have opted for a more conservative source height for heavy trucks, so that the receiver line of sight will be broken with respect to the top of an exhaust stack. These states include Virginia—13 ft (4.0 m), Connecticut—12 ft (3.7 m), and Iowa—11.5 ft (3.5 m).

Another conservative measure in barrier design is to design for completely adequate protection to the most critical receptor, which is usually an individual residence. An alternative to such an approach would be to design for the centroid of a cluster of affected houses; thus the typical house would receive adequate protection, even though a small percentage of houses may not be adequately protected. Nearly two-thirds of the 27 responding states take the conservative approach and design for the most critical receptor. Several of the states with considerable experience in barrier design and construction, such as Colorado, Connecticut, and Minnesota, follow this approach. However, several other states with much experience, including California, Michigan, and Virginia, do not follow this conservative approach.

There are several measures that should be applied in the evaluation of a barrier: aesthetics, community acceptance, optimized cost, and acoustical effectiveness (insertion loss). The last measure, acoustical effectiveness, is important to the state highway agency because real noise reduction is the initial and principal justification for even considering the required expenditures. Therefore it is important to know which type of barrier provides the most acoustical value.

In those states responding to the survey, earth berms, without question, are perceived to be the most effective for noise reduction. This is not at all surprising when the geometry and absorptive characteristics of berms are considered; in fact, the prediction models allow an extra 3 dBA attenuation when a barrier is specified as a berm.

Interestingly, the second choice of the states is also clear.

Four states (Arizona, Colorado, Iowa, and Virginia) that listed second most effective barriers rated concrete more acoustically effective than wood or metal. It should be pointed out that this selection (concrete) is intuitive in nature, because, as can be seen in Appendix C, none of these states reported field measurements for insertion loss with concrete barriers.

A problem often encountered in design, which can lead to compromise in noise reduction, is leakage of sound through required openings for maintenance access or drainage. Several states have attempted to solve this problem, with varying degrees of success. Louisiana, for example, has used gravel fill in lieu of openings or structures for drainage. This is a very effective solution from the acoustics standpoint, but may have limited application due to flow rates and quantities of runoff. Virginia uses box culverts, which also are effective but may be expensive.

The problem of noise leakage through maintenance access openings has been solved in several ways. For example, Maryland has prepared detailed door designs that do not allow leakage when properly installed. In Virginia, doors or gates are designed with rubber seals to ensure a tight fit. It is usually necessary to include small openings for fire hoses in case of certain types of accidents. Minnesota, as well as several other states, solves this problem by placing "knock away" covers over the openings.

An important aesthetic consideration is to maintain continuity of appearance throughout the barrier section. For example, it would not be wise to place a brown wooden access door in an otherwise grey concrete wall. Instead, the door should be painted a color similar or identical to the rest of the wall. It is also important for the door area to be the same height as the wall at either side.

A potential problem, but one that has rarely been documented, is loss of acoustical effectiveness due to parallel barriers and the resultant reverberant buildup. This has not generally been recognized as a problem because, in most actual applications, walls are not close enough together to bring about insertion loss degradation. The sole situation reported was on I-95 in Philadelphia; the problem was solved by lining one of the two walls with absorptive material (*14*).

There have been several attempts to reduce possible sound reflections by noise walls. For example, Minnesota has extended barrier heights in order to avoid the first reflections when parallel barriers are used. This is because parallel barriers are thought to raise the effective source height of the roadway. In Oregon and Washington, the walls have been tilted back slightly under similar circumstances in order to reduce sound reflections. A tilt angle of 5 to 10 degrees may be sufficient (*11*).

Other states, such as New Jersey, Pennsylvania, and Virginia, have attempted to solve the sound reflection problem by acoustically treating, or texturing, the wall surface. This results in a higher coefficient of absorption, although the wide range of wavelengths associated with broad-banded highway noise minimizes the effects of surface treatments. When it is necessary to significantly reduce reflections from vertical walls, it is advisable to use a material with a high overall noise reduction coefficient (NRC), and with adequate absorption in all four of the frequency bands making up the NRC: 250, 500, 1000, and 2,000 Hz. Generally, the absorption coefficients for each of these bands should be no lower than 0.6, and preferably no lower than 0.8.

The prediction models provide for the calculation of insertion loss. However, it is good engineering practice to validate the model results in the field and thus determine the insertion loss via field measurements. Several of the states with barriers in place make it a practice to measure insertion loss; however, many do not (Appendix C). For those that do measure, the most commonly used procedure for measuring insertion loss is contained in the report "Sound Procedures for Measuring Highway Noise" (*15*). The insertion loss measurement procedure from this document is presented in Appendix E.

CHAPTER THREE

SOCIAL IMPACTS

The ultimate test of the effectiveness of a noise barrier project is its impact on society (residents and the motoring public). Many questions, therefore, were asked of the state highway agencies concerning societal impacts. The questions were grouped into three general categories: community involvement, perceived effectiveness, and aesthetics. Areas VI, VII, and XI of the survey form contain these questions (Appendix B).

COMMUNITY INVOLVEMENT

Highway noise and noise control are apparently serious issues in the public domain. More than 80 percent of the 27 responses indicated that the public is interested in highway noise abatement. Several states (Missouri, Nevada, New Jersey, Ohio, Texas, and Wisconsin) qualify this conclusion by stating that only those who are directly affected are interested. California, Colorado, and Michigan report that interest is sufficient to generate numerous requests for abatement projects. Only the state highway agency in Louisiana reports that its citizens do not appear to have much interest in highway noise abatement.

Not only is public involvement and input sought by the state highway agencies, it is often used as the primary decision-making tool for determining whether a barrier will be constructed, assuming technical feasibility and cost-effectiveness. One-half of the 27 responding state agencies are on record as stating that the public choice will be satisfied in go or no-go decisions. Illinois goes so far as to abide by a vote record. A generalization on this issue is that the more experience an agency has in barrier construction, the more important it considers public opinion and input.

Most of the states utilize systematic procedures to obtain community involvement. These procedures are designed to involve the public as early in the process as possible, which is usually about the same time that the go-ahead decision on barrier implementation is made—early in the design phase or in the midst of the EIS development. Several states, including Minnesota and New Jersey, with Type II programs require that the public organize and endorse potential projects before the highway agency will implement a retrofit solution.

Traditional techniques for involving the public are used by the states for highway noise issues, including project public hearings, special meetings on noise issues, informational mailings, telephone and personal interviews, and questionnaires. In Oregon, the state works with citizen advisory committees; Delaware works with civic associations. Pennsylvania has established working groups made up of neighborhood association representatives and state highway engineers. These approaches have proven effective in obtaining general cooperation, coordination, and satisfaction.

Almost all of the states with noise barrier experience present noise-abatement plans at formal and informal meetings. Only Delaware and Texas report that these meetings are poorly attended. On the average, 50 percent of the affected residents may be expected to attend such a meeting. The states usually rely on visual and/or audio aids in presenting the case for noise abatement. Many states, including Michigan and Minnesota, use plans, sketches, renderings, slides, and, sometimes, models to visually represent a barrier. In California, Illinois Kentucky, Michigan, and Minnesota, tapes of highway noise are placed with differences in sound level simulating insertion loss, in order to give the public a better understanding of proposed barrier effectiveness. Maryland, Minnesota, and Virginia have also used coordinated slide/tape presentations to graphically describe highway noise principles.

Although rare, there have been instances where completed noise barriers have been removed. In Minnesota, safety considerations dictated the removal of a wall; however, the protected property owners requested its reconstruction. A proprietary barrier was temporarily removed in New York because of unsatisfactory soil conditions and subsequently reinstalled with a strengthened foundation design. Earth berms were removed in Wisconsin because adjacent residents could not see the freeway or their neighbors across the right-of-way. Apparently, these considerations were believed to be more important than the achieved noise reduction.

There have also been several incidents where barrier implementation has negatively affected advertising by commercial and industrial organizations. In Washington, a small end section of an earth berm that was blocking exposure to an appliance store was removed. An earth berm was removed in Wisconsin because the owners of an industrial park claimed that exposure and therefore potential profits were significantly reduced. Minnesota reported at least one location where a barrier height was reduced directly in front of a business because the owner vigorously objected to the loss of exposure. The state highway agency readily admitted that this height reduction compromised noise reduction at several residences, but believed it was necessary in order to adequately consider the interests of the business. Colorado also reports incidents of accommodation to business concerns and interests. This problem has also been encountered in California.

Only 11 states have developed procedures for considering Type II retrofit projects. In almost every case where such procedures do exist, however, provision is made for adequate consideration of community and public views. In fact, the policy in Minnesota is that a Type II project will not be implemented unless a resolution in support has been passed by the appropriate local government legislative body. Other states, such as Connecticut and Iowa, conduct special meetings where public sentiment can be determined. The details of these Type II retrofit procedures are described in full in Chapter Five. However, one conclusion may be drawn at this point: the 11 states agree that these procedures should include adequate community involvement.

PERCEIVED EFFECTIVENESS

There are several methods a state can use to ascertain the perceived effectiveness of its barrier projects, some of which are passive and some active. The passive methods include the cataloging and analysis of unsolicited public complaints and comments, and the recording of media statements, such as newspaper articles and editorials and television reports. The experienced state highway agency goes beyond the passive and actively pursues data concerning perceived effectiveness of its barriers. This is usually accomplished through some form of systematic solicitation, such as questionnaires or telephone surveys.

Most states realize the need to perform social surveys on their barrier projects, but are often unable to do so because of limited resources. In fact, only 12 of the 27 responding states indicate that they perform social surveys as a matter of practice, and several of those were limited in scope. For example, in Connecticut social surveying is done only on the retrofit program, and in Minnesota social surveying is performed in only one of the two Twin Cities districts.

The questionnaire is by far the most commonly used tool for social surveying. Every state that performs social surveys reports utilizing questionnaires, either through direct mailing or door-to-door interviews. Content of the questionnaires obviously varies depending on the particular situation, but some general guidance can be offered. First, it is important for the questionnaire and the interviewer (if personal contact is used) to be totally objective and nonintimidating to the property owner. Second, it is important that the questionnaire not be cluttered with too many unrelated questions and focus directly upon the issue at hand—the highway and its impacts (*16*). However, noise should not be over-emphasized in the survey, in order to prevent bias. Third, the questionnaire should deal with all subjects related to the barrier, such as noise reduction, aesthetics, landscaping, and view. Examples of questionnaires from Minnesota and California are given in Appendix F). Also included in Appendix F are suggested questionnaires for use before and after barrier construction; these questionnaires were developed by F. L. Hall of McMaster University (*16*).

Noise impacts from highways are by their nature quite localized in their sphere of influence. Therefore, it is usually possible and appropriate for virtually *all* affected residential dwellers within the project area to be contacted. The basic issue to be decided, then, is how far back into the project area the survey should extend. The responding states generally agree that it is not necessary to go deeper than the second row of houses back from the right-of-way. In California, the survey usually stops at the first row; however, a recent research study went to the third row. Michigan goes to the fourth row, and Minnesota has been as far back as the fifth, although the second row is usually the limit. Colorado extends its survey area back to the (before barrier) L_{eq} = 67 dBA contour line, as does Virginia. Kentucky also bases its survey depth upon degree of impact. For a more complete analysis of data gathered beyond the first row, it is usually advisable to keep the responses separated by row, so that trends may be better observed.

It is appropriate to mention some of the problems experienced by the state highway agencies in their attempts at social surveying. One of the less critical problems is an unsatisfactory return of mailed questionnaires. Iowa, for example, reports a return rate of only 50 to 60 percent. Oregon reports not finding people at home during working hours when surveys are conducted. Florida reports that frequently the tenants of a particular dwelling unit will change during the period between the before and after surveys, thus reducing the validity of comparisons.

Other problems reported include the large amount of manpower required to quickly gather social survey data in a large area. However, the costs associated with the survey are not really significant when compared to costs of the barrier itself. The real problem is one of nuisance, because the project manager must somehow acquire enough volunteers or draftees to actually go into the field.

An important consideration in the perceived effectiveness of a barrier is its appearance. A major factor in appearance is attractiveness of the material used to construct the barrier. A general consensus from the responding states is that earth berms make the most attractive barriers. Beyond that, most states have not had enough experience with other types of materials for a statistically strong pattern to emerge. Three states (Florida, Maryland, and Washington) reported that their constituents have not expressed any preference. Significant conclusions are drawn, however, by five states (Colorado, Connecticut, Minnesota, Oregon, and Virginia). These states rate the various types of barrier in order of their community acceptance:

Barrier Type	Acceptance Ranking
Berm	1
Wall*/Berm Combination	2
Wood	3 } tie
Concrete	3 } tie
Metal	5

*Wall can be wood, concrete, or metal.

Surprisingly, not all of the states report a correlation between acoustic considerations and perceived effectiveness. Oregon and Connecticut have observed that existing levels and insertion loss achieved have a bearing upon perceived effectiveness. However, Colorado and Minnesota have noted no such effect, and Florida has noted a correlation only in the case of insertion loss.

The responding states indicated that landscaping and other aesthetic amenities have a greater influence on perceived effectiveness than does acoustics. Another important parameter affecting perceived effectiveness is the timeliness of public involvement. The earlier the public is involved in the barrier selection process, the higher the perceived effectiveness of that barrier.

When properly conceived, designed, and constructed, a barrier should always have a positive impact on the community. In actual practice, however, it does not always work that way. Two states (Michigan and Minnesota) have actually been taken to court by citizens attempting to have barriers removed or to recover damages resulting from a barrier. In addition, Oregon has taken down a barrier under the threat of litigation.

Many studies conducted throughout the United States and Canada have concluded that barriers are well-received by the community (*17–19*). In fact, many highway projects would meet greater opposition from the community if barriers were not included (*20, 21*). In addition, those states that have initiated retrofit projects have found that the community is enthusiastic about and supportive of barriers (*18, 22*).

Only two states noted negative driver reaction to in-place barriers. Complaints in Minnesota have come not from commuters but, surprisingly, from tourists. Virginia reported various driver complaints, including (slightly paraphrased):

Why spend so much on so few?
Why do *I* pay for someone else's comfort?
Barriers are eyesores.
They make driving monotonous.
They block the scenery.
They make the highway ride noisier.

AESTHETICS

Aesthetics is a concept that is quite subjective by nature and a major component in perceived effectiveness. This subjective nature increases the importance of obtaining approval of the affected community. Almost without exception, the public-involvement process used by the states for presenting general environmental and specific noise-related issues is also the process by which aesthetic input is obtained. This process, including public meetings, mailed questionnaires, and door-to-door surveys, was discussed above. Only two states (Nevada and Wisconsin) report that they have no process for receiving public input concerning barrier aesthetics.

The states with significant experience in barrier design and construction usually have an effective aesthetics plan. In fact, 95 percent of the 27 responding states indicate that landscape architects and/or other design professionals are involved in the aesthetic treatment design. Typical aesthetic treatments include decisions on type, density, and location of plantings; material selection and color; and, sometimes, surface texture. These decisions can be complicated, and, without the assistance of trained professionals, may be easily misdirected. Several situations have been reported around the country where acoustically effective barriers have become targets of public derision because of an improperly selected color or landscaping scheme.

This issue is a particularly sensitive one. Only three of the responding states even ventured to draw conclusions concerning the relationship among aesthetics, perceived effectiveness, and acoustical effectiveness. Colorado claims that a "psychological attenuation" of up to 7 dBA in perceived effectiveness may be gained with a well-received aesthetics plan. Florida, while not quantifying the relationship, concurs that the correlation is strong. Washington notes that there is a stronger correlation for landscaped earth berms and perceived effectiveness than for other types of barriers. Most states, however, are unwilling to draw any conclusions, usually citing a lack of data.

Noise barriers are often massive and expensive structures. It is to be expected, therefore, that the print and broadcast media would generate, or at least report, reaction to barrier aesthetics. However, less than one-half of the 27 responding states report such reactions, and the reactions are extremely varied. Washington, for example, reports generally unfavorable media coverage, despite the fact that adjacent residents favor the barriers. Colorado, Florida, Louisiana, and Pennsylvania report generally favorable media reaction to their projects. Connecticut has one particular set of barriers that have been extensively vandalized with graffiti; these barriers have received adverse media coverage. Three states (Michigan, Minnesota, and Virginia) have encountered mixed reviews from the press. In Virginia, there has been mainly negative reaction to the I-495 barriers in suburban Washington, but generally positive reactions elsewhere in the state.

The concept of placing murals or graphics on barriers as an aesthetic treatment is innovative and trend-setting. Only Minnesota and Pennsylvania report any great amount of experience in this area. In New Brighton, Minnesota, a sailing and swimming scene is depicted on the backside of a barrier along I-694 (Figure 1). The barrier is protecting a recreational lake, and the state highway agency deemed it essential to maintain the general flavor of the area through the use of murals. On a different section of the same barrier system, in an effort to reduce driver monotony, some graphics were added to the roadway side of the barrier (Figure 2). Pennsylvania was ordered by the court to work with the local citizens in developing an aesthetics plan for the barriers along I-95 in Philadelphia. The result was an extensive series of murals that depict the sunset and provide historical insight into the area's past. The murals were developed by using concrete blocks of different colors set in prearranged patterns (Figure 3).

FIGURE 1 Mural on back of barrier in Minnesota (*23*).

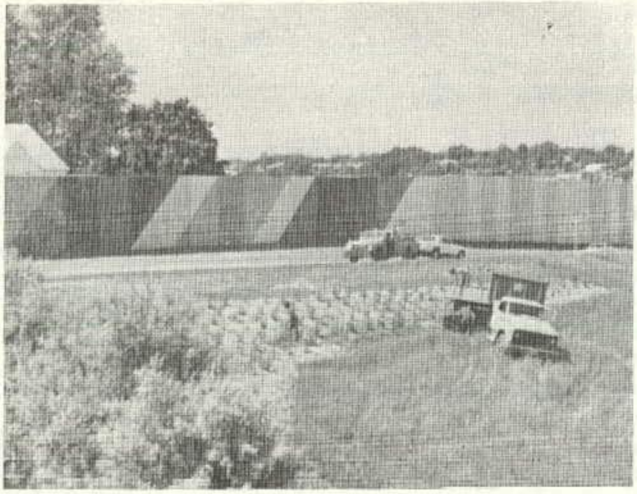

FIGURE 2 Graphics on roadway side of barrier in Minnesota (*23*).

Whether a state highway agency ultimately includes complicated treatments such as murals and graphics in its aesthetics plan or simply uses standard landscaping techniques, one conclusion is quite clear: maximizing public involvement in the development of an aesthetics plan will significantly increase the perceived effectiveness of the barriers.

REPORTED PROBLEMS

Several problems that have serious implications for state highway agencies have been identified. First, Colorado has reported a problem in defining what constitutes majority acceptance of a proposed barrier. This is especially critical for Type II retrofit programs, where the state needs a clear indication as to whether or not it should proceed. The fundamental question is: What is a clear indication? Suppose, for example, a survey reveals that 60 percent of the involved public favors construction of a barrier but the other 40 percent is opposed. To satisfy the 60 percent in favor, the wishes of a large segment of the public must be ignored. On the other hand, not to construct will disappoint a majority segment. Unfortunately, there is no quantitative formula that can be applied to develop the "*clear* indication."

It should be determined, however, that a significant majority are in favor, or the state may be vulnerable to the argument of squandering tax dollars. The state may also be vulnerable to lawsuits from citizens seeking relief from the loss of view and light; Minnesota has been involved in such litigation. Colorado has attempted to overcome this problem by leaving gaps in barriers behind those homes where the property owners prefer view over noise reduction. This approach, however, has greatly compromised insertion loss for other property owners in the vicinity of the gaps. The most effective solution is for the state to accept the formal opinion of the governing local legislative body or elected officials.

A second major problem has been encountered in both Virginia and New York. This concerns the separation of general opposition to a controversial highway project from an accurate assessment of community feelings toward barriers included as *part* of the project. Quite frequently, especially at public hearings, residents exhibit animosity toward the barriers in the hope that it will help kill the entire project.

Another problem that warrants mention has been reported by Virginia. Property owners who just barely miss qualifying for barriers because their predicted noise levels come extremely close to but do not exceed the design noise levels often do not understand the reasons for the decision not to construct the barriers, and have complained to the state highway agency that they are victims of "a silly magic federal guideline." It should be noted, however, that FHWA regulation (FHPM 7-7-3) and policy actually *encourage* state highway agencies to seriously consider barriers even where the design noise levels are approached but not exceeded, or where predicted levels significantly exceed existing levels. The FHWA has never intended for the DNL to serve as an arbitrary cutoff point.

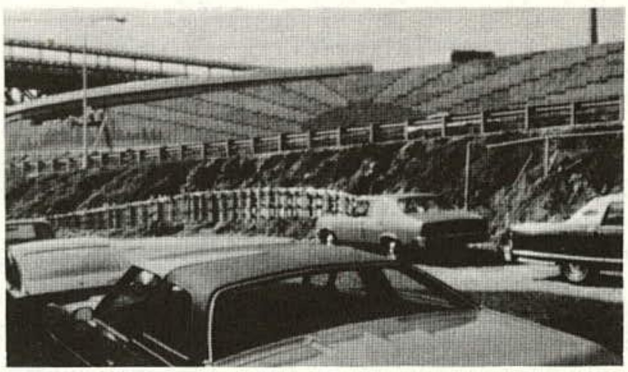

FIGURE 3 Multicolored concrete block barrier in Philadelphia (*14*).

CHAPTER FOUR

OPERATIONAL ELEMENTS

Once a noise barrier project leaves the design phase, it presents an entirely different set of challenges to the state highway agency. No longer are insertion loss and public involvement issues to be confronted. Instead, the highway agency is concerned with highway operations, including construction, maintenance, and safety. Questions on the survey form concerning these three subjects are found in areas VIII, IX, and XII, respectively (Appendix B).

CONSTRUCTION

Construction of noise barriers is ordinarily accomplished by experienced highway contractors who are accustomed to confronting complex field challenges. Therefore, it would be expected that barrier construction would not present any particularly difficult problems that could not be resolved on the site. For several reasons, however, this is not the case. First, barriers are frequently made of materials (wood, metal) that are not normally used as finished products in highway construction. Second, the tolerances for acoustic performance are often very tight, yet not comprehensible to the contractor. Last, the aesthetic design of the barrier is often misunderstood by the contractor, in whose hands the visual quality of the final product lies. Thus, without careful design and planning, the barrier as constructed on the site may not resemble what the noise analyst, environmental planner, or landscape architect had in mind.

Many of the 27 responding states report no special or unusual problems during barrier construction, including those with much experience such as Connecticut, Illinois, Nevada, Oregon, and Washington. Other states, however, report a wide variety of construction problems, including:

- Difficulty in establishing slope controls for berms with complicated geometrics (Arizona).
- With 4-ft (1.2-m) concrete panel widths, difficulty in traversing slopes of 8:1 or steeper while maintaining a 6-in. (150-mm) maximum drop in panel levels (North Carolina).
- Lack of uniformity in barrier material color, particularly wood (Colorado).
- Inventory damaged while waiting erection (Colorado).
- Difficulty in forming precast concrete barriers so that the cap fits properly (Florida).
- Insufficient soil-boring information leading to improper foundation design (Michigan).
- Barrier tilted (Minnesota).
- Problems with wood shrinking, warping, and separating (Minnesota, Missouri).
- Inadequate seal between barrier and interface with ground, post, or safety barrier (Delaware, Minnesota).
- Mounting of concrete panel directly behind an in-place retaining wall requiring tiebacks to relieve added load (Minnesota).
- With a metal wall, expansion and contraction causing panels to detach (Iowa).
- Problems with material availability (Virginia).
- Difficulty in obtaining lateral support for concrete panels in unstable wet soil conditions (North Carolina).
- Difficulty in obtaining borings for a metal wall foundation in a rock fill (Arizona).
- Complications in removing existing utilities and old foundations (Pennsylvania).
- Certain soil conditions requiring the use of cast-in-drill-hole piles (Nevada).

Connecticut reported a unique problem with an earth berm. The original side slopes were too steep (1.5:1), which resulted in failure during a particularly rainy season. The problem was solved by flattening the slopes to 2:1, eliminating step benches midway up the berm, and covering the berm with gravel.

In Wisconsin several problems in barrier construction were reported, and some rather innovative solutions to these problems were developed. The following paraphrased statements relate the experience of Wisconsin in efforts to construct barriers made of three different materials—fiber glass, precast concrete, and wood:

1. Fiber-Glass Barriers

   a. The required wall thickness was not always obtained. The contractor chose to manufacture the fiber-glass planks using a section-by-section method; however, quality control was difficult to maintain. In future contracts the department would require that the planks be manufactured by an extrusion method, which had been an option.

   b. The fiber-glass barrier system was designed to allow the planks to be slipped into posts and provide a snug fit. Dimension tolerances within the plan, however, were not stringent enough and allowed excessive movement in the wind. The problem was solved by using polystyrene and wood wedges to produce a tight fit at all posts. In future contracts, the design would include a positive method of attaching planks to posts by bolting or some other means.

2. Precast Concrete Barriers

   a. The design of the precast concrete barrier system resulted in numerous panel sizes and caused inefficiencies in storage and erection. The number of different panel sizes will be kept to a minimum in future contracts.

b. Materials testing showed that some panels were unacceptable. It was not possible to pick the unacceptable panels from the numerous panels of the same size. In future contracts, all panels will be required to have their own identifying marks, so that unsatisfactory panels will be easily identified.

c. Some of the panels had cracking at a 45-degree angle in the corner. In future contracts, some additional steel, possibly in the form of an angle bar, will be placed in the corners.

d. The ASTM A 588 structural low alloy steel posts used were not uniform in color or texture because of mill scale. Future contracts will require sandblasting to obtain more uniformity.

3. Wood Barriers

a. Most of the construction problems that occurred can be attributed to the moisture content. The specifications allowed 19 percent; since then it has been determined that moisture content in excess of 15 percent will cause warping. The contract provided extra vertical braces to keep the tongue and groove decking from separating.

b. In addition to the above changes, the design would also reduce the number of planks by using a wider plank (or built-up section) and eliminate butt splices except at vertical braces. These changes would all contribute to a tight fit of all planks to eliminate openings.

It is sometimes difficult for the state highway agency to determine accurate costs for barrier construction when the barriers are included as a bid item in the highway construction package. This usually results in excessive reported barrier expenses, because a common practice among highway contractors is to "load" the front end, or early portion, of the contract in order to get ahead in reimbursements from the state. Nearly one-half of the 27 responding states have attempted to solve this problem by letting separate contracts for the noise barriers. This has several advantages, not the least of which is that the lowest possible price is secured. Also, the selected contractor will concentrate efforts on constructing the barriers, which should generally increase the overall quality of the final product. However, when an earth berm is to be constructed of excess excavation material, a separate barrier contract is not advisable.

The states that have Type II retrofit experience report that the construction period is less than 1 yr. In Connecticut, Colorado, Iowa, and Oregon, the typical construction period has been 3 to 6 months, or one construction season or less. Maryland, Minnesota, and Pennsylvania report the typical construction period to be 9 to 12 months, or one to two construction seasons, depending on the weather. Obviously, the length of the construction period depends on the size and complexity of the project involved. Michigan and Ohio indicated that no typical period may be assumed. (Type II projects are discussed more fully in Chapter 5.)

An advantage can be gained by constructing noise barriers early in the highway construction project schedule in order to shield construction-related noise. More than 60 percent of the 27 responding states ordinarily attempt to gain this advantage, although several report difficulties in accomplishing early barrier construction because of phasing problems. In Washington, the contractor is given the decision-making authority to construct the barriers at any time in the project schedule.

MAINTENANCE

One of the most critical issues concerning noise barriers is maintenance. Highway maintenance is an area where needs greatly outstrip available funds, which means that any new, ancillary activity causing increased maintenance costs will be viewed negatively. Noise barriers would certainly qualify as a new, ancillary activity, and, therefore, the noise barrier design objective should be a maintenance-free structure. Unfortunately, the experience of the states does not reflect this objective. More than 80 percent of the 27 responding states report one or more problems that have resulted in higher maintenance costs.

Several problems are relatively common throughout the country. For example, many states report increased difficulty in mowing, with the result that more manpower is needed to cover a given area. Colorado reports an inability to mow berms with side slopes steeper than 3:1. Another common problem is litter accomulation and excessive weed growth in the immediate vicinity of the barrier. Elimination of litter and weeds is a task accomplished principally with manual labor and may therefore become quite expensive.

Another problem widely reported is vandalism, particularly on unopened sections of highway. The most common activity of vandals is covering the barriers with graffiti using paint brushes or spray paint. The removal of graffiti can be both expensive and difficult. Painting over graffiti usually produces unacceptable variation in color or tone. For concrete barriers, nothing short of sandblasting will work, unless the surface has been treated with a sealant. This treatment will add significant capital cost to the barrier (on the order of 10 dollars per square meter) but in the long run may reduce maintenance costs. Another solution to the graffiti problem is to plant a thick, thorny ground cover on both sides of the barrier in order to eliminate access to the barrier face. This is commonly done in states, such as Minnesota, where barriers are placed on top of berms. Other vandalism problems that have been reported include: stolen wood slats and plantings in North Carolina, a piece of a metal wall cut out of a barrier in Michigan, wood barriers set on fire in Colorado and Minnesota, a metal wall in Arizona pelted with rocks and gunshots, a cap removed from a concrete block wall in Oregon, and a barrier in Colorado destroyed in order to gain access to an adjacent roadway.

Additional maintenance problems reported by the states include:

- Damage of a metal wall from baseball activity (Arizona).
- Snow removal (Colorado, Minnesota).
- Icing on protected areas (Colorado).
- Loss of caulking material (Minnesota).

• Unavailability of replacement parts and materials (Colorado, Virginia).
• Warping and openings in wood barriers *after* construction (Connecticut, Colorado, Minnesota).
• Death of vegetation (North Carolina).

State highway agencies usually place chain link fences on ROW lines of controlled-access highways in order to prevent random encroachment and activity on the ROW. The introduction of noise barriers within that ROW creates a "dead space" between the barrier and ROW fence. This space is virtually inaccessible from the highway side, where most maintenance activities originate. A good solution to this problem is to place the barrier right *on* the ROW line, thereby allowing the barrier to also serve as the ROW fence. Colorado reports general use of this approach, as does New Jersey.

The majority of the responding states do not place or replace ROW fences behind noise barriers other than berms. Berms, of course, do not physicially block potential trespassers, unless a prohibitive ground cover is used on the berm.

It is often difficult and expensive to provide adequate maintenance services behind barriers. Therefore, several states have given, through deed, that area to the property owners with the provision that maintenance is the responsibility of the property owner. To do this, of course, the highway agency must take down the ROW fence so that the property owner can have complete access to the "new" property. In order to be fair to the property owner, the deed must clearly prohibit an increase in property taxes resulting from the transfer. Colorado, Iowa, Louisiana, Minnesota, Nevada, and New Jersey have all at one time or another completed this type of agreement (although not necessarily by deed) with adjacent property owners. In Washington there have been situations where such an offer was made but not accepted by the property owners.

One way to minimize future maintenance costs and problems is for the noise analyst, barrier designer, and landscape architect to consult with highway agency maintenance engineers before and during the barrier design. Nearly 60 percent of the 27 responding states routinely include such consultation in their design process. Several states have gone so far as to set up interdisciplinary teams to review barrier plans. These teams usually include a maintenance representative (see Chapter 2 for discussion concerning decisionmakers for barrier projects).

The need to provide maintenance access doors was discussed in Chapter 2, as were two concepts designed to minimize insertion loss degradation. Approximately one-half of the 27 responding states have not addressed the problem of maintenance access, preferring instead to send their crews around the ends of barriers, or to approach the back sides of barriers from frontage roads or through yards.

One alternative to providing access gates that still allows for maintenance access is to place an overlapping section (Figure 4). It has not yet been determined how far the overlapping section must extend before insertion loss degradation becomes negligible. However, it is clear that reverberant buildup within the overlapping section is significant. Construction of a section that is sufficiently long may appreciably

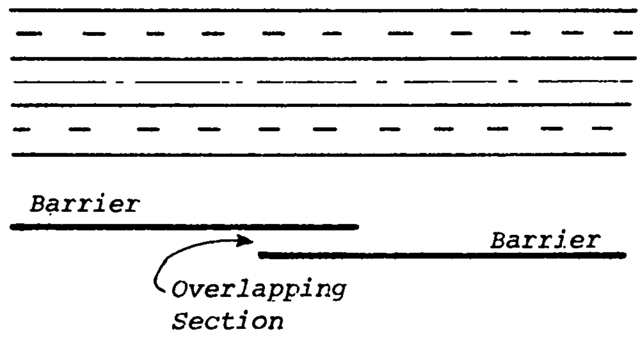

FIGURE 4 Overlapping section of barrier to allow access for maintenance.

increase barrier cost. The California Department of Transportation (Caltrans) Research Laboratory (*24*) has determined through a recent study that the overlapping section can be greatly shortened with the insertion of sound absorbing cladding into the overlap area on one side. For one particular test site, it was found that an opening-to-overlap ratio of 2.4, with cladding, was sufficient to eliminate any degradation at a distance of 45 ft (13.7 m). Caltrans (*24*) also found that:

> There is a degradation in acoustical properties of noise barriers when maintenance access openings are constructed. However, the high noise levels are concentrated near the opening and diminish rapidly as distance from the opening increases. Therefore, the locations of the receiver, the noise source, and the barrier opening position are determining factors in designing barrier openings and assessing impacts.

SAFETY

Only four of the responding states reported any experience with vehicular collisions with in-place noise barriers. These events should be minimal because the barriers must always be set a good distance away from the driving lanes, or protected by guardrails or traffic safety barriers. Nevertheless, Colorado, Michigan, Minnesota, and Virginia each reported one or more collisions. Minnesota reported one fatality resulting from a high-speed chase that ended in a collision with a noise barrier.

With the exception of the collisions reported above, there have been no major safety problems encountered in the use of barriers. Several states, however, reported two concerns relating to safety that are dealt with in the design phase. The first is providing protection to the ends of barriers at exit ramps, which is usually accomplished with protective guardrail end treatments or impact attenuators. The second concern is that of sight distance around curves. It is often necessary to increase the perpendicular distance from the pavement edge to the barrier at mid-curve, in order to maintain adequate stopping sight distance. This increased distance between source and barrier will in most cases degrade insertion loss. Nearly one-half of the 27 responding states noted this concern.

The principal reason that safety has not been more of a problem is that particular care is usually taken in design. In addition to barrier-end protection and adequate sight distance, safety barriers or guardrails are routinely provided if the noise barrier is within 30 ft (9 m) of the travelway. Minnesota uses "rub rails" attached to the walls in such situations. Pennsylvania includes specifications for minimizing glare in its contract documents.

As discussed previously, one-half of the 27 responding states do not provide access doors for maintenance activities. Instead, access is usually provided around the ends of the barrier. It would be reasonable to assume that even fewer states provide access doors for emergency vehicles. Several states indicated that the maintenance access doors could also be used for emergency access. More than 80 percent of the 27 responding states, however, report no consideration of this issue.

It might be expected that long sections of noise barriers on both sides of a highway could cause a "tunnel effect" for drivers, which might result in possible driver-alertness problems. However, no state responding to this survey reported any knowledge of such a problem. It may be safely assumed, then, that the tunnel effect is not a significant problem.

Another potential problem concerns personal and/or home safety. Because noise barriers reduce visibility and shield certain areas from light, it is reasonable to assume that acts of vandalism, muggings, or burglaries might increase. Only two states (Connecticut and Florida) indicate any problems in this area. On the other hand, the additional security provided by barriers has been reported as a significant benefit for property owners. With barriers in place, residents are no longer bothered by motorists climbing ROW fences to enter property and seeking aid.

CHAPTER FIVE

PRIORITY RATING SYSTEMS FOR TYPE II RETROFIT PROJECTS

As part of the survey effort, each state highway agency was asked to provide information concerning its policy and rating system, if any, for Type II noise barrier retrofit projects (Area X of the survey form, Appendix B). Eleven states reported that they have a priority rating system. Table 4 shows the number of retrofit projects constructed by each of these states; only 6 of the 11 states have constructed Type II barriers.

Most of the projects listed for California in Appendix C are Type II retrofit projects. In Minnesota, all barriers except the one on T.H. 3 in St. Paul are Type II projects (Appendix C). Therefore it may be concluded that California and Minnesota are predominant with respect to retrofit projects in this country.

The other nine states with priority rating systems, however, have invested considerable effort in developing their systems. Most have specific plans for implementing projects, based primarily on recent priority rating activity. Ten of the 11 states consider their lists to be static, with a resultant need for periodic update. The periods between updating run from 1 yr (Connecticut) to 4 yr (Washington). Only New Jersey reports a continuing update as new projects are received. The Minnesota retrofit procedure and listing are currently inactive, at the direction of the state legislature.

Many of the priority rating systems were developed as a result of public insistence for relief of excessive highway noise. The state highway agencies were obviously seeking ways to quantitatively order noise abatement needs, so that the most serious problems could be addressed first, and to provide insulation from political pressure.

Colorado and Minnesota report experiences with public groups attempting to have the priority listing overruled. In Colorado overt political pressure was brought to bear on elected and appointed officials and the State Highway Commission. In Minnesota apartment dwellers and certain groups living adjacent to non-Interstate highways protested to the state Department of Transportation. The department remained firm that these situations did not qualify for Type II projects according to Minnesota's priority rating system. The justification for excluding apartments is that they generally do not have significant exterior activity. Because retrofit projects are funded at the federal-state matching ratio appropriate for the highway system on which it is placed, the justification for excluding non-Interstate highways is economics. For a project on the federal-aid primary system, for example, the state would pay 25 percent of the barrier cost, as compared to 10 percent on the Interstate system.

Presented below are brief descriptions, as provided by the 11 states, of their priority rating systems.

CALIFORNIA

The Caltrans retrofit program is mandated by state law. Section 215 of the California Streets and Highways Code states:

> Priority System for Noise Barriers
>
> 215.5 (a) The department shall develop and implement a system of priorities for ranking the need for installation of noise attenuation barriers along freeways in the California freeway and expressway system. The priority

TABLE 4

TYPE II PROJECTS CONSTRUCTED BY STATES WITH PRIORITY RATING SYSTEMS

State	Number of Type II Projects Constructed
California	80
Minnesota	26
Colorado	10
Michigan	6
Connecticut	4
Iowa	1
Georgia	0
Maryland	0
New Jersey	0
New York	0
Washington	0

system shall include as criteria the existing and future intensity of sound generated by the freeway.

(b) When all freeways have been ranked in priority order, the department shall, consistent with available funding, recommend in the 6-year plan, and in succeeding 6-year plans, a program of construction of noise attenuation barriers beginning with the highest priority.

(c) Should any city or county construct a sound attenuation barrier along a freeway using public funds prior to the time that such barrier reached a high enough priority for state funding, then, when the funding priority is reached, the department shall reimburse the city or county without interest for the cost of such construction when constructed, but the reimbursement may not exceed the cost of the department to construct such barriers. Reimbursement shall be made only if the city or county constructs the sound attenuation barrier to the standards approved by department, follows bidding and contracting procedures approved by the department, and the project is approved by the California Transportation Commission.

In compliance with this law, Caltrans has developed a methodology for priority ranking of potential projects. Top priority is to be given to those projects with the highest noise index:

$$\text{Noise index} = \frac{(\text{dBA red}) \times (PL - 67)^2 \times DU}{\text{cost}}$$

where

dBA red = dBA reduction with barrier,
PL = predicted L_{eq} in dBA at first row,
DU = number of dwelling units protected in first row, and
Cost = total barrier cost in \$1000's.

Caltrans studies potential projects in three categories: I—receptors built before highway route adoption; II—receptors built after route adoption but before highway construction; and III—receptors built after highway construction. Currently the Caltrans retrofit program extends only to Category I situations.

COLORADO

Colorado uses the following formula to calculate a rating factor (RF):

$$RF = \sum_{i=1}^{n} \frac{(ENL_i - DNL)^2 \times N_i}{\text{cost}}$$

where

ENL_i = existing noise level at each group of dwelling units and/or activity area,
DNL = design noise level (FHPM 7-7-3, Fig. 3-1).
N_i = number of ground level dwelling units and/or activity areas subjected to the same noise level that will be brought into compliance.
Cost = total cost of noise abatement in \$1000's.

RF values are calculated for potential projects and the projects are then arranged into groups of ten, based on those values. Then, according to state policy (*25*):

> Priorities for providing noise abatement projects within a Rating Group shall be based upon items such as Rating Factor, the date of construction of the highway, the public's attitude regarding the need for noise abatement, and the availability of funding.

CONNECTICUT

The Connecticut Department of Transportation priority rating method assigns each potential project a project priority rating number (PPRN), which is the ratio of a benefits factor (BF) to the total project cost multiplied by 1000. The value for BF is:

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

where PI is the project effectiveness index, which is a surrogate for L_{10}. An L_{10} value of 60 dBA has a PI of 3.33, and for each 10 dBA increase in L_{10}, PI increases by a factor of 3. The parameters N_b and N_a are the number of receptor units expected to receive benefit, with the subscripts denoting whether the receptors were constructed before or after the highway. N is determined by multiplying four factors concerning number of families per facility, number of days of use per week, number of hours of use per day, and number of months of use per year. The sensitivity factor (SF) is 1.5 for FHPM 7-7-3 Land Use Category A receptors (where serenity and quiet are of extraordinary significance) and 1.0 for Category B receptors (residences, schools, churches, hospitals, and the like).

GEORGIA

The Georgia Department of Transportation has developed a method that combines a field inventory with a priority rating formula to produce a static listing. After a rather extensive effort by staff engineers who visually surveyed the entire Georgia Interstate system, potential retrofit sites were rank ordered using weighted variables in four categories: noise level, cost unit, time of construction, and public involvement.

The FHWA model was used to calculate a "before" L_{10} value. A weighting was then calculated as follows:

L_{10} *dBA*	*Weighting Value*
69	0
70	20
71	40
72	60
73	80
74*	100

*An L_{10} of 74 dBA was the highest predicted value.

For considering cost/unit, a value of 0 to 75 was assigned to each site, depending on dwelling unit abatement costs. Except for two sites, barrier heights of 14 ft (4.3 m) were assumed, with costs of $10.00 per square foot. A total barrier cost was then calculated based on estimated area of barrier needed. This value was divided by the number of dwellings protected to produce the cost per dwelling for abatement. The highest cost per dwelling ($70,000) was assigned a weighting value of 0 and the lowest cost per dwelling ($10,500) was assigned a value of 75. A linear interpolation was performed to provide the weighting values for the intermediate cost per dwelling. The values produced from this interpolation were rounded to the nearest fifth increment for ease of computation and so as not to overstate the level of significance of the answer.

The time of construction variable was assigned a value of 50 if the adjacent houses were in existence before the highway was built and 0 if not. The public involvement variable was either 0 or 25, based on correspondence and contacts by citizens to the department.

The total number is calculated by summing the values for the four variables. The maximum value that could be obtained is 250:

Noise Level		*Cost/Unit*		*Time of Construction*		*Public Involvement*		*Total*
100	+	75	+	50	+	25	=	250

This procedure produced a listing of 48 potential sites for retrofit, rank ordered based on their point totals. Cost for implementing the projects was estimated to be $17,686,000 in 1980 (*26*).

IOWA

In Iowa, a preliminary field review was used in the priority setting procedure. Eighteen areas were determined to be potential candidates, based upon reconnaissance of Interstate routes in the state. Although the procedure in Iowa has not been quantified to the point of developing a formula, areas are assigned "priority traffic noise abatement designations" based on:

1. Measured noise levels.
2. Concentration of noise sensitive sites, which determines abatement cost per site protected. This translates into cost per home for a 10 dBA reduction.
3. Practical engineering feasibility.

MARYLAND

The Maryland Department of Transportation has developed a priority rating methodology that involves the tabulation of points per site based on several factors. First, five points are awarded for each year development existed before the highway was opened. Second, one point is given per residence in the 71–75 dBA (L_{10}) range, three points per residence in the 76–80 dBA (L_{10}) range, and nine points per residence greater than 80 dBA (L_{10}). For schools the respective points are 10, 30, and 90 points per school; and for churches, 3, 9, and 27 points per church.

The Maryland system is unique among the 11 states in that it does not consider cost in establishing the initial priority listing. As projects move closer to implementation, however, cost becomes a significant concern. Initially, Maryland purposely only examines potential benefits.

MICHIGAN

In January 1978, the Michigan Department of State Highways and Transportation issued its formal policy entitled *Guidelines for Highway Noise Barriers for Type II Projects* (*27*). The criteria for action and setting priorities were delineated as follows:

> Construction of a Type II project noise barrier in the highway right-of-way adjacent to a developed site requires the following:
>
> A. Proposed noise barrier projects must be supported by a formal, local government resolution.
>
> B. The local government must also furnish the Department with documentation of its land use controls. These controls must be such as to reasonably preclude the necessity for publicly funded noise barriers in highway rights-of-way adjacent to such future developments. They should include, but are not limited to:
>
> (1) Transportation noise as a component of the community's general development plan.
>
> (2) Regulation of subdivision development providing for proper site design and building location where noise sensitive uses are to locate close to freeways.
>
> (3) Zoning regulations which separate noise sensitive land uses from proximity to freeways and locate land uses compatible with traffic noise adjacent to freeways.
>
> (4) Construction regulations insuring that all future buildings located close to freeways will be sound-proofed against exterior noise.
>
> C. A noise analysis performed in accordance with the general guidelines outlined in FHPM 7-7-3 must confirm that the noise level for the appropriate land use category is being exceeded.
>
> (1) The day-night use of residential property, in the absence of evidence to the contrary, will be assumed typical. That is, it will consist of a day-time activity period beginning between 5:00-7:00 AM and ending

between 9:00-12:00 PM; and a sleep period beginning between 9:00-12:00 PM and ending between 5:00-7:00 AM.

(2) In residential areas the design noise level of FHPM 7-7-3 must be exceeded during the period 9:00 PM to 6:00 AM.

(3) In reducing the noise impact (level) in a residential area the barrier design must, to the extent technically and economically feasible, insure that there is no increase in the variability factor (L_{10} minus L_{90}).

D. The assignment of priorities to noise barrier projects will be as follows:

Priority 1: Development that existed or was under development before the date that the Department officially notified the public of the adoption of the route location of the highway project. (FHPM 7-7-3—Date of Public Knowledge of a Proposed Highway Project.)

Priority 2: Development started after route adoption but before the date of construction contract award.

Priority 3: Development started after date of construction contract award.

Within each of the above priorities, highest consideration will be given to development experiencing the highest noise levels. To differentiate between those areas of similar noise level, that is, to further prioritize the above, the following will be used:

$$\text{Priority Factor} = \frac{\text{Achievable Reduction} \times \text{Number of Living Units Protected}}{\text{Adjusted Barrier Cost}}$$

where:

"*Achievable Reduction*" is the difference between the predicted average existing noise level and the predicted average noise level after barrier construction. Its determination will be based on achieving a noise level of L_{10}(h) 70 dBA or L_{eq}(h) 67 dBA at the development nearest the roadway.

"*Number of Living Units Protected*" is the total number of living units whose external traffic noise level will be reduced to or below L_{10}(h) 70 dBA or L_{eq}(h) 67 dBA by the barrier.

"*Adjusted Barrier Cost:*" On FAI projects the Adjusted Barrier Cost will equal the total cost of installation minus those portions paid by the Federal Government, Local Government, and others. On FAP and FAS projects the Adjusted Barrier Cost will equal the total cost of installation minus those portions paid by the Local Government, and others. (Financial participation by Local Governments, citizen groups, homeowner associations and others are to be encouraged, where appropriate, as a means to reduce the denominator in the Priority Formula above and thereby achieve a higher priority.)

E. Where structures post-dating route adoption are intermixed with those pre-dating route adoption, as a general rule, no distinction will be made. All will be considered as warranting protection. Judgment, however, will be required in deciding whether or not to treat high ratio mixes of post-date to pre-date structures and the extent of barrier to install, if any.

F. The noise abatement benefits must be judged to outweigh the overall social, economic, and environmental effects of the project.

G. There must be no foreseeable, future public need for the highway right-of-way on which the noise barrier is to be erected.

MINNESOTA

The Minnesota Department of Transportation has recently revised its priority setting procedure. The earlier procedure included an annoyance component, which was basically a doubling factor for each 10 dBA over 60 dBA L_{10}. The current Minnesota method sums a value called "dBA houses" for the first two rows of houses and divides by cost. Mathematically stated:

$$B/C = \frac{(\text{No. first row houses})\ (IL) + (\text{No. second row houses})\ (IL\text{-}5)}{\text{total cost (\$1000's)}}$$

If the *B/C* (benefit/cost) ratio is greater than one, the project is placed on the priority list. If *B/C* is less than one, the project is not considered eligible.

NEW JERSEY

The New Jersey Department of Transportation is currently (mid-1981) preparing a quantitative procedure for priority rating of potential retrofit projects. When completed and adopted, the procedure will interrelate these factors:

1. Peak noise level,
2. Estimated magnitude of traffic noise impact,
3. Existing overall noise levels,
4. Intrusiveness,
5. Duration of traffic noise impact,
6. Protection from high interior noise levels,
7. Type of development to be protected, and
8. Local government effort to control land use.

NEW YORK

New York has developed a prioritizing method similar to the one used in Georgia in that it reflects extensive field reconnaissance. Noise level predictions were made for all Interstate highway segments that were adjacent to sensitive land-use activities. Field visits were then made to each segment exceeding the design noise levels, for the purpose of determining engineering feasibility. The remaining segments were examined in more detail to determine the projected barrier height necessary to break the line-of-sight, precise barrier terminii, and the number of receivers to be protected. With this information, a benefit/cost (*B/C*) surrogate was calculated. The surrogate used was square feet of barrier required per number of receivers protected (ft^2/R).

The remaining potential project sites were rank ordered by the *B/C* surrogate within three separate zones. Zone 1 sites had "before" L_{10} values greater than 80 dBA; Zone 2, 75–80 dBA; and Zone 3, 70–75 dBA. The zone lists have been provided to the New York DOT regional offices to serve as guides in project initiation. In most cases, Zone 1 projects will receive the highest priority, and Zone 3, the lowest (*6*).

WASHINGTON

The Washington Department of Transportation uses a priority setting method that relates a logarithmic impact reduction with cost. The formula is:

$$\text{Priority number} = B/C = \frac{BIF - AIF}{\text{cost (\$1000's)}}$$

where *BIF* and *AIF* are the before and after impact factors, respectively. To determine these values, an *F* factor is multiplied by the total number of dwelling units protected, with a house weighted as one and an apartment unit weighted as one-half. The *F* factor is 0.5 for an L_{10} of 60 dBA, 1.0 for an L_{10} of 70 dBA, and 2.0 for an L_{10} of 80 dBA. *BIF* contains an *F* factor reflecting the "before" L_{10}, while the *AIF F* factor reflects the "after" L_{10} (*28*).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Within the last 10 or so years, noise abatement has become a major activity in the state highway agencies across the country. This is consistent with recent trends in transportation project development, which show that increased emphasis is being placed on the analysis and mitigation of potential impacts. No longer is the public willing to stand by while decisions that produce serious problems are implemented. The state highway agencies have become keenly aware of this new public activism, especially as it relates to situations involving excessive noise levels.

The solution to excessive highway noise most frequently used by the states is a noise barrier along the highway. These barriers are in the form of vertical walls or earth berms that are designed to reduce noise levels at sensitive receivers adjacent to a highway and to break the line of sight between the vehicles on the highway and the receivers. The vertical walls are almost always made of wood, metal, or concrete (block, masonry, or post and panel). The states have learned through experience that the public generally favors berms as the first choice for type of material, followed by concrete and wood, and then metal.

Through 1980 the states reported constructing 189 mi (304 km) of barriers at a total cost of more than $100 million (Table 3). Total cost to implement a barrier project can be broken into various components, such as engineering, materials, and so on. Although any breakdown of component costs would not be accurate for all barriers, the following rough estimate is based on information provided by the states.

Cost Component	*% Total Cost*
Engineering	5
Materials	45
Foundation	15
Labor	20
Drainage	5
Landscaping	5
Other	5

A major cost item that does not appear in this list often has serious and far-reaching effects. That cost is maintenance. State highway agencies are finding that barriers frequently create problems for maintenance personnel. These problems include mowing, snow removal and storage, repair of damaged sections, removal of graffiti, and repair of other acts of vandalism. With careful consideration, however, the states should seek as their objective maintenance-free barriers.

Data received from the states clearly indicate that noise barriers have been successful. The number of complaints received has been small when compared to the intensity and diversity of the positive comments received and to the widespread pressure by various groups for more barriers. Eleven states have responded to this public pressure by retrofitting existing highways with noise barriers.

One recommendation may be offered at this point. Without question, barriers are expensive. As costs continue to increase and highway dollars become more scarce, it will be increasingly difficult for the states to meet their noise barrier needs. In consideration of these realities, it is recommended that states seek innovative ways to reduce barrier mass while maintaining adequate insertion loss. This may be accomplished by the use of two concepts. First, a cost-reduction prediction methodology such as STAMINA/OPTIMA (*29*) should always be used to minimize the amount of barrier area needed. Second, the structural and foundation design criteria and common practice should be *thoroughly* reexamined and revalidated, and possibly completely redone. It is quite possible that by using techniques of risk analysis and optimization, design criteria can be significantly modified to reduce the structural bulk and mass of the typical wall, particularly for those barriers using post embedment or concrete. Taken together, these two measures could save up to one-half of the total cost of barrier implementation (*9*).

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APPENDIX A

PRINCIPLES OF INSERTION LOSS

The following material expands on the concepts discussed in Chapter 1 relating to insertion loss (*IL*). Insertion loss is defined as:

$$IL = L\text{ (before)} - L\text{ (after)} \tag{1}$$

where *L* (before) is the noise level (in dBA) existing before a barrier is inserted, and *L* (after) is the noise level existing after the same barrier is inserted.

IL is a function of diffraction, transmission loss, reflections, and ground cover. Insertion loss is *not* the same as barrier attenuation, which traditionally has been limited to those factors relating to Fresnel diffraction.

DIFFRACTION

Fresnel diffraction analytically defines the amount of acoustical energy loss encountered when sound rays are required to travel over and around a barrier. Figure A-1 illustrates this concept of path length difference, δ.

The path length difference is defined as: $\delta = A + B - C$, where *A*, *B*, and *C* are as shown in Figure A-1. Path length difference is the extra distance the sound travels as a result of the barrier. Once δ is known, the Fresnel number *N* may be calculated as

$$N = 2\frac{\delta}{\lambda} \tag{2}$$

A composite wavelength, λ, for traffic noise is usually taken to be 2 ft (0.6 m). Thus a barrier with δ = 3 ft (0.9 m) would have *N* = 3.

Given the Fresnel number, *N*, barrier attenuation may be determined, through the application of Equation 3, *for individual vehicles*. This limitation (for individual vehicles) must be enforced because *N* depends on δ_0, which is maximum path length difference. For a road of constant elevation and

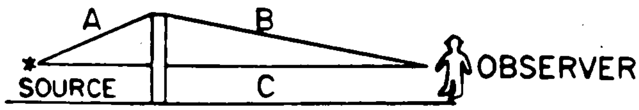


FIGURE A-1 Path length difference, $\delta = A + B - C$.

a barrier of constant height, δ_0 occurs when the vehicle is closest to the observer (at the perpendicular point). The Fresnel number corresponding to this maximum path length difference δ_0 is designated N_0. Barrier attenuation at the perpendicular point (△) for the individual vehicle is given as

$$\Delta = \begin{cases} 0, \text{ for } N \leq -0.1916 - 0.0635\epsilon \\ 5(1 + 0.6\epsilon) + 20 \log \dfrac{\sqrt{2\pi|N|}}{\tan\sqrt{2\pi|N|}}, \\ \quad \text{for } (-0.1916 - 0.065\epsilon) \leq N \leq 0 \\ 5(1 + 0.6\epsilon) + 20 \log \dfrac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}}, \\ \quad \text{for } 0 \leq N \leq 5.03 \\ 20(1 + 0.15\epsilon), \text{ for } N \geq 5.03 \end{cases} \tag{3}$$

where $\epsilon = 0$ for a wall and $\epsilon = 1$ for a berm. With $\epsilon = 0$, Equation 3 is applicable to thin vertical barriers. Because natural earth berms are more effective in noise reduction, a supplemental 3 dBA attenuation is added when the barrier is a berm by setting $\epsilon = 1$.

The value of N_0 varies depending on the type of vehicle involved, because design source heights vary from 0 (autos) to 8 ft (2.4 m) (heavy trucks) (Figure A-2). Accurate calculations must be made for each source type in the traffic mix. Computer versions of the FHWA Model do this internally.

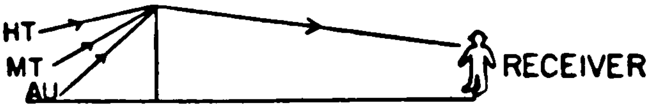


FIGURE A-2 Varying source heights.

In actual operating conditions, the interest is in the effect of shielding on the overall traffic stream and its L_{eq}, rather than the individual vehicle. Equation 3 is not adequate to address this situation, because it is based on the idea of maximum path length difference, which occurs only at the perpendicular point. The solution to this problem is to examine simultaneously the attenuation values of all the vehicles up and down the roadway segment with regard to the receivers. This is accomplished through the integration of Equation 4, once each for automobiles, medium trucks, and heavy trucks:

$$\Delta_{B_i} = 10 \log \left[\frac{1}{\phi_R - \phi_L} \int_{\phi_L}^{\phi_R} 10^{\frac{-\Delta}{10}} \, d\phi \right] \tag{4}$$

where Δ_{B_i} is the attenuation for the ith class of vehicle, and ϕ_R and ϕ_L are the angles measured from the perpendicular to the right and left ends of the barriers, respectively. Δ_i in Equation 4 is defined as:

$$\Delta_i = \begin{cases} \phi, \text{ for } N_i \le -0.1916 - 0.0635\epsilon \\[2ex] 10 \log \left[\dfrac{\sqrt{10}\; 10^{0.3\epsilon}\; 2\pi |N_0|_i \cos\phi}{\tan^2 \sqrt{2\pi |N_0|_i \cos\phi}} \right], \\ \text{for } (-0.1916 - 0.0635\epsilon) \le N_i \le 0 \\[2ex] 10 \log \left[\dfrac{\sqrt{10}\; 10^{0.3\epsilon}\; 2\pi (N_0)_i \cos\phi}{\tanh^2 \sqrt{2\pi (N_0)_i \cos\phi}} \right], \\ \text{for } 0 \le N_i \le 5.03 \\[2ex] 10 \log [100 \times 10^{0.3\epsilon}], \text{ for } N_i \geqslant 5.03 \end{cases} \tag{5}$$

An infinitely long barrier would have $\phi_L = -90°$ and $\phi_R = +90°$. Solution of Equations 4 and 5 for such a barrier yields the curve shown in Figure A-3, where it can be seen that when $N = 0$, $\Delta_B = 5$ dBA. That is, when the barrier just *grazes* the line between the source and receiver, a significant attenuation (due to diffraction) still occurs. In fact, the figure shows that detectable attenuation still occurs when N is "negative"; that is, when the source is just barely visible over the top of the barrier.

Because the solution of Equation 4 for each possible set of angles ϕ_L and ϕ_R is complex and cumbersome, the FHWA has computer-generated 60 pages of tabular results, which is given in Appendix B of the FHWA Model (Report FHWA-RD-77-108).

TRANSMISSION LOSS

The effectiveness of a barrier may be significantly compromised when acoustical energy is allowed to transmit *through* the barrier to the receiver. The amount of this transmission through the barrier depends on several factors relating to the barrier material (such as its density and stiffness and loss factors), the angle of incidence of the sound, and the frequency spectrum of the sound. The preferred method of rating the ability of a material to transmit noise is by the use of a quantity known as the transmission loss (*TL*), which is related to the ratio of the incident acoustical energy to the transmitted acoustical energy. For highway noise sources and their typical spectral content, the transmission loss of common barrier materials increases with increasing surface weight of the material.

The mathematical relationship for transmission loss is

$$TL = 10 \log 1/\tau \text{ dBA} \tag{6}$$

where τ is the transmission coefficient and is the ratio of incident to transmitted acoustical energy as mentioned above.

As a general rule, the transmission loss should be at least 10 dBA above the attenuation resulting from diffraction over the top of the barrier to ensure that barrier noise reduction will not be significantly affected by transmission through the barrier (less than 0.5 dBA). For many common materials used in barrier construction, such as concrete and masonry blocks, transmission loss values are usually more than adequate. For less massive materials, such as steel, aluminum, and wood, transmission loss values may not be adequate, especially where large insertion losses are required. Typical *TL* values for common materials are given in Table A-1.

Even if a barrier material is dense enough to prevent significant sound transmission, the barrier insertion loss can be compromised if there are holes or openings in the barrier. For large openings, sound energy incident on the barrier will be directly transmitted through the opening to the receiver. When the opening is small, an additional phenomenon occurs: upon striking the barrier wall, the sound pressure will *increase*, resulting in an amplification of the transmitted sound to the receiver. Thus the presence of openings or holes may seriously degrade the noise reduction provided by otherwise effective barriers (*8*).

REFLECTIONS

Barrier performance can also be compromised by reflections, particularly in the presence of parallel barriers (Figure A-4). When the parallel barriers are reflective, additional acoustical energy reaches the receiver as if it were coming from an image source, or even several image sources (Figure A-5). The degradation of barrier performance occurs because these image sources create longer path lengths than that present for the original source, S. Because new path lengths are longer, δ (path length difference) is smaller, and therefore the diffraction for the image sources is less significant than for the original source. The net effect is reduced insertion loss. In typical highway configurations, the reduction in insertion loss can be 4 to 8 dBA (*29*).

To solve this problem, the front face of one of the barriers can be treated with an absorptive material, thereby eliminat-

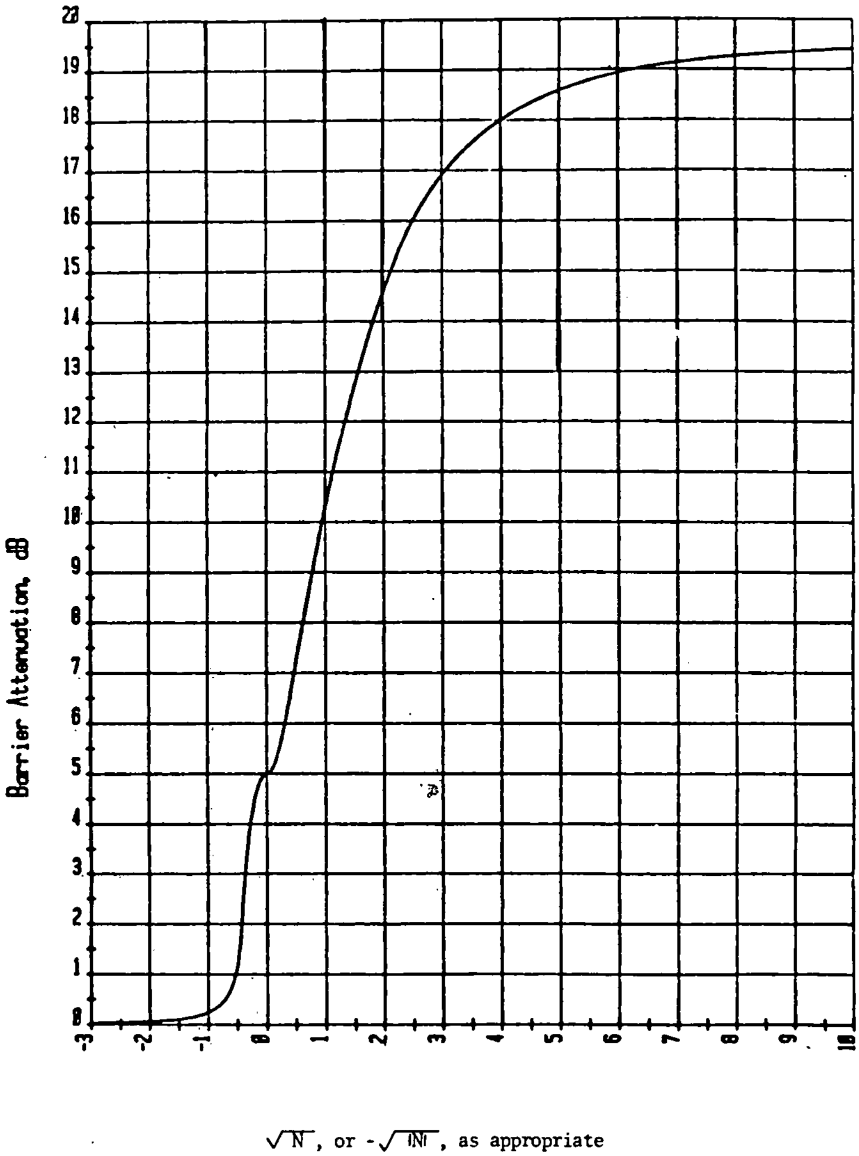


FIGURE A-3 Solution of Equations 4 and 5 for infinitely long barrier.

ing all of the image sources. Alternatively, the barriers can be tilted back 5 to 10 degrees, which would cause the image source reflections to propagate upward toward space. A more extensive discussion of this topic, including an analytical procedure for quantifying the effect, is presented by Simpson (*30*).

GROUND COVER

When a barrier is used where the ground is covered with a soft, absorptive material, insertion loss will be less than at a site with a hard cover. Without the barrier, the soft ground cover will provide an *excess* attenuation on the order of 1.5 dBA per distance doubling. When the barrier is introduced, a new, less intense source is created at the top of the barrier, which is often higher than 10 ft (3 m) above the ground. This new "elevated" source will not be as affected by absorption as the original source. The result is that the excess attenuation resulting from soft ground cover will be lost, and the insertion loss will be compromised. This effect is shown in Figure A-6.

TABLE A-1

BARRIER MATERIALS (8)

MATERIAL	THICKNESS (in.)	(mm)	TL[a] (dBA)
Woods[b]			
Fir	1/2	13	17
	1	25	20
	2	50	24
Pine	1/2	13	16
	1	25	19
	2	50	23
Redwood	1/2	13	16
	1	25	19
	2	50	23
Cedar	1/2	13	15
	1	25	18
	2	50	22
Plywood	1/2	13	20
	1	25	23
Particle Board[c]	1/2	13	20
Metals[d]			
Aluminum	1/16	1.6	23
	1/8	3	25
	1/4	6	27
Steel	24 ga.	0.6	18
	20 ga.	0.9	22
	16 ga.	1.6	25
Lead	1/16	1.6	28
Concrete, Masonry, etc.			
Light Concrete	4	100	36
	6	150	39
Dense Concrete	4	100	40
Concrete Block	4	100	32
	6	150	36
Composites			
Aluminum-Faced Plywood[e]	3/4	19	21-23
Aluminum-Faced Particle Board[e]	3/4	19	21-23
Plastic Lamina on Plywood	3/4	19	21-23
Plastic Lamina on Particle Board	3/4	19	21-23
Miscellaneous			
Glass (Safety Glass)	1/4	6	22
Plexiglas (Shatterproof)	-	-	22-25
Masonite	1/2	13	20
Fiber Glass/Resin	1/4	6	20
Stucco on Metal Lath	1	25	32
Polyester with Aggregate Surface[f]	3	75	20-30

[a] A-weighted TL based on generalized truck spectrum.

[b] Tongue and groove boards recommended to avoid leaks (for fir, pine, redwood, and cedar).

[c] Should be treated for water resistance.

[d] May require treatment to reduce glare (for aluminum and steel).

[e] Aluminum is 0.01-in. (0.25-mm) thick. Special care is necessary to avoid delamination (for all composites).

[f] TL depends on surface density of the aggregate.

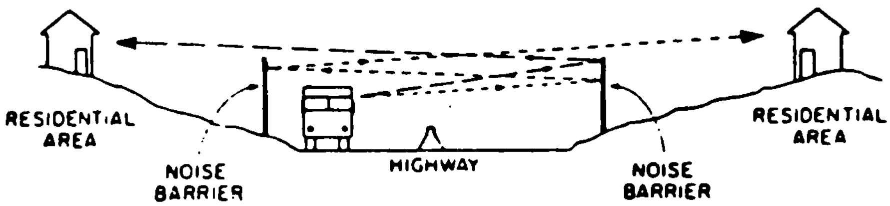


FIGURE A-4 Barrier performance compromised by reflections (*29*).

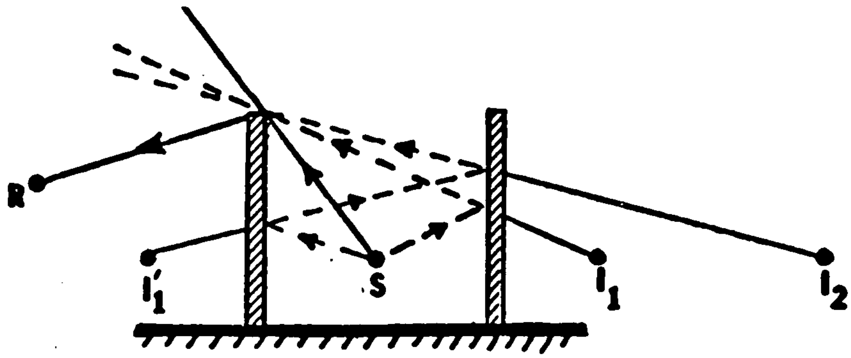
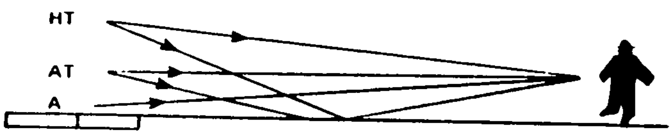
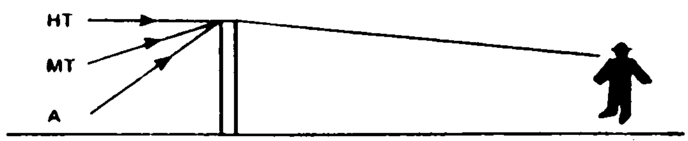


FIGURE A-5 Image sources for reflective barriers (*29*).



a.) Excess attenuation due to ground cover absorption available.



b.) Excess attenuation lost.

FIGURE A-6 Loss of excess attenuation when barrier is used where there is soft ground cover (*1*).

APPENDIX B

AUGUST 1980 SURVEY FORM

SURVEY OF PRACTICE

HIGHWAY NOISE BARRIERS

AREA I — BARRIER MATERIALS AND TYPES

A. DATA—Please provide approximate figures

	Linear Feet (Statewide)	Percent of all barriers in state
Concrete		
Wood		
Metal		
Berm		
Concrete/Berm		
Wood/Berm		
Metal/Berm		
Other (Identify)		

B. QUESTIONS

1. Define the Criteria used in material selection.
2. Rank order the listing in A. above in terms of community acceptability for your state.
3. (If one is used) Describe the multi-disciplinary team used in material acceptance and 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 treatment.

AREA II. — COSTS

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

	$\$/FT^2$	%
Engrg.		
Material		
Foundation		
Labor		
Drainage		
Landscaping		
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 the inputs considered.
   b. Does FHWA (Div.) require B/C justification for projects?
4. Define criteria used when evaluating cost/FT^2 of wall, cost/receiver protected, etc. (i.e., when is a wall too expensive?)
5. Describe any experiences with community cost-sharing.
6. If absorptive treatment has been used what % has it added to in-place costs?
7. Have the in-place costs for patented barrier systems been relatively consistent with manufacturers claims?

AREA III. — DESIGN DETAILS

A. DATA — Please provide 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 project life is a firm decision made to construct a barrier?
2. Identify the principal decision-makers (by title only).
3. Does the community have any input into design details?
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. Define, if applicable, criteria for
   a. seismic
   b. post imbedment
   c. wind load (is AASHTO sign spec used?)
7. Describe any special designs used to reduce reflections.

AREA IV — ACOUSTICAL DESIGN

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

1. Δ IL
2. STL
3. barrier justification (ΔL_{10} or ΔL_{eq} with project)

B. QUESTIONS

1. Is noise pollution level (NPL), or any other measure of intrusiveness, ever used?
2. What prediction model is used in barrier analysis? (STAMINA, SNAP, etc.)
3. Does your model use the national reference energy mean emission level ($\bar{L}_{OE_i}$), or have you generated your own?
4. What source height is used in barrier analysis?
5. Do you always design for the highests or most critical receptor?
6. Rank order the various barrier types utilized in your state in terms of overall acoustical effectiveness.
7. Describe any solutions to the problem of noise leaks around required openings.
8. Describe any experiences with barriers on both sides of a highway
   a. How has reflection been handled?
   b. Has absorption been utilized?

AREA V. — MEASURED NOISE REDUCTION

A. DATA — For those barriers where such data 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 and volume, ground cover, and weather accounted for?

AREA VI. — PERCEIVED EFFECTIVENESS

A. DATA — Please provide examples 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 sound surveys usually performed on barrier projects 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 order the barrier types in terms of community acceptance.
5. Have your surveys sighted specific correlation 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?

AREA VII — COMMUNITY INVOLVEMENT

QUESTIONS

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

AREA 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. For Type I projects, are barriers usually installed early for construction noise abatement?
5. For Type I projects, are barriers ever let as separate contracts?
6. Have any barriers ever been constructed not contiguous to existing right-of-way? Describe.

AREA 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 and during barrier design?
3. Are Row fences used behind barriers?
4. Is property behind the barrier given to adjacent landowners to maintain?
5. To what extent have these been problems?
   a. graffiti
   b. snow removal or storage
   c. litter accumulation
   d. mowing
6. Describe any experiences with vehicle impact.
7. Describe access points for maintenance operations.

AREA X — PRIORITY SYSTEMS FOR TYPE II PROJECTS

QUESTIONS

1. Fully describe and define your state's priority rating system, if one exists, including all input parameters.
2. Is the system responsive to:
   a. individual or group complaints
   b. local government influence
   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?

AREA XI — ESTHETICS

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

B. QUESTIONS

1. Rank order the various barrier types concerning their esthetic acceptability.
2. Describe the process used to satisfy the public concerning esthetics.
3. Are landscape architects and/or other design professionals involved in the esthetic treatment design?
4. What is the correlation between esthetics and
   a. perceived effectiveness
   b. acoustic effectiveness
5. Describe specific media reaction to the esthetic impact of the barrier
6. Describe (and provide pictures of) any experiences with graphics or murals on barriers.
7. Have there been reportings of driver distractions?

AREA XII — SAFETY

QUESTIONS

1. Describe any specific 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 vehicle 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?

APPENDIX C

LISTING OF BARRIERS BY STATE

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Alabama	No Barriers											
Alaska	Peger Road	Combination Wood/Berm	1978	313	.560	4-5 (Wall & Berm) 3-wall			75			Yes
Arizona	I 40 Kingman	Combination Slump Block/Berm	1980	163	367	1.5-2.7		Residential				No
	I 40 Kingman	Combination Slump Block/Berm	1980	163	427	3.2	75	30				No
	I 40 Kingman	Combination Slump Block/Berm	1980	163	232	2.2		Church			6 dBA /	No
	I 40 Ashfork	Combination Aluminum Panels/Berm	1980	577	160	2.4		High School				No
	S.R. 360 Tempe	Combination Slump Block/Berm	1974	216	2790 (EB) 2790 (WB)	2.6-3.7		390+	Grade	School		No
	S.R. 360 Tempe	Variable Height Earth Berm	1978	190*	1474 (EB) 1474 (WB)	1.8-3.7	40	+ School				No
	S.R. 360 Mesa	Variable Height Earth Berm	1979	190*	2713 (WB) 2622 (EB)	2.4-3.7						No
	19th Avenue and Orangewood Phoenix	Cinder Block	1979	26	105	1.8		School				No
Arkansas	No Response											
California	U.S. 50 Sacramento	Earth Berm	73-74	109	792	1.5						
	U.S. 50 Sacramento	Metal	73-74	181	378	1.8						
	U.S. 50 Sacramento	Stucco	73-74	171	351	1.9						

*Estimated

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	I 405 Los Angeles	Concrete Block	73-74	342	3810	1.8		160*				
	I 5 Los Angeles	Concrete Block	74-75	314	583	2.8		24*				
	I 605 Los Angeles	Concrete Block	74-75	189	290	3		12*				
	I 5 Los Angeles	Concrete C.I.P. on N.J. Barrier wall	74-75	311	1030	2.4		43*				
	U.S. 99 Modesto	Wood	74-75	279	762	3.1						
	I 405 Los Angeles	Concrete C.I.P. on N.J. Barrier Wall	74-75	306	323	2.4		13*				
	I 210 Los Angeles	Combination Block/Berm	74-75	269	447	3		19*				
	U.S. 60 Los Angeles	Concrete Block	74-75	565	446	3		19*				
	U.S. 60 Los Angeles	Precast Concrete	74-75	579	581	2.13		24*				
	U.S. 101 Rosa	Metal	74-75	802	113	4.5						
	I 15 Temecula	Metal	74-75	168	93	2.4						
	I 15 Temecula	Earth Berm	74-75	6	93	.6						
	I 210 Los Angeles	Masonry Block	74-75	244	1359	1.4		57*				
	I 210 Los Angeles	Precast Concrete	74-75	469	158	2.3		7*				
	I 210 Los Angeles	6 inch Concrete C.I.P.	74-75	268	1517	2.4		63*				
	I 210 Los Angeles	8 inch Concrete C.I.P.	74-75	617	66	2						
	U.S. 118 Los Angeles	Masonry Block	74-75	148	244	2		10*				
	U.S. 118 Los Angeles	Concrete	74-75	171	588	1.5		25*				

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	U.S. 118 Arleto City	Berm	74-75	66	1338	1.5		56*				
	I 5,15 San Diego	Concrete Block	75-76	309	453	2.6						
	U.S. 242,4 Concord	Combination Masonry Block/Berm	75-76	315	393	4.6						
	I 5, U.S. 250 Anaheim	Concrete	75-76	229	169	2		7*				
	U.S. 2 Los Angeles	Concrete	75-76	216	300	2.4		13*				
	U.S. 2 Los Angeles	Concrete	75-76	296	124	3.3		5*				
	U.S. 2 Los Angeles	Concrete	75-76	596	531	3.3		22*				
	U.S. 2 Los Angeles	Concrete	75-76	238	86	2		4*				
	I 5 Santa Ana	Masonry Block	76-77	201	140	2.2		6*				
	U.S. 101 San Jose	Masonry Block	76-77	308	160	3						
	I 605 Los Angeles	Masonry Block	76-77	123	232	3		10*				
	I 605 Los Angeles	Earth Berm	76-77	317	427	4		18*				
	I 5 Los Angeles	Combination Masonry Block/Berm	76-77	881	1812	3.6		75*				
	U.S. 11 Los Angeles	Concrete	76-77	376	117	2		5*				
	U.S. 126 Oxnard	Masonry Block	76-77	500	333	3.2		14*				
	U.S. 37 Vallejo	Masonry Block	77-78	90	108	1.6						
	U.S. 37 Vallejo	Concrete	77-78	183	34	1.6						
	I 210 Los Angeles	Masonry Block	77-78	118	2796	2.6		116*				

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	I 210 Los Angeles	Combination Masonry Block/Barrier	77-78	231	253	2.6		11*				
	U.S. 101 Los Angeles	Concrete	77-78	318	813	3.5		34*				
	U.S. 92 Hayward	Masonry Block	77-78	487	49	3.4						
	I 80, U.S. 123 El Cerrito	Concrete	77-78	281	369	2.4						
	I 5 Sacramento	Masonry Block	77-78	594	699	4.8						
	I 805 San Diego	Masonry Block	77-78	205	650	2.3						
	U.S. 118 San Diego	Masonry Block	77-78	63	95	2		4*				
	I 405 Los Angeles	Masonry Block	77-78	169	1035	3		43*				
	I 405 Los Angeles	Concrete	77-78	509	46	2.7						
	U.S. 92 Hayward	Masonry Block	77-78	29	301	3.5						
	I 15 Corona	Berm	77-78	44	335	2.2						
	I 580 San Leandro	Masonry Block	77-78	325	95	2.7						
	U.S. 7 Los Angeles	Masonry Block	77-78	451	3720	3.4		155*				
	I 10 Los Angeles	Masonry Block	77-78	712	1561	3.4		65*				
	U.S. 7, 91 Los Angeles	6 inch Masonry Block	77-78	115	452	3		19*				
	U.S. 7, 9 Los Angeles	8 inch Masonry Block	77-78	149	2582	3.1		107*				
	U.S. 7, 9 Los Angeles	Concrete	77-78	225	369	3		16*				
	I 280 Cupertino	Masonry Block	77-78	453	445	3						

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	I 210 Los Angeles	Masonry Block	77-78	399	6868	2.8		286*				
	I 210 Los Angeles	Masonry Block	77-78	83	3712	2.01		154*				
	I 210 Los Angeles	Concrete	77-78	192	224	2.65		9*				
	I 680 Dublin	Masonry Block	77-78	233	823	2.7						
	I 680 Dublin	Masonry Block	77-78	92	808	1.8						
	I 680 Danville	Masonry Block	77-78	598	530	4.4						
	Route 17 San Leandro	Masonry Block	78-79	347	453	3.9		25				
	U.S. 41, 180 Fresno	Masonry Block	78-79	173	70	3.3						
	I 10 Los Angeles	Masonry Block	78-79	574	1561	3.4		65*				
	U.S. 101 Santa Barbara	Masonry Block	78-79	674	130	4.1					10 dBA/10 dBA	
	I 5 Los Angeles	Masonry Block	78-79	446	305	3.8		13*				
	U.S. 101 Santa Barbara	Concrete Block	78-79	568	212	4.5						
	I 680 Danville	Concrete Block	78-79	311	591	4.1						
	I 280 Cupertino	8 inch Precast Concrete	78-79	214	99	2.4						
	I 280 Cupertino	10 inch Precast Concrete	78-79	262	130	3						
	I 280 Cupertino	12 inch Precast Concrete	78-79	323	216	3.7						
	I 5 Sacramento	Masonry Block	78-79	380	173	4.4						
	I 680 Dublin	Masonry Block	78-79	179	823	2.8			30		dBA/9dBA	No

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	U.S. 8 La Mesa	Masonry Block	78-79	224	234	2.8						
	I 5 Oceanside	Masonry Block	78-79	199	309	3						
	U.S. 73 Costa Mesa	Masonry Block	78-79	123	984	2.4		41				
	I 10 Los Angeles	Masonry Block	78-79	141	1560	2.1		65*				
	U.S. 57 Anaheim	Masonry Block	78-79	165	5660	3		235*				
	I 5 Los Angeles	Masonry Block	78-79	187	649	3.4		27*				
	I 10 Los Angeles	Masonry Block	78-79	273	492	3.7		21*				
	I 5 Los Angeles	Masonry Block	78-79	221	1534	2.6		64*				
	U.S. 99 Sacramento	Masonry Block	78-79	287	808	4.0			14		M 74	SIP
	I 10 Los Angeles	Masonry Block	78-79	156	5278	3.6		220*	300		P 82 M 82	SIP
	I 5 San Clemente	Masonry Block	78-79	148	6518	2		271				
	I 5 Sacramento	Masonry Block	78-79	289	1357	4						
	U.S. 17 San Jose	Masonry Block	78-79	254	3498	3.3			178		/8 dBA	SIP
	I 680 San Jose	Masonry Block	78-79	314	99	3	4				7 dBA/	No
	U.S. 101 Santa Rosa	Masonry Block	79-80	261	195	3.7	8				4 dBA/	No
	U.S. 2 Los Angeles	Masonry Block	79-80	300	28	2.8						
	I 10 Ontario	Masonry Block	79-80	252	117	3.9						
	I 10 Los Angeles	Masonry Block	79-80	166	442	2.2						

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	I 10 Los Angeles	Concrete	79-80	315	151	2.7						
	U.S. 99 Madera	Masonry Block	79-80	167	341	3						
	U.S. 7 Los Angeles	Masonry Block	79-80	250	2275	3.9	105				10 dBA/11 dBA	
	I 15 Lake Elsinore	Masonry Block	79-80	270	233	2.5						
	I 15 Los Angeles	Masonry Block	79-80	197	1627	3	70				10 dBA/11 dBA	
	I 5 Los Angeles	Concrete	79-80	311	268	2.7		11.1				
	I 5 Los Angeles	Masonry Block	79-80	152	1325	2.8	90				10 dBA/	
	I 5 Los Angeles	Concrete	79-80	357	40	2.5						
	U.S 91 Los Angeles	Masonry Block	79-80	179	503	3.6		21*				
	U.S. 91 Los Angeles	Concrete	79-80	394	60	3.1						
	I 405 Los Angeles	Masonry Block	79-80	180	566	3.5		School				
	I 405 Los Angeles	Concrete	79-80	1006	23	4.9						
	I 605 Los Angeles	Masonry Block	79-80	184	339	2.6		School				
	U.S. 2 Los Angeles	Masonry Block	79-80	150	674	2.7		25*			8 dBA/12 dBA	
	U.S. 60 Los Angeles	Concrete Block	1980	567	505	2.3						No
	I 405 Los Angeles	Combination Concrete/Metal	1980	590	388	3.5						No
	I 280 Cupertino	Concrete Panel	1980	519	3388	3.7						No
	U.S. 41 Fresno	Concrete Block	1980	212	628	2.0						No

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
California	U.S. 60 Los Angeles	Concrete Block	1980	362	287	4.6						No
	U.S. 101 Los Angeles	Concrete Block	1980	292	99	2.7						No
	U.S. 101 San Francisco	Concrete Block	1980	778	176	3.8						No
	U.S. 99 Modesto	Concrete Block	1980	291	527	4.9						No
	U.S. 99 Sacramento	Concrete Block	1980	302	1650	3.4						No
Colorado	47th St. Parkway Boulder	Earth Berm	1972	40	868							
	U.S. 285 Tamarac	Wood	1974	90	380	2.5						
	I 25, Tray Ave. Pueblo	Wood	1975	70	407	2.5						
	I 225 Denver	Wood	1975	100	1269	2.5						
	SH 95 Denver	Wood	1975	80	680	2.5						
	I 25 Denver	Wood	1975	100	1442	3						
	I 25 Denver	Wood	1976	90	98	2.5						
	I 70 Vail Pass	Wood	1977	150	520	2.4						
	SH 83 Denver	Wood	1977	105	183	2.5						
	47th St. Parkway Boulder	Combination Concrete/Berm	1978	70	5053	2-3						
	I 25 Denver	Combination Berm/Wood	1978	125	572	3						
	I 25 Denver	Combination Wood/Aluminum	1978	178	756	2						
	Potomac Blvd. Denver	Wood	1978	50	704	2						

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Colorado	I 76 Denver	Wood	1978	153	2395	2						
	S. Kipling St. Denver	Wood	1978	120	1405	2						
	I 25 Denver	Wood	1979	125	1137	2						
	I 70 Denver	Wood	1979	175	2798	2						
	W. 6th Avenue Denver	Wood	1979	175	1242	2						
	I 25 Denver	Combination Wood/Masonry	1979	250	3265	3						
	I 25 Denver	Wood	1979	150	1698	3.5						
	I 70 Denver	Combination Concrete/Wood	1980	250	857	2.5-3.5						
	Almeda Ave. Denver	Berm	1980	40	800							
Connecticut	I 84 West Hartford	Earth Berm	1974	378	549	5.2-6	150	110			7-15 dBA/5-12 dBA	Yes
	I 84 West Hartford	Wood	1977	597	671	5	200	120			10 dBA/6-10 dBA	Yes
	I 84 West Hartford	Combination Concrete/Berm	1978	583*	621	2.4-5.2	150	120			10 dBA/9-10 dBA	Yes
	I 84 Danbury	Wood	1979	690	412	4.5-5.2	120	80			9-11 dBA/	Yes
	I 84 Newton	Wood	1979	547	167	1.2-3					8-10 dBA/	
	Rt. 25 Trumbull	Earth Berm	1980	190*	909	5.5					10 dBA/	
	Rt. 25 Trumbull	Wood	1980	445	230	3-4.5					10 dBA/	
	Rt. 25 Trumbull	Combination Wood/Berm	1980	583*	323	Wall 4.5 Berm 3					10 dBA/	
	I 86 Tolland	Berm	1978	190*	303	3.6					10 dBA/10 dBA	

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Connecticut	I 86 Willington	Berm	1977	190*	143	3	8				10 dBA/5 dBA	
	I 86 Vernon	Concrete	1978	299	667	2.4-4.5					10 dBA/10 dBA	
	I 86 Vernon	Concrete	1978	310	667	3.3-4.2					10 dBA/	
	I 86 Vernon	Concrete	1978	571	303	6.7	50	45	40		10 dBA/11 dBA	
	I 86 Vernon	Concrete	1978	389	576	4.5	20	18	15		10 dBA/10 dBA	
Delaware	I 95 Wilmington	Metal	1978	403	457	1.4	School				4 dBA/	
Florida	I 375 St. Petersburg	Concrete Block	1977	640	367	2.4	45				11 dBA/	Yes
	I 175 St. Petersburg	Concrete Block	1980	49	270	2.4	92				6 dBA/	Yes
	I 175 St. Petersburg	Concrete Block	1980	322	448	2.4	160				6 dBA/	Yes
	I 375 St. Petersburg	Concrete Block	1979	442	160	1.5-3	60	42			7 dBA/	Yes
	I 375 St. Petersburg	Concrete Block	1979	66	265	1.8	66	137			11 DBA/	Yes
	I 275 St. Petersburg	Concrete	1980	351	420	2.4	200				4-6 dBA/	Yes
	I 175 St. Petersburg	Concrete Block	1977	396	534	3	60	36			10 dBA/10 dBA	Yes
Georgia	No Barriers											
Hawaii	No Barriers											
Idaho	No Barriers											
Illinois	U.S. 51 Monroe Center	Concrete	1979	817	731	6.4	125	16				
	U.S. 662 Springfield	Earth Berm	1978	458	1250	4.6	126	70				

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Illinois	U.S. 662 Springfield	Earth Berm	1979	54	457	2.4	110	42				
	U.S. 662 Springfield	Earth Berm	1979	81	610	3	207	50				
	U.S. 662 Springfield	Earth Berm with retaining wall	1979	1284	360	3	232	70				
Indiana	No Barriers											
Iowa	I 380 Cedar Rapids	Precast Concrete	1979	738	135	Wall 4-4.5 Berm 2-3	40	40			9 dBA/	
	I 380 Cedar Rapids	Precast Concrete	1979	861	165	3.75-4	40	30			9 dBA/	
	I 380 Cedar Rapids	Earth Berm	1979	123	390	5.5-9.0	50-60	60	80		9 dBA/	
	I 380 Cedar Rapids	Combination Concrete on Berm	1979	615	105	Wall1.5-3.5 Berm 1.5-4	15-20	25	25		9 dBA/-	
	I 380 Cedar Rapids	Precast Concrete	1979	861	150	4-5.5	40	40	35		9 dBA/	
	U.S. 218 Keokuk	Wood (Glulam) P&P	1980	630	300	4	16	17			8-10 dBA/8-10 dBA	No
	I 235 Des Moines	Metal P&P	1980	320	1060	3-5	42	48	40		10 dBA/12-14 dBA	Yes
Kansas	No Barriers											
Kentucky	No Barriers											
Louisiana	LA 3132 Shreveport	High Density Polyurethane	1979	870	424	4.5	196	48				No
Maine	I 95 Kittery	Earth Berm	1978	60	213	3	35	35			9 dBA/	No
Maryland	Maryland Route 197 Laurel	Combination Polyester with Steel Beam/Berm	1978	519	396	2.5		72				No
Massachusetts	I 495 Mansfield-Norton	Concrete	1980	305	823	3					10 dBA/	Yes
	I 495 Norton	Combination Wood/Berm	1980	272	732	5					10 dBA/	Yes

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Massachusetts	I 95 Newbury Port	Concrete	1975	225	518	2					7 dBA/	Yes
	I 95 Newbury Port	Concrete	1975	225	259	2					7 dBA/	Yes
	I 95 Newbury Port	Concrete	1975	223	503	2					7 dBA/	Yes
	I 95 Boxford	Wood	1975	86	1006	2.5-3						Yes
	I 95 Boxford	Wood	1975	70	503	2-2.5						Yes
	I 190 Worcester	Steel	1980	394	244	4.5					12 dBA/	
	I 190 Lancaster	Earth Berm	1979	190*	244	Varies						
	I 190 Leominister	Wood	1980	98	61	2						Yes
	I 190 Leominister	Earth Berm	1979	190*	701	Varies						Yes
	Route 2 Leominister	Concrete	1976	458	122	2						Yes
	I 190 Leominister	Wood	1976	313	76	2						Yes
	I 190 Leominister	Wood	1976	313	793	2						Yes
	Peabody-Salem Rd. Salem	Concrete		394	110	4.3					9 dBA/	
	Peabody-Salem Rd. Salem	Concrete		394	153	3					8 dBA/	
	Peabody-Salem Rd. Salem	Concrete		361	580	2.5-3.7					8-10 dBA/	
	I 93 Somerville	Combination Concrete/Steel		583*	640	9-12						Yes
Michigan	I 94 Kalamazoo	Earth Berm	1973	93	564	3.0		(School Playground)				
	I 75 Allen Park	Wood	1974	378	823	4.1						Yes

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Michigan	I 75 Southgate	Combination Steel/Earth	1975	619	533	2.7-3.7						
	I 75 Lincoln Park	Precast Concrete	1978	513	549	4.9-5.5						
	I 275 Canton	Precast Concrete	1977	419	7500	2.1-3.4						
	I 75 Lincoln Park	Concrete	1980	285	610	5.8						
Minnesota	I 35 W Minneapolis	Wood (Post & Plank)	1972	888	1126	2-4.5						
	I 94 Minneapolis	Concrete Panels	1975	750	1126	3-6						
	I 94 St. Paul	Earth Berm	1973	624	322	3.5						
	I 35 W Roseville	Wood (Post & Plank)	1975	609	1287	1.5-5.5						
	I 94 St. Paul	Combination Wood/Steel	1975	330	3702	1.5-4.5						
	I 35 W Minneapolis	Wood (Post & Plank)	1974	93	644	5.5**						
	T.H. 100 Edina	Concrete	1979	180	2736	3-3.5						
	T.H. 3 St. Paul	Wood	1975	370	4828	1.5-4.5						Yes
	I 94 Brooklyn Park	Concrete Block	1979	664	4667	5-7						
	I 94 Brooklyn Center	Concrete Block	1979	642	483	5-7						
	I 694 Findley	Wood (Post & Plank)	1977	487	3058	2.5-5.5						Yes
	I 694 New Brighton	Concrete Panel	1977	843	3058	2.5-5.5						Yes
	I 35 W Moundsview	Wood (Glue Laminated)	1978	628	1448	2-4.5						Yes
	I 694 Shoreview	Wood (Post & Plank)	1978	719	1127	2.5-3.5						Yes

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Minnesota	I 35 E Maplewood	Wood (Glue Laminated)	1977	968	322	2.5-5						Yes
	I 94 Minneapolis	Wood (Post & Plank)	1978	370	1770	5-7						Yes
	I 94 Minneapolis	Combination Concrete/Wood	1979	609	4023	5-7						
	I 94 Minneapolis	Combination Concrete/Wood	1979	432	2092	5-7						
	I 94 Minneapolis	Combination Concrete/Wood	1979	465	2092	5-7						
	I 35 W Richfield	Combination Concrete/Wood	1978	462	2092	5-7						Yes
	I 35 W Richfield	Combination Concrete/Wood	1978	479	3702	5-7						Yes
	I 35 W Bloomington	Combination Concrete/Wood	1978	617	3380	5-7						Yes
	I 35 W Bloomington	Combination Concrete/Wood	1978	426	1770	2-8.5						
	I 494 Minnetonka	Wood (Glue Laminated)	1979	959	2253	5-7						Yes
	I 94 St. Paul	Wood (Post & Plank)	1978	378	1126	1.5-7						
	I 694 Oakdale	Wood (Post & Plank)	1980	605	1126	2-3.5						
	I 94 Brooklyn Center	Concrete Block	1980	559	1609	1.5-7						
Mississippi	No Barriers											
Missouri	I 229 St. Joseph	Wood	1980	134	182	2.7	25					
Montana	No Barriers											
Nebraska	Omaha	Earth Berm	1979	Utilized Excess Fill	W-915 E-730	3						
Nevada	U.S. 95 Las Vegas	Combination Concrete/Berm	1975	Wall 126 Berm 68	Conc. 530 Berm 582	2.4		Residences				

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Nevada	U.S. 95 Las Vegas	Concrete	1976	528	250	2.3-4.1						
	McCarran Blvd. Reno	Concrete	1978	290	680	2.4-3						
	I 580 Reno	Concrete	1979	420	1053	3-3.8						
	I 580 Reno	Concrete	1979	230	267	1.8-2.1						
	I 580 Reno	Concrete	1980-1981	430	484	1.5-4.1						
New Hampshire	I 93 Manchester	Earth Berm	1977	53	122	2.2	0	40	0	0		No
New Jersey	I 676 Camden	Precast Concrete	1980	464	2586	3						
	Garden State Pkwy. Woodbridge	Precast Concrete	1980	386	152	3						
New Mexico	Gibson Blvd. Albuquerque	Concrete Masonry	1978	572	220	3.1	0	48	16	0	10 dBA/9 dBA	Yes
New York	Sprain Brook Pkwy. White Plains	Earth Berm	1980	25	335	1.2-5.5	10	5			9-11 dBA/	No
	Sprain Brook Pkwy. White Plains	Earth Berm	1980	25	305	1.2-5.5	6	3			9-11 dBA/	No
	Sprain Brook Pkwy. White Plains	Earth Berm	1980	25	244	2.4	3	2			9-11 dBA/	No
	I 390 Rochester	Concrete	1979	242	564	2.4-3.7						No
	I 390 Rochester	Concrete	1979	276	673	2.4-4.0						No
	I 390 Rochester	Concrete	1979	246	235	2.4						No
North Carolina	I 77 Charlotte	Wood	1973	440	1961 (3 sections)	3.1					1-8 dBA/ 6-7 dBA/	No
	I 40 Raleigh	Precast Concrete	1977	244	628 (2 sections)	4.3	18	22	2	3	6-7 dBA/	No
	I 40 Buncombe-McDowell Co.	Precast Concrete	1980	165	632 (1 section)	4.6					6-10 dBA/	No

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
North Carolina	I 40 Raleigh	Earth Berm	1980	166	2682 (7 sections)	6.1	55	23	2	0	3-10 dBA/	No
	Inner Loop Charlotte	Earth Berm/Precast Concrete	1980	469	475 (1 section)	5.2		16			6-8 dBA/	No
North Dakota	No Barriers											
Ohio	I 270 Gahanna	Combination Concrete/Earth Wall	1979	460	1174	3.5 Conc. 4.3-8 Earth	0	24	91	9		Yes
Oklahoma	No Barriers											
Oregon	I 5 East Portland	Earth Berm	1975	10	396	1.5-1.8	MOBILE HOME PARK				10-12 dBA/	
	U.S. 30 Columbia Cty.	Earth Berm	1979	10	183	4.3	SCHOOL, AND OUTDOOR ACTIVITY AREA				5 dBA/	
	U.S. 101 Curry Cty.	Earth Berm	1976	10	335	0-4.6						
	U.S. 30 Columbia Cty.	Earth Berm	1979	10	91	1.8-3					9 dBA/5 dBA	
	I 205 Clackamas Cty.	Earth Berm	1970	10	1067	0-3					/12 dBA	
	Santium H.W. Linn County	Wood Wall	1978	80	82	1.8					3 dBA/7 dBA	
	I 205 Clark-Multnomah Counties	Concrete	1978	546	168	1.8						
	I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1978	427	201	3						
	I 205 Clark Multnomah Counties	Concrete	1978	105	762	4.6						
	I 205 Clark-Multnomah Counties	Concrete	1978	742	91	3						
	I 205 Clark-Multnomah Counties	Earth Berm	1978	77	213	3						
	I 205 Clark-Multnomah Counties	Earth Berm	1979	106	396	3					4 dBA/	
	I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1979	169	610	3					7 dBA/	

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STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Oregon	I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1979	119	183	3					3 dBA/	
	I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1979	169	366	3					10 dBA/	
	I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1979	112	305	3					3 dBA/	
	N.E. 102nd Ave. Clark-Multnomah Counties	Combination Earth/Concrete	1979	350	579	3						
	Banfield to I 205 Clark-Multnomah Counties	Combination Earth/Concrete	1979	583	183	3						
	I 205 & Maywood Clark-Multnomah Counties	Combination Earth/Concrete	1980	95	549	3-4.6					5-7 dBA/	
	I 205; Sta.No.211-214 Clark-Multnomah Counties	Combination Earth/Concrete	1980	385	91	3						
	I 205;Sta.No.206-210,Clark-Multnomah Counties	Earth Berm	1980	35	122	3					6 dBA/	
	I 205;Sta.No.276-285,Clark-Multnomah Counties	Earth Berm	1979	12	274	3						
	I 205;Sta.No.324-336,Clark-Multnomah Counties	Combination Earth/Concrete	1980	125	366	3					5 dBA/	
	I-205;Sta.No.337-349,Clark-Multnomah Counties	Concrete	1979	169	366	3					5 dBA/	
	I-205;Sta.No.353-380,Clark-Multnomah Counties	Earth Berm	1979	81	823	3					3 dBA/	
	I-205;Sta.No.381-394,Clark-Multnomah Counties	Combination Earth/Concrete	1979	100	396	3					3 dBA/	
	I-205,Sta.No.404-409 ,Clark-Multnomah Counties	Earth Berm	1979	88	152	3					7 dBA/	
	I-205;Sta.No.418-428,Clark-Multnomah Counties	Combination Earth/Concrete	1979	150	305	3						
	I-205;Sta.No.437-455,Clark-Multnomah Counties	Earth Berm	1978	77	549	3						
	I-205;Sta.No.457-481,Clark-Multnomah Counties	Earth Berm	1978	77	732	3						
	I 5 Comstock Anlauf	Earth Berm	1980	10*	488	2.5					7 dBA/	

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Oregon	I 5 Battle Creek	Earth Berm	1980	30	335	3					3 dBA/	
	I 5 Battle Creek (being removed)	Earth Berm	1980	35	549	3					5-9 dBA/	
	I 205 Portland	Combination Berm/Concrete	1980	760	704	7.6-8.8					6-8 dBA/6-13 dBA/	
	Allen Blvd. Highway 217 Washington County	Concrete	1980	350	85	3					5 dBA/	
	Allen Blvd. Highway 217 Washington County	Concrete	1980	260	38	2.5					5 dBA/	
	Banfield Freeway Portland	Combination Concrete/Berm	1979	188	762	1.5-3					4-8 dBA/	
	Banfield Freeway Portland	Earth Berm	1979	425	427	3					10-12 dBA/	
	Banfield to I 205 Portland	Concrete	1980	35	305	3					4-6 dBA/	
	I 205 Portland	Concrete	1980	45	213	3					4 dBA/	
	I 205 Portland	Concrete	1980	95	427	3					6 dBA/	
Pennsylvania	I 95 Philadelphia	Concrete C.I.P. with brick facade	1979	6550	229	3-6					10-14 dBA/	Yes
	I 95 Philadelphia	Concrete	1979	1420	506	3-4.3					4-15 dBA/	Yes
	I 95 Philadelphia	Combination Earth/Concrete	1979	2910	509	2.4-8.2					3-8 dBA/	Yes
	I 95 Philadelphia	Combination Steel on Structure	1979	1400	87	3					3-10 dBA/	Yes
	I 95 Philadelphia	Precast Concrete with brick imprint facade	1979	1081	420	3-4.3					3-10 dBA/	Yes
	Everett Bypass Everett	Earth Berm	1980	waste material	906	3-4					8-10 dBA/	No
Rhode Island	No Barriers											
South Carolina	No Barriers											

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
South Dakota	No Barriers											
Tennessee	No Barriers											
Texas	Rt 47 Arlington	Wood	1977	210	180	2.8		12				
	I 447 Wichita Falls	Wood	1979	120	110	2.2		25				
	U.S. 281 San Antonio	Concrete	1978	403	525	3		4				
	I 45 Houston	Concrete	1977	541	39	2.4		4				
	I 45 Houston	Wood	1979	283	166	3.7		150				
	I 45 Houston	Wood	1979	355	45	3		4				
	Rt. 34 El Paso	Precast Concrete	1978	365	341	2.4		60				
Utah	No Barriers											
Vermont	No Barriers											
Virginia	Rt. 33 Richmond	Wood	1976	271	483	3.7					5-10 dBA/	
	Virginia Beach Blvd. Virginia Beach	Wood	1979	51	299	2.4						
	Virginia Beach Blvd. Virginia Beach	Wood	1979	51	1632	2.4						
	I 495 Fairfax County	Combination Concrete/Berm	1978	738	640	4.9		13	13		7-13 dBA/	
	I 495 Fairfax County	Combination Concrete/Berm	1978	376	866	4.9		10	11		7-13 dBA/	
	I 495 Fairfax County	Combination Wood/Berm	1978	524	488	3.7		75			9 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood	1978	770	1136	2.4-6.7			78		12 dBA/	

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Virginia	I 495 Fairfax County	Concrete	1978	673	579	3.7-6.1			336		12 dBA/	
	I 495 Fairfax County	Combination Wood/Berm	1978	725	351	3.7			112		11 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	750	1220	1.2-7.3				44	18 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	1030	611	4.0-7.0			46		13 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	1000	593	1.0-3.7			39		12 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	882	701	1.8-3.7			246		12 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	989	1158	3.8	15	15			5 dBA/	
	I 495 Fairfax County	Combination Metal/Berm	1978	622	338	3.7		19			6-10 dBA/	
	I 495 Fairfax County	Combination Wood/Berm	1978	880	1093	1.2-3.7			56		11 dBA/	
	I 495 Fairfax County	Combination Concrete/Wood/Berm	1978	1270	703	4.0-6.1			336		12 dBA/	
	I 495 Fairfax County	Combination Metal/Berm	1978	838	1002	4.3		38	38		10 dBA/	
	I 495 Fairfax County	Combination Metal/Berm	1978	744	945	3.7			117		10-13 dBA/	
	I 495 Fairfax County	Combination Metal/Berm	1978	1159	873	4.9		57	56		10 dBA/	
	I 495 Fairfax County	Combination Concrete/Metal/Berm	1978	1307	457	5.8			15		10-11 dBA/	
	I 495 Fiarfax County	Metal	1978	938	579	4.7		20			4-7 dBA/	
	Route 17 Norfolk	Metal	1978	284	139	3.7		4				
	Route 265 Danville Bypass	Concrete	1976	25	305	1.8-3.7		9			4-10 dBA/	
	Route 265 Danville Bypass	Concrete	1976	84	412	1.8-3.7		17			4-10 dBA/	

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Virginia	I 95 Richmond	Combination Wood/Berm	1980	186	244	2.4-3.0		4			8 dBA/	
	I 95 Richmond	Combination Wood/Berm	1980	258	229	1-3.7		6			5-9 dBA/	
	I 95 Richmond	Metal	1980	279	1006	5.5			44		14 dBA/	
	Route 71 Wythe County	Combination Wood/Berm	1976	90	228	2.6		1			6 dBA/	
	I 65 Hampton	Metal	1976	852	289	5.5						
Washington	I 90 East Gate	Earth Berm	1975	176	244	3		14	14		10 dBA/	
	I 90 Issaquah	Earth Berm	1978	48	366	1.5		10			7 dBA/	
	I 90 High Point	Earth Berm	1978	190*	488	.91	7				2 dBA/	
	I 90 Preston	Earth Berm	1977	115	183	2.4		34			10-6 dBA/	
	I 90 North Bend	Earth Berm	1976	177	152	3					4-7 dBA/	
	I 90 North Bend	Earth Berm	1976	115	442	2.4		9			5-10 dBA/	
	I 90 North Bend	Earth Berm	1976	232	335	3		6				
	I 90 North Bend	Earth Berm	1977	190*	442	.9	2	2			4-6 dBA/	
	I 90 North Bend	Combination Earth/Stone	1976	170	427	2.4		1			5-8 dBA/	
	I 90 North Bend	Earth Berm	1976	232	610	4			6		14 dBA/	
	I 405 Bellevue	Wood	1973	353	224	3-4.3		12	8		3-6 dBA/	
	I 405 Kirkland	Earth Berm	1978	336	189	4.3					5-6 dBA/	
	S.R. 520 Evergreen Floating Bridge	Earth Berm	1963	114	55	2.4		School			6 dBA/	

LOCATION		DESCRIPTION	YEAR	UNIT COST Linear Meter (1980 Dollars)	SIZE		NUMBER OF DWELLING UNITS PROTECTED PER 5dBA IL ZONE				IL PREDICTED/ MEASURED	SOCIAL STUDY
STATE	ROUTE/CITY				LENGTH M	HEIGHT M	0-5	5-10	10-15	15-20		
Washington	S.R. 16 Port Orchard	Earth Berm	1976	340	229	4.3		School			12-15 dBA/	
	I 5 Vancouver	Concrete	1980	259	1259	2.24 on 4.11 Bank			160		15 dBA/	
	S.R. 500 Orchard	Earth Berm	1976	67	366	1.8 High 1.2 Bank		35			4-10 dBA/	
	S.R. 500 Orchard	Earth Berm	1976	144	244	2.7		35			7-10 dBA/	
	I 205 Mill Plain Road	Earth Berm	1977	67	235	1.8-1.2		15	3		10-17 dBA/	
	I 205 Orchard	Earth Berm	1978	102	286	2.3		3	5		9-13 dBA/	
	I 205 Orchard	Earth Berm	1978	102	290	2.3	2	2			4-6 dBA/	
	I 205 Orchard	Earth Berm	1978	102	351	2.3	1	1			4-6 dBA/	
	S.R. 12 Pasco	Earth Berm	1974	115	244	2.4		Cemetery			8-10 dBA/	
	S.R. 14 Kennewick	Textured Concrete	1980	551	439	3.7		30			7-11 dBA/	
	I 90 High Point	Earth Berm	1977	90	259	3.3			4		10-12 dBA/	
West Virginia	I 77 Raleigh County	Earth Berm	1980	31	259	2-2.4						
Wisconsin	I 94 Milwaukee	Fiberglass	1978	296	330	1.8						
	I 94 Milwaukee	Wood	1978	196 262	260 180	1.8 3						
	I 94 Milwaukee	Concrete Panel	1978	327	240	3.0						
	I 94 Milwaukee	Concrete Panel	1978	327 242	240 270	3.0 1.8						
Wyoming	No Barriers											
Puerto Rico	P.R. 2 Aguadillo	Concrete Block	1979-80	454	91	5.5					14 dBA/	Yes
	P.R. 2 Aguadillo	Concrete Block	1979-80	462	44	5.5					15 dBA/	Yes

APPENDIX D

TYPICAL BARRIER DESIGN CRITERIA (CALIFORNIA)

21-8

SOUND WALL
DESIGN CRITERIA
CALTRANS

MEMO TO DESIGNERS:

The following criteria shall be used when designing sound walls.

I. LOADS

WIND LOAD = 15 lb/ft^2, except for wall on bridges or retaining walls, use 30 lb/ft^2.

When the top of wall is higher than 30 feet above the average level of the adjoining ground, these wind loads shall be increased by multiplying by $(\frac{h}{30})^{2/7}$ where h is the distance in feet measured from the top of wall to the average level of the adjoining ground.

SEISMIC LOAD = 0.30 Dead Load, except on bridge.
1.00 Dead Load, on bridge.
2.00 Dead Load, connections for pre-fab sound walls on bridge.

TRAFFIC IMPACT LOADING: It will not be necessary to apply a traffic loading to sound walls. However, the supporting system for the combined sound wall and traffic barrier shall not be less than is required for traffic alone. (See "Minimum Foundation Requirements for Traffic Loading" contained herein.)

EARTH PRESSURE: 36 lbs per cubic foot equivalent fluid pressure except a pressure of 27 lbs. per cubic foot shall be used to obtain maximum loads on heels of wall footings. When highway traffic can come within a distance equal to one-half the height of the retained earth, the pressure shall be increased by adding a live load surcharge equal to not less than 2 feet of earth except that no live load surcharge shall be combined with a seismic load.

II. COMBINING LOADS

The following groups represent various combinations of loads to which the sound wall structure may be subjected. Each part of the structure and its foundation shall be proportioned for either Groups A, B and C or Groups D, E, as applicable. Earth retaining portion of sound wall structure shall be designed by working stress method.

Working Stress Design	Percentage of Unit Stress
GROUP A = D + E	100%
GROUP B = D + W + E	133-1/3%
GROUP C = D + EQ + E	133-1/3%

Load Factor Design - Reinforced Concrete

GROUP D = 1.3 (D + W)
GROUP E = 1.3 (D + EQ)

NOTE: The reinforcement design will usually be governed by AASHTO Specifications.

Where
W = Wind Load
D = Dead Load
EQ = Seismic Load
E = Earth Pressure

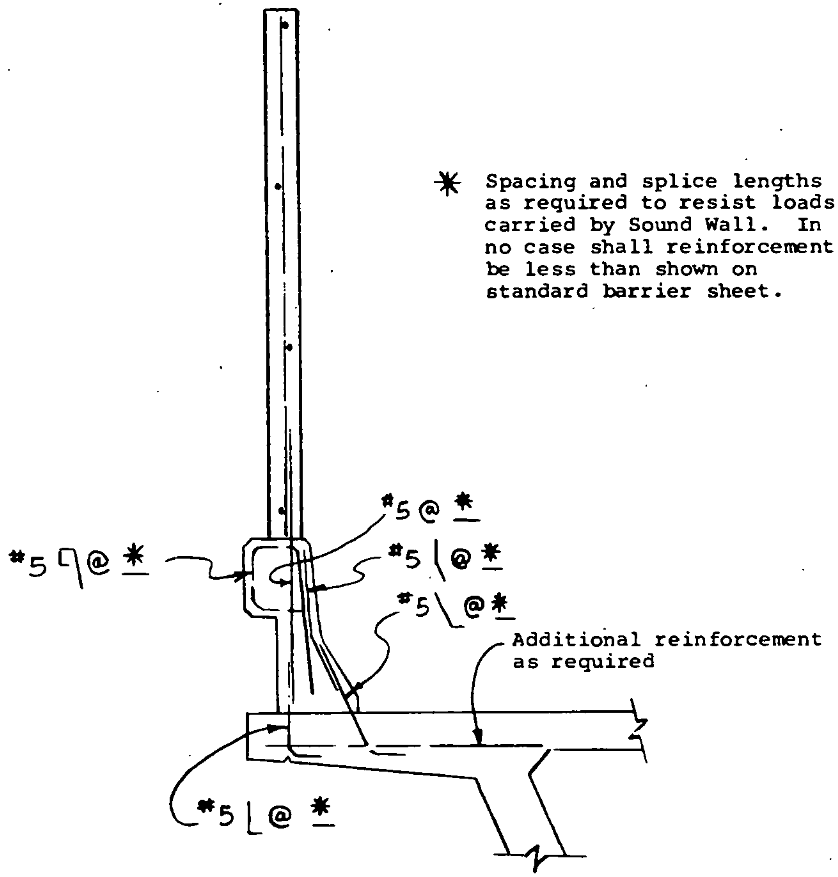
When the sound wall is supported by the bridge superstructure, the wind or seismic load to be applied to the superstructure and substructure shall be as specified in Articles 2-8 and 2-16 of the Bridge Planning and Design Manual, Volume I and Memo to Designers 15-10. Note that additional reinforcement may be required in the barrier to resist the loads carried by the sound wall. See example.

III. WALL DESIGN

The structural members of the sound wall and its foundation shall be proportioned according to allowable stresses given by the codes listed below. Masonry walls shall not be used on bridges.

MATERIAL	APPLICABLE CODE
Concrete	Section 6 - Concrete Design, Volume I Bridge Planning and Design Manual for working stress design. AASHTO Specifications for load factor design.
Masonry	Concrete Masonry Structures - Design and Construction, UBC Code, 1976 Edition.

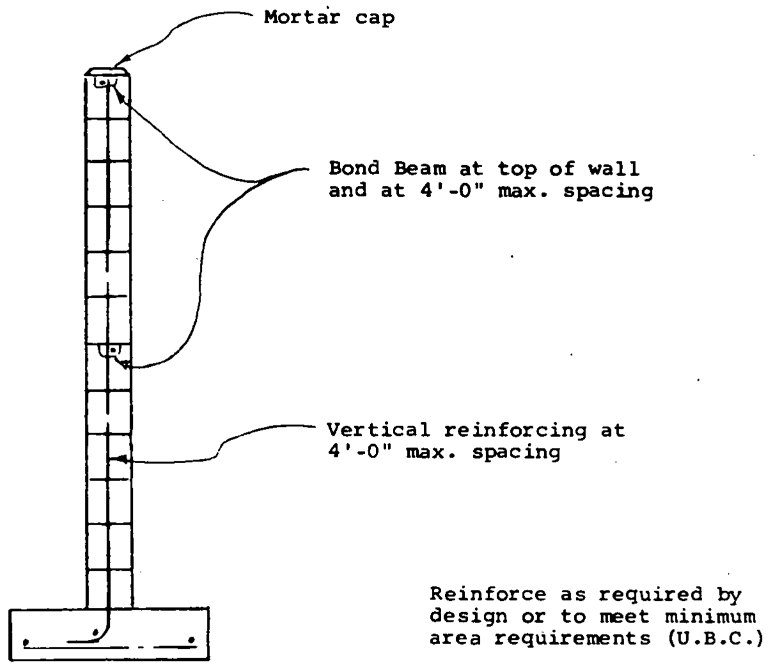
MATERIAL	APPLICABLE CODE
Timber	National Design Specification for Wood Construction, 1977 Edition and Supplement. National Forest Products Association.
Plywood	Plywood Design Specifications American Plywood Association (A minimum 1/2" thick plywood is required).
Steel (Hot Rolled Shapes and Plates)	Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, American Institute of Steel Construction, 1970.
Steel (Sheet Metal)	Specification for the Design of Cold-Formed Steel Structural Members-American Iron and Steel Institute.
Welding	Table 27-B Uniform Building Code 1976.



EXAMPLE - SOUND WALL ON BRIDGE

Minimum Bar Reinforcing Requirement for Masonry Block Wall

Maximum spacing of bar reinforcing in masonry wall is 4'-0" on centers for both vertical and horizontal bar reinforcing. Bond beams will be required at locations where horizontal bar reinforcing is needed. Shown below is an example of the minimum bar reinforcing required for a masonry wall.



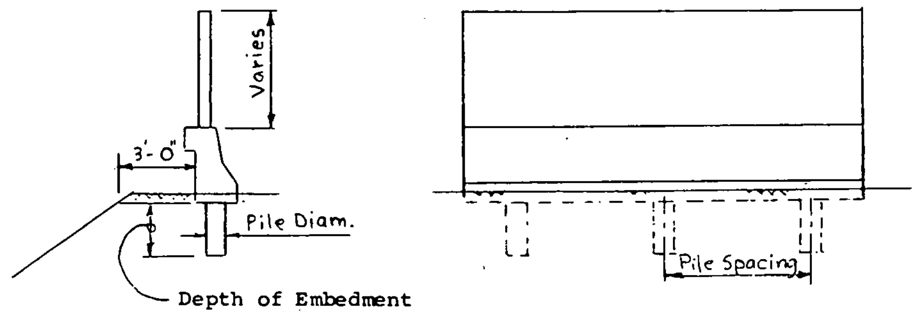
Example: Masonry Block Wall

IV. FOUNDATION DESIGN

Minimum Foundation Requirements for Traffic Loading

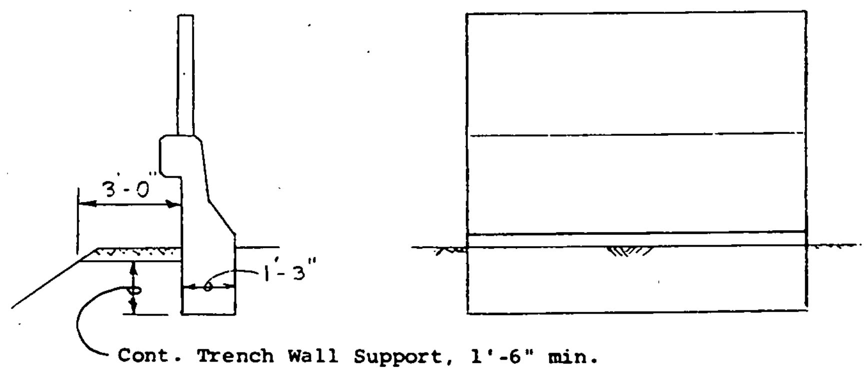
When the sound barrier wall is combined with a traffic barrier the resulting foundation shall meet or exceed the following minimum foundation requirements:

1) Barriers with Pile Supports



Pile Diameter	Minimum Depth of Embedment	Maximum Pile Spacing	Minimum Pile Reinforcing	Spiral Reinforcing
12"	4' - 0"	10' - 0"	#6 tot 7	W3.5 @ 6" pitch
14"	4' - 0"	10' - 0"	#6 tot 6	W3.5 @ 6" pitch

2) Barriers with Continuous Trench Wall Support



3) Sound Walls on Retaining Walls

The walls and foundations of Standard Retaining Walls Types 1-5 can be considered to withstand the traffic impact loading of the traffic barrier. The addition of a Sound Wall will have to be investigated using Group A, B, & C load combinations.

Design of Short Rigid Pile Supports not on or Adjacent to a Fill Slope (UBC Method)

The following formula may be used in determining the depth of embedment required to resist lateral loads where no constraint is provided at the ground surface. A computer program is available on the Tenet Timeshare System to solve this formula.

$$d = \frac{A}{2}\left(1 + \sqrt{1 + \frac{4.36\,h}{A}}\right)$$

Where $A = \dfrac{2.34\ P}{S_1\ b}$

P = Applied lateral force in pounds.

S_1 = Allowable ultimate lateral soil pressure (psf) at a depth of one-third the depth of embedment. $\left(S_1 = \frac{Rd}{3}\right)$

b = Width or diameter of pile in feet.

h = Distance in feet from supporting material to point of application of "P". Disregard upper 6" of supporting material.

d = Depth of embedment of pile in feet (the above equation should not be applied to piles with embedment depth greater than 12 b).

R = Allowable ultimate lateral soil pressure. Use passive pressure less the active pressure from the opposing side. See page 11 for example.

EXAMPLE:

Given $P = 900 \text{ lbs.} \times \underbrace{1.5}_{\text{Safety Factor}} = 1350$

h = 3'-0"

R = 906 psf/ft of depth (See page 11)

b = 12"

Try d = 3 ft.

$S_1 = 906\ \frac{(3)}{3} = 906$ psf

$A = \dfrac{2.34\ (1350)}{906\ \frac{(12)}{12}} = 3.49$

$d = \frac{3.49}{2}\left(1 + \sqrt{1 + \frac{4.36\ (3)}{3.49}}\right) = 5.55$ ft $>$ 3 ft. assumed

Try d - 4.33 ft.

$S_1 = 906\ \frac{(4.33)}{3} = 1308$ psf

$A = \dfrac{2.34\ (1350)}{1308\ (1.00)} = 2.42$

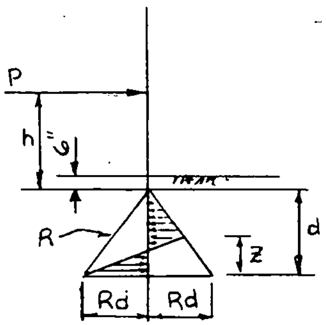
$d = \frac{2.42}{2}\left(1 + \sqrt{1 + \frac{4.36(3)}{2.42}}\right) = 4.27$ ft. - close enough to d = 4'-4" assumed

Use d = 4'-4"

The maximum moment in the pile can be assumed to occur at 0.25d, thus maximum = P (h + .25d).

Design of Continuous Trench Wall Supports Not on or Adjacent to a Fill Slope

The following procedure may be used in determining the depth of embedment of continuous trench wall support to resist lateral loads.



P = Applied lateral load in pounds.

h = Distance in feet from supporting material to point of application of P. Disregard upper 6 inches of supporting material.

R = Allowable ultimate lateral soil pressure. Use passive pressure less active pressure from opposing side. See page 11 for example.

d = Required depth of embedment in feet.

$$\sum F_H = 0 = (2\,Rd)\,(1/2Z) - 1/2\,Rd^2 + P; \quad Z = d/2 - P/Rd$$

$$\sum M = 0 = (2\,Rd)\,(1/2Z)\,(1/3Z) - (1/2\,Rd^2)\,(1/3d) + P(h + d)$$

Substituting $Z = d/2 - P/Rd$

$$\sum M = 0 = \frac{Rd(d/2 - P/Rd)^2}{3} - \frac{Rd^3}{6} + P(h + d)$$

$$= \frac{Rd^3}{12} - \frac{2\,Pd}{3} - \frac{P^2}{3\,Rd} - Ph$$

Example:

Given $P = 142.5 \times \underbrace{1.5}_{\text{Safety Factor}} = 214$ lbs.

$h = 5.25'$

$R = 604$ psf/ft.

Try $d = 4.00'$

$$\sum M = 0 = \frac{604 \times 4.00^3}{12} - \frac{2(214 \times 4.00)}{3} - \frac{(214)^2}{3(604 \times 4.00)} - 214(5.25)$$

$= 3221 - 571 - 6 - 1124$

$= +1520$ N.G.

Try $d = 3.17'$

$$\sum M = 0 = \frac{604 \times 3.17^3}{12} - \frac{2(214 \times 3.17)}{3} - \frac{214^2}{3(604 \times 3.17)} - 214(5.25)$$

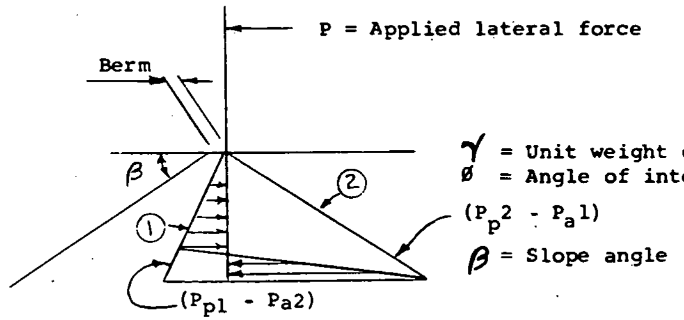
$= 1603 - 452 - 8 - 1124$

$= 19$ Close enough to zero

use d = 3'-2"

The maximum moment in the trench support can be assumed to occur at .25d, thus, Max. = P(h + .25d)

Guidelines for Determining Pile Embedment on Fill Slopes



1. Determine pile embedment by structural analysis. Procedure on page 19 of U.S.S. Steel Sheet Piling Design Manual may be used. The depth of embedment, however, should be limited to about 12 times the diameter of the pile because the analysis is based on the assumption that the pile is relatively stiff.

   Note also, that the analysis is based on passive pressures which are limiting stresses. A factor of safety must be included in the analysis.

2. A non-production type program is available for the U.S.S. Steel Sheet Piling Design Manual analysis. For more information see G. Fung.

3. Berm should be 1'-0" min. wide and provide 6" min. depth of cover above the top of pile.

Determining allowable ultimate lateral soil pressure for use in the design of short rigid pile or continuous trench wall supports.

1. Obtain ϕ & γ from engineering geology.
   (ϕ = Angle of internal friction, γ = Unit weight of soil).

2. For cohesionless fill the ϕ angle must be greater than the slope angle, β. Generally, fills are designed for FS of 1.25, where $FS = \frac{\tan \phi}{\tan \beta}$.

   On cohesive fills, for determining passive and active pressures, $\tan \phi$ may be assumed to be equal to 1.25 $\tan \beta$ and $c = 0$. A more rigorous analysis may be used to include c with actual ϕ angle for determining passive and active pressures. (β = Slope angle).

3. For concrete piles, δ (Wall friction angle) of 2/3 ϕ may be assumed.

4. Determine active and passive pressures of the slope and/or level fill. Fig. 5(a) in the U.S.S. Steel Sheet Piling Design Manual may be used (Attached). Note that if wall friction angle is used, P_p force is not acting horizontally and must be considered in the stability analysis. Note also that the net soil pressures acting on the embedded pile is equal to the passive pressure less the active pressure from the <u>opposing</u> side.

Example:

Given $\phi = 35^\circ$; $\gamma = 120$ lbs/c.f.; β -26.57° (2:1 slope)

$-\delta = 2/3\ \phi = 2/3\ (35) = 23.35^\circ$; $\cos \delta = .918$

$-\delta/\phi = .667$; $\beta/\phi = -26.57/35 = -.759$

From Fig. 5(a)

$R = .808$; $K_p = 2.3$; $Ka = .22$

$P_p = .808 \times 2.3 \times 120 = 223$ psf/ft

$P_{P_H} = 223 \times .918 = 205$ psf/ft.

$Pa = .22 \times 120 = 26$ psf/ft.

$P_{a_H} = 26 \times .918 = 24$ psf/ft.

Allowable ultimate lateral soil pressure

$= P_{P_H} - P_{a_H} = 205 - 24 = 181$ psf/ft.

<u>Design of Pile and Trench Foundations</u>

Load Factor for Overturning	=	2.0 Group A Loading 1.5 Group B or C Loading

<u>Design of Spread Footings</u>

Minimum Factor of Safety for Overturning	=	2.0 Group A Loading 1.5 Group B or C Loading
Minimum Factor of Safety for Sliding	=	1.5 Group A Loading 1.2 Group B or C Loading

<u>Design of Pile Section</u>

The attached Fig. 5(b) may be used for designing pile sections. Note that service loads are to be used with this graph.

<u>Foundation Design Parameters</u>

The foundation requirements for each sound wall should be reviewed by the Engineering Geology Branch which will recommend the design parameters to be used in calculating the lateral soil bearing pressure or allowable vertical soil bearing capacity.

V. <u>GENERAL REFERENCE</u>

For additional information concerning the problems of highway noise control and the alternatives available for sound barrier construction, consult the following reference.

O'Gara, M.B., "Highway Noise Control - A Value Engineering Study," California Division of Highways, October, 1972.

G. A. Hood

G. A. Hood

Guy D. Mancarti

Guy D. Mancarti

Attach

GF:lm

COMMENTARY ON SOUND WALL DESIGN CRITERIA

Building specifications, rather than bridge specifications, are more applicable for designing sound walls and most of the requirements in this criteria are taken from the 1976 edition of the Uniform Building Code.

The 15 lb/ft^2 wind load meets UBC wind requirements for structures located less than 30 feet above the average level of the adjoining ground. Sound walls are generally no higher than 14 feet, and usually placed less than 30 feet above the average level of the adjoining ground.

Sound walls on bridges and retaining walls are subject to a higher risk of endangering lives if failure were to occur and 30 lb/ft^2 of wind load is recommended for designing these walls. The 30 lb/ft^2 is approximately equal to a wind pressure created by an 80 mph wind. This is the highest wind velocity for a 50-year mean recurrence interval in California (Figure 4, 1971, AASHTO Specifications for the Design and Construction of Structural Supports for Highway Luminaires).

The seismic load of .3 dead load also meets UBC seismic requirement for masonry or concrete fence over six feet in height. Because the seismic response characteristics of a sound wall may be adversely affected by the bridge supporting it, a seismic load of 1.0 dead load is recommended for designing sound walls on bridges. For the same reason, a seismic load of 2.0 dead load is recommended for designing connections of prefabricated sound walls on bridges.

The minimum foundation requirements for barriers on pile supports were developed from results of dynamic tests of Type 8 Bridge Approach Guardrail (Research Report No. M & R 36412).

The UBC formula for determining the depth of pile embedment is taken from UBC, Section 2907 (f).

REDUCTION FACTOR (R) OF K_p FOR VARIOUS RATIOS OF $-\delta/\phi$

ϕ \ δ/ϕ	-0.7	-0.6	-0.5	-0.4	-0.3	-0.2	-0.1	-0.0
10	.978	.962	.946	.929	.912	.898	.881	.864
15	.961	.934	907	.881	.854	.830	.803	.775
20	.939	.901	.862	.824	.787	.752	.716	.678
25	.912	.860	.808	.759	.711	.666	.620	.574
30	.878	.811	.746	.686	.627	.574	.520	.467
35	.836	.752	.674	.603	.536	.475	.417	.362
40	.783	.682	.592	.512	.439	.375	.316	.262
45	.718	.600	.500	.414	.339	.276	.221	.174

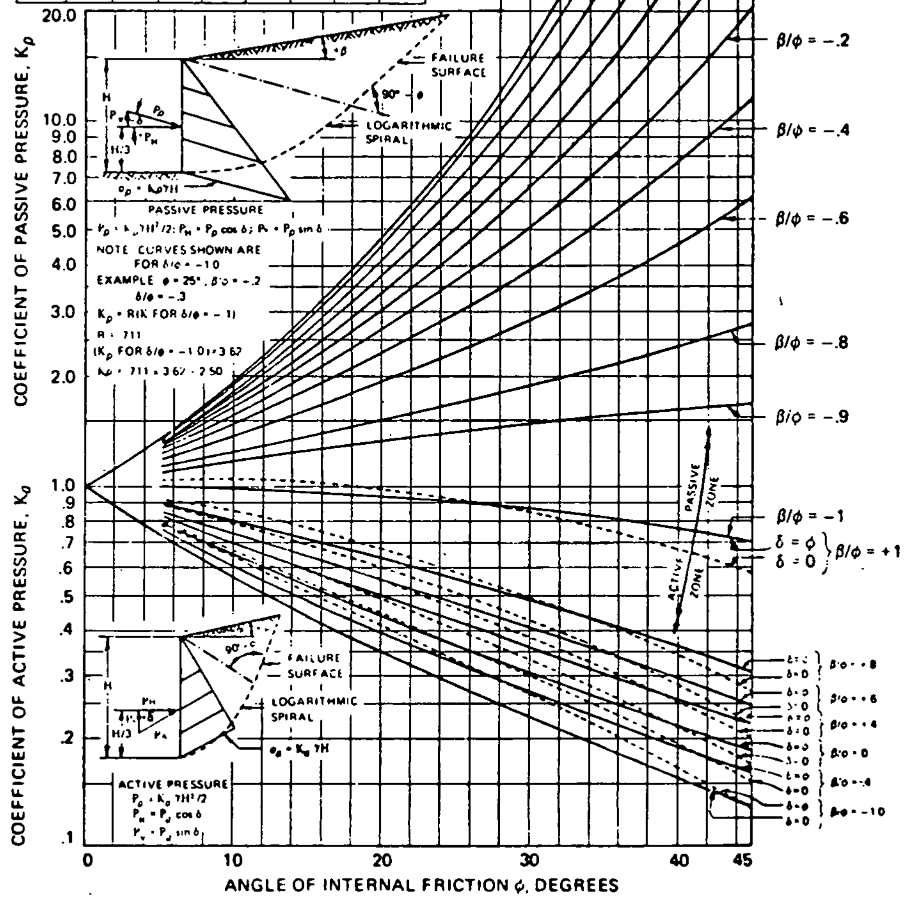
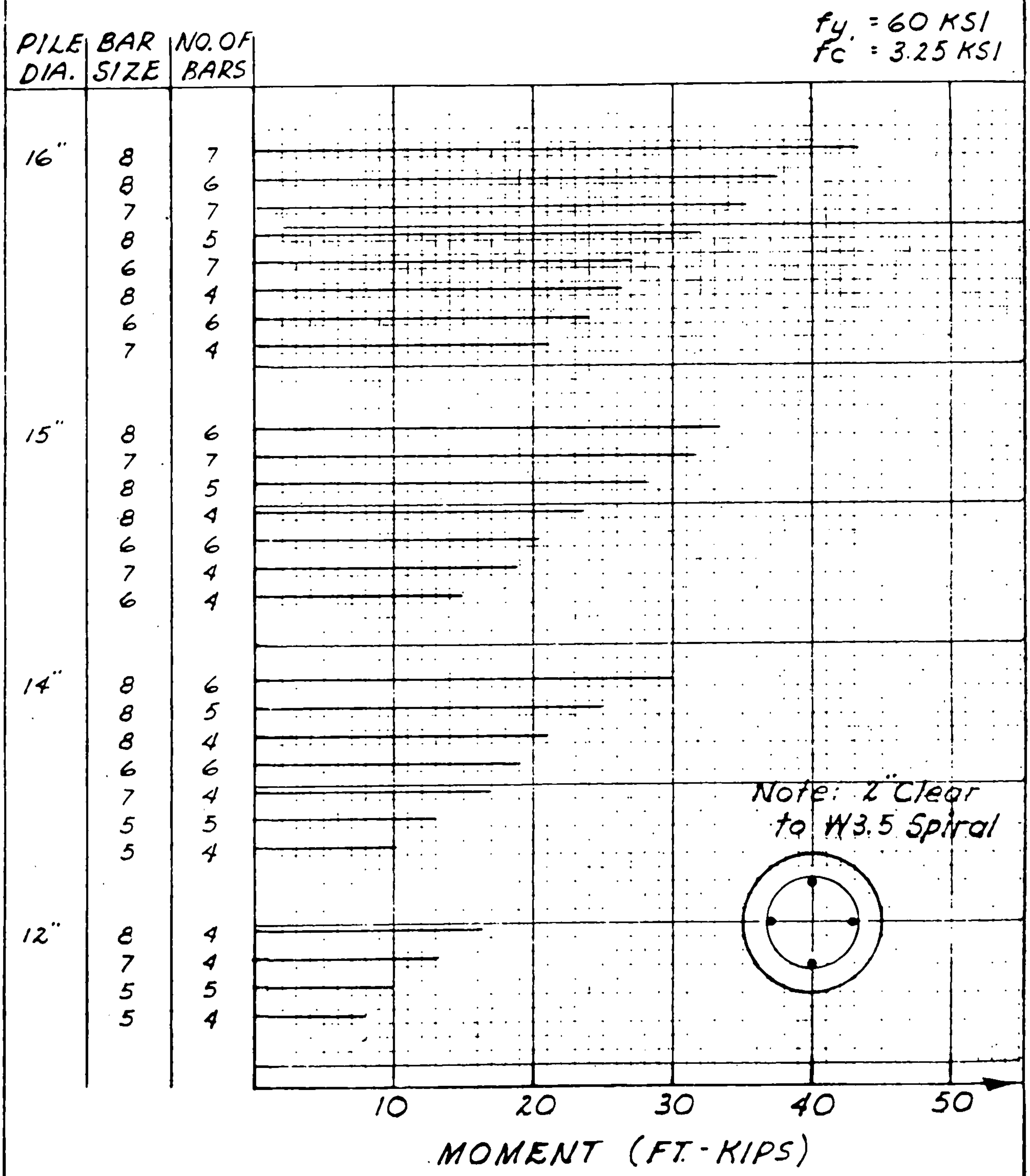


Fig. 5(a) — Active and passive coefficients with wall friction (sloping backfill) (after Caquot and Kerisel[21])
(Printed with permission from United States Steel)

Fig. 5(b)

CIRCULAR SHORT COLUMNS

MOMENT CAPACITY FOR PURE BENDING By SERVICE LOAD ANALYSIS (AASHTO 1.5.28)



5-291.567 NOISE BARRIERS

A. General

Noise barriers are constructed to intercept noise created by vehicles on highways, thereby reducing the adjacent neighborhood annoyance. Noise barriers may take a number of forms with the most effective being earth mounds, walls, or combinations of mounds and walls.

While the primary function of a barrier is to reduce noise, aesthetics and safety must also be considered. Designers should contact the Environmental Services Section early in the planning stage for input on conceptual plans and alternates as well as final design for landscaping and special wall treatment. Safety aspects to be considered during design are covered in Section D.

Noise wall standards are divided into several basic designs: timber planking, timber plywood, concrete block, precast concrete panels and Glu Lam panels. The details for each design are provided in the Standard Plans Manual 5-297.600 series. As additional designs are developed they will be incorporated into the Standard Plans Manual.

Alternate post designs and alternate facing designs are included in the Standard Plans Manual. Including suitable alternate wall designs in construction plans will tend to minimize construction costs.

B. Acoustical Design

1. Objectives:

a. To satisfy the applicable FHWA Design Noise Levels in the "FHWA Noise Standards".

b. To attain the applicable daytime Minnesota Noise Standards (NPC-2) for land use NAC-1, L_{10} and L_{50}, whenever technically feasible and economically reasonable. (There is currently no reliable way to estimate noise levels for night time traffic.)

c. To achieve at least ten decibels (dbA) total noise reduction at receptors along each noise abatement project to assure significant and lasting public benefits.

d. To attain significant reductions in present or anticipated sound levels in a manner acceptable to those receiving the noise and consistent with safety, traffic operation, environmental, maintenance, and cost constraints.

2. Noise Prediction Method

The noise prediction method based on the National Cooperative Highway Research Programs (NCHRP) reports 117 and 144 shall be used for all predictions. The computerized version of this model is usually the most convenient to use (Hewlett-Packard desk top Model 9810). Please note that the barrier design chart in the manual method (previously circulated in draft form) is based solely on the NCHRP 117 report and should no longer be used. A new chart based on the NCHRP 114 report will be developed and distributed. The computer model should be used until the new chart has been prepared.

3. Receptors

a. A receptor is defined as a location where human use, during the summer, can reasonably be expected to result in exposure to highway traffic noise for a period of one hour or more daily.

b. Outdoor receptors shall be assumed to be five feet above the ground. Locations yielding the highest sound level after barrier construction shall be used for design. This location may be near the right of way, or further away (where barriers are generally less effective). Normally outdoor receptors at residences will be located in front yards, backyards and play areas. Barriers for multiple dwellings with no outdoor recreation areas may be designed for window receptors only.

c. The noise standards are outdoor standards but are set to assure acceptable in-door levels. First story windows should be considered receptors. Locations at second story windows and balconies that face the highway should be investigated on a case-by-case basis. Barrier heights needed to satisfy the standards at second story levels may often be unreasonable. If so, reasonable attempts should be made to block visual line of sight to the highway from these locations. Noise barriers to protect third story locations and higher will not normally be feasible.

d. While nearby receptors will usually govern barrier design heights, more distant receptors may govern the design length of a barrier.

4. Traffic

a. Truck noise will usually determine the noise barrier design heights. Therefore, truck volumes to be used should be determined within +50% to have sufficient accuracy to ensure an adequare basis for design.

b. On existing highways, use the peak traffic hour truck volumes now present unless substantial increases are anticipated. For new highways or if substantial increases are expected, use projected peak traffic hour truck volumes for 20 years from estimated date of completion of the barrier. Peak traffic hour truck volumes are the maximum hourly truck volume expected during the peak traffic hour on an average day.

c. On existing highways use the automobile traffic volume (reduced for truck traffic) consistent with service level "C". If service level "C" does not occur, use the present peak hour automobile volume. (Automobile volumes will usually have little affect upon noise barrier design heights, unless truck volumes are very low). For new highways, or if substantial modifications or traffic increases are expected, use projected auto volumes for 20 years from estimated date of completion of the barrier.

d. For new and existing highways use 50 mph speeds for both trucks and autos when service level C governs volumes determined in b. and c. for noise level predictions (even if posted speed is less than 50 mph). Use the speed consistant with peak hour service level if it is higher (ie, A or B) than C. Use the posted speed for urban streets.

e. On existing highways the noise prediction method should be calibrated by comparing observed traffic conditions with measured noise levels for each measurement site.

5. Roadway and Terrain

a. Predictions should be based on as many roadway elements as necessary to adequately describe the terrain and roadway relationship.

b. Each roadway of a divided highway should normally be computed separately for purposes of barrier design.

c. Noise may be transmitted from sections of roadway beyond the barrier unless the length of the barrier is designed to prevent it.

d. Reflections from hard surfaces, such as opposing noise walls, retaining walls, paved surfaces, and large bridges, should be considered as additonal source elements using virtual image procedure. Reflections may affect L_{10} and L_{50} levels differently. If reflections are a severe problem consider using a sound absorbent facing. Contact the Office of Technical Support Services (Design for assistance).

6. Noise Barrier Design Considerations

a. Noise barriers should normally be designed to provide not more than 15 dbA noise reduction at the most vulnerable receptor after the barrier is built. Receptors in more favorable locations may in some cases receive greater than 15 db reductions. Design procedure currently available can be used to design a noise barrier for up to 20 db reduction. However, designs for reductions greater than 15 db are not considered feasible because of unpredictable and uncontrollable atmospheric and terrain surface effects, scattering from trees and buildings, and other unknowns.

b. Gaps in barriers will produce undesirable fluctuations or bursts of sound at nearby receptors and should be avoided. The Office of Road Design may be contacted for technical assistance in analysis of gaps.

c. Designated material thickness and weights for walls in these standards are adequate to assure that sound transmission through the barrier will not noticeably affect the sound level at receptors behind the barrier. A minimum 22 dbA sound transmission loss has been used in the standard wall design. This transmission loss ensures that sound transmitted through a barrier will be imperceptible (less than one db to the total sound level behind the barrier) if the barrier is designed for a maximum 15 db attenuation. If modifications in wall surface densities or thicknesses are desired, a re-check of the transmission loss should be required from the Office of Technical Support Services (Design).

d. Consistent with other constraints, noise barriers should be located as close to the roadway as practical in order to achieve the greatest benefits for the most people behind the barrier.

e. Noise barrier designs that "wrap around" noise sensitive areas may be more economical in certain cases. Each case should be decided on its merits. Usually a noise barrier must be extended some distance beyond the edge of the areas being protected to adequately protect properties near the edge of the development. If the barrier is wrapped around the end of the residential area, often less barrier but more right of way will be needed. Large hills or buildings may substitute for a noise barrier "wrap around" at the end of a residential area. On the other hand, frontage roads may prevent such shielding. Another advantage of wrap-around design is that new noise sensitive development on any vacant lands behind the down road ends of a roadside noise barrier is discouraged.

f. All noise abatement projects should be designed to achieve at least ten db reduction in L_{10} and six db reduction in L_{50} from existing traffic noise levels.

C. Structural Design Criteria (Information Only)

1. Wind Load

The design wind load is based on information in the 1975 AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminary and Traffic Signals" and the 1973 AASHO "Standard Specification for Highway Bridges." A design wind speed of 75 miles per hour was selected which corresponds to the speed for a 50 year wind recurrance interval for Minnesota according to the 1975 AASHTO Sign Specifications. AASHO 1.2.14 (1973) states that the wind load may be varied in proportion to the wind speed and that the force applied to a bridge substructure (centroid of which is similar to a noise wall) shall be 40 pounds per square foot. The wind force would equal 23 psf according to the following formula:

$$P = \left(\frac{75\text{ MPH}}{100\text{ Mph}}\right)^2 \quad (40\text{ psf}) = 23\text{ psf}$$

AASHTO 1.2.5 Sign Specifications (1975) gives a $P = 0.00256\ (1.3v)^2\ CdCh$ formula for wind pressure. Two different conditions were considered for application of this formula as shown below:

a. Walls with Length to height ratios of 15 or less

$P = 0.00256\ (1.3v)^2\ CdCh$

Assume: Cd = 1.3
Ch = 0.8
V = 75 Mph

$P = 0.00256\ (1.3 \times 75)^2\ (1.3)\ (0.8) = 25$ psf

b. Walls with Length to height ratios greater than 15

Assume: No gust factor because of the distribution of load over the long wall

Cd = 2.0
Ch = 0.8
V = 75 Mph

$P = 0.00256\ (75)^2\ (2.0)\ (0.8) = 23$ psf

A design wind pressure of 23 psf was selected based on the above study of AASHTO specification. This 23 psf load is slightly higher than the 20 psf minimum load pressure recommended by the Uniform Building Code.

2. Soil Parameters

a. Use $\phi = 30^\circ$ for granular soils to determine post embedment.

b. Use 2000 psf for allowable bearing capacity.

3. Prestressed Concrete Panel Walls

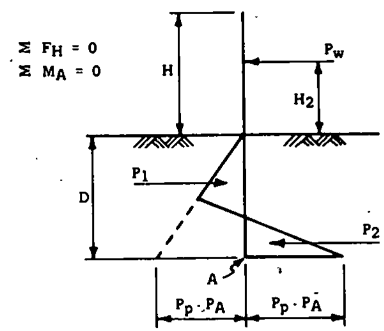
a. Design of panel is based on 1973 AASHTO Standard Specifications for Highway Bridges 1.6.1 and the following:

Load = 23 psf

Prestressed Steel: f's = 270 ksi

Concrete: f'ci = 4000 psi
f'c = 5000 psi

b. Embedment design is based on soil parameters recommended by the Materials Office using Coulomb and Rankine theories and the following assumptions:



4. Concrete Block Panel Walls

a. Design of panel is based on AASHTO ultimate strength design and the following:

Load = 23 psf
Reinforcing Bars fy = 60,000 psi
Masonry f'c = 2,000 psi
Concrete f'c = 4,000 psi footing, pilasters and cap beam

b. Foundation design based on normal cantilever wall criteria and above soil parameters.

5. Timber Wall - Posts and Planks

a. Wind load - 23 psf

b. Design of facing: based on AASHTO working stress design
(1973) AASHTO 1.10.1 F_t = approximately 1250 psi lumber.
(1973) AASHTO 1.10.1 (E) provides for an increase of 33-1/3%
Note: $F_t = 1.33\ (1250) = 1663$

c. Posts

1) Reinforced concrete post: based on AASHTO ultimate strength design. f'c = 5000 psi, fy = 60,000 psi.

2) Prestressed concrete post: based on 1973 AASHTO "Standard Specifications for Highway Bridges" 1.6.1 f's = 270 ksi, f'ci = 4000 psi, f'c = 6000 psi, fy = 60,000 psi

3) Glu-laiminate post: based on AASHTO wet working stress design combination symbol 24F.
(1973) AASHTO 1.10.1 (E) provides for an increase of 33-1/3% for wind

4) Timber posts: based on working stress design
(1973) AASHTO 1.10.2 F_t = 1500 psi for lumber
(1973) AASHTO 1.10.1CE) provides for an increase in stress of 33-1/3%. Note: F_t - 1.33 (1500) = 1995 psi

d. Post embedment - based on theory given in HRB - 30 report, and 0 = 30° granular soil.

6. Timber Wall - Posts and Plywood

a. Wind load - 23 psf

b. Design of facing: based on AASHTO working stress design:

(1974) Plywood Design Specification (American Plywood Association) F_t = 1650 psi
(1973) AASHTO 1.10.1 (E) provides for an increase in stress of 33-1/2%. Note: F_t = 1.33 (1650) = 2195 psi

c. Posts

1) Reinforced concrete post: based on AASHTO ultimate strength design. f'c = 5000 psi, fy = 60,000 psi

2) Prestressed concrete post: based on 1973 AASHTO "Standard Specifications for Highway Bridges" 1.6.1 f's = 270 ksi, f'ci = 4000 psi, f'c = 6000 psi, fy = 60,000 psi

3) Glu-laminate post: based on AASHTO wet working stress design combination symbol 24F.
(1973) AASHTO 1.10.1 (E) provides for an increase of 33-1/3% for wind.

4) Timber posts: based on working stress design
(1973) AASHTO 1.10.2 F_t = 1500 psi for lumber
(1973) AASHTO 1.10.1 (E) provides for an increase in stress of 33-1/3%. Note: F_t - 1.33 (1500) = 1995 psi

d. Post embedment - based on theory given in HRR - 39 report, and 0 = 30° granular soil.

7. Timber Wall - Glued Laminated Wood Panels

a. Wind load = 23 psf

b. Design of wall: based on AASHTO wet working stress design combination symbol 20 F.
(1973) AASHTO 1.10.1 (E) provides for 33-1/3% stress increase for wind load.

c. Embedment design based on $\emptyset$ = 30° granular soil and Coulomb and Rankins theories and the assumptions in C.3.b. above.

d. Maximum wall height normally limited to 15 feet for economic reasons.

D. Safety Aspects

1. General

Although the primary function of a noise barrier is to reduce noise reaching neighborhoods adjacent to the highway while being aesthetically pleasing, safety must also be a major consideration. A number of factors must be considered with regard to safety:

a. Location of barrier along mainline roadway.

b. Slopes of earth mounds.

c. Wall and earth mound terminals.

1) Along mainline
2) In gore areas

d. Sight distance at cross roads.

e. Plantings

f. Transitions to other structures

g. Barrier walls

h. Guardrail

i. Right of Way fences

2. Location of Barrier Along the Roadway

Along the mainline designers are to make every effort to maintain the required clear zone. Clear zone is defined as the roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. Figure A indicates required clear zone distances for speeds of 40, 50, and 60 mph for various slope conditions. Consideration should be given to acquiring additional R/W so that the required clear zone can be obtained in areas of restricted R/W.

Design of the barrier depends somewhat on the location of the wall. When the clear zone cannot be obtained, the wall should be capable of deflecting vehicles. Materials such as heavier timbers or concrete to provide barrier walls should be incorporated into the design, see Section 8. Use of guardrail as an alternative to increasing the strength of the wall could also be considered, see Section 9.

When the wall is located near the edge of the clear zone engineering judgement should be used in the evaluation of whether it is reachable by a vehicle and the need for building in deflection capabilities.

When horizontal stepping is used in the wall design, it should be done going away from traffic to avoid creating protruding angles or pockets to approaching traffic. If these obstructions are created within the clear zone or where they can be reached by an out of control vehicle, guardrail or attenuators are necessary. In addition, posts can sag an errant vehicle and so should not be located on the mainline traffic side of a wall.

Along ramps it is generally not possible to maintain the required clear zone because of right of way restrictions; so the wall should be located as far from it as possible. This is especially true for ramps with cirvilinear alignment and at the higher speed ends of the ramps such as the beginning of the off ramp and the end of an on ramp. Consideration should be given to providing a smooth surface along the wall adjacent to the ramp to deflect the vehicle either by placing the posts on the other side of and increasing the width of wood sheeting for the first 3 feet or by adding guardrail. Speeds should be evaluated to determine which is safer.

For adjacent local streets and frontage roads where considerably lower speeds are expected, the clear zone is not as critical. Care should be taken not to build in potential hazardous conditions. Engineering judgement should be used in determining need for redirection capability.

3. Slopes of Earth Mounds

Earth mounds, used alone or in combination with walls, should have side slopes as flat as possible. A slope of 3:1 shall be considered as the steepest slope with 4:1 or flatter as desirable. 4:1 slopes will provide a slope that can be readily maintained and provide a transversable slope to a wayward motorist. These slope may require the acquisition of additional R/W.

Noise wall and earth mound construction provides the opportunity for the designer to improve the steep slope conditions that exist along some of the existing highways or to provide a berm section between the wall and roadway on existing fill conditions. The slopes can be flattened and the sound barrier incorporated as part of a retaining wall structure. See Figure B for example.

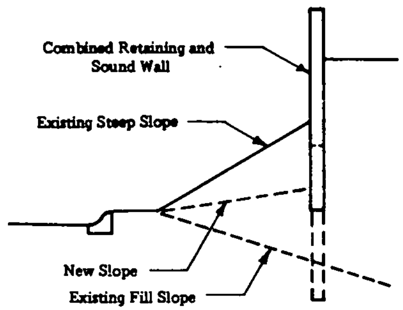
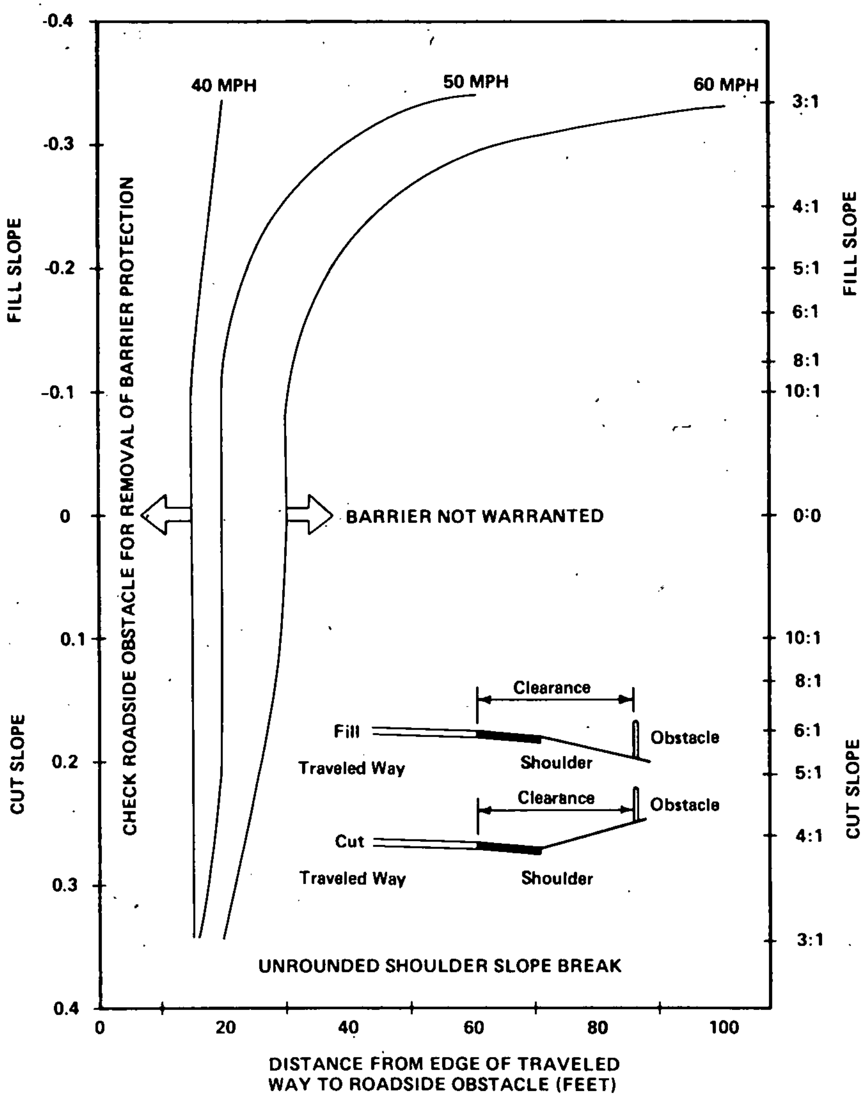


Fig. B 5-291.567



4. Wall and Earth Mound Terminals

The end of a noise wall or of an earth mound can be a hazard to approaching traffic. This is especially true when located in the gore of off ramps. To reduce the hazard of the end of a noise barrier the designer should consider the following:

a. Adjacent to the mainline

When the end of a noise wall is exposed to approaching traffic within the clear zone area it should be considered as another fixed object and protection provided. The protection may be either in the form of guardrail or an attenuator (crash cushion). The end of an earth mound should be sloped on a 6:1 or flatter slope (10:1 or 15:1 desirable) to approaching traffic.

b. In a gore area

When the terminus of a noise wall is located in a gore area an attenuator (crash cushion) will generally be required. Since the recovery area in a gore is very limited, guardrail is generally not appropriate. When an earth mound has its terminus in a gore area and there is insufficient room for a 6:1 end slope for the mound it may be necessary to add a short section of wall to the mound and protect a vehicle from the wall end with an attenuator.

5. Sight Distance at Crossroads

A major safety aspect associated with sound barriers is their effect on sight distance at intersections of ramps, frontage roads, and crossroads. Drivers approaching an intersection at grade should have an unobstructed view of the whole intersection and a length of the intersecting roadway sufficient to permit control of the vehicle to avoid collisions. No wall should be placed within this area high enough above the elevation of the adjacent roadways to constitute a sight obstruction.

The setback distance on each approach necessary to achieve the sight triangle desired at the intersection varies with the approach speeds. The following should be used:

Speed, m.p h.	20	30	40	50	60	70
Distance, feet	90	130	180	220	260	310

For an example of how this works, refer to Figure C. If vehicle A is approaching at 30 m.p.h. and vehicle B is approaching at 50 m.p.h., an unobstructed sight triangle between points on highway A and B with legs extending at least 130 feet (da) and 220 feet (db), respectively, from the intersection would be required.

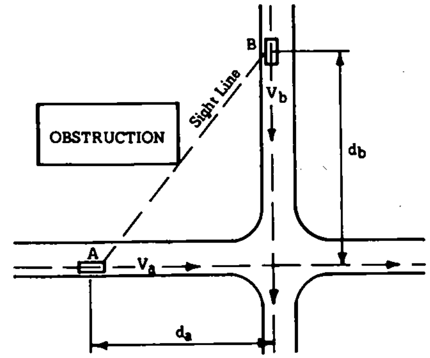


Fig. C 5-291.567
Sight Distance Triangle

Designers should establish how close the noise wall must be to the intersection to adequately abate the noise problem. This location should be balanced with the noise generated from the local cross street. If the Barrier must encroach on the setback distances provided above, then the designer should consult the district traffic engineer to establish a specific desirable triangle.

Another possible problem area that must be considered is the merge areas of ramps joining the mainline. The barrier may reduce the back sight distance for this merging condition. One possible solution to the problem is to adjust the barrier overlap on each side of the ramp.

6. Plantings

Although plantings in connection with a noise barrier are necessary for the aesthetic effect of the wall or mound, safety must also be considered. Large plantings which may become a hazard to traffic should either be avoided or located so they are well outside the required clear area. The above sight distance restrictions will also apply to plantings. Plantings are to be avoided in critical areas such as sight distance corners and gores. Also, plantings requiring considerable maintenance should be avoided since the maintenance crew itself may become a hazard to traffic.

7. Transitions to Other Structures

The transition from a noise wall to another structure such as a bridge rail or retaining wall is potentially another safety problem area. When the transition falls within the required clear area and there is a structural strength difference between the two, the same type of problem as transitioning guardrail to a bridge rail may occur. The designer must consider this problem when designing the wall. The use of guardrail to protect the transition is one possible solution to the problem.

8. Barrier Walls and Noise Walls

As stated in D.2., a noise wall located within the required clear zone should be capable of deflecting a vehicle, or if not, redirection capability should be provided. Materials such as heavy planking or concrete can be used to create a traffic barrier wall in the lower portion of the noise wall. A straight section, without jogs, of pre-cast concrete panel wall normally will not require the addition of a barrier wall or guardrail.

a. Height of Barrier Wall

The height of barrier wall required will vary depending on its distance behind a curb. For sections without curbs and curbed sections with the noise wall less than 2 feet behind the curb the minimum height of barrier wall is 27 inches. The following table provides minimum barrier wall heights related to distance behind a curb:

Distance from Curb to Face of Wall	Min. Height of Barrier Wall
0' - 2'	27"
2' - 5'	33"
5' - 10'	36"
10' - 12'	33"
12' - 14'	30"
14'	27"

Table A 5-291.567

These heights are the minimum heights necessary to stop a vehicle that might be vaulted by the curb.

b. Concrete Traffic Barrier Wall

A concrete barrier wall may be either a flush concrete surface (similar to a retaining wall) or in the shape of the concrete median barrier. Either shape may be located at the front (traffic side) side of noise wall or incorporated into the lower portion of the noise wall, see Fig. D.

These designs are to be considered special designs and the Bridge and Structures Section contacted for details regarding the design.

c. Heavy Plank Traffic Barrier Wall

For timber or plywood noise walls the use of heavier planks in the lower portion of the noise wall may be substituted for the concrete barrier wall, see Fig. E. For the standard 8 foot post spacing a minimum 5-1/4" x 10-3/4" Glu Lam rail plank size is required. At least two planks (21-1/2" depth) are required for a barrier, with the top of the upper plank at a height of at least 27 inches or the values from Table A. Again these are special designs and the bridge and Structures Section should be contacted for details.

9. Guardrail and Noise Walls

When using guardrail in connection with a noise wall a regular guardrail installation set in front of the wall should be used. The advantage of this type of installation is the elimination of damage to the noise wall from vehicle impact thus reducing maintenance costs.

An alternate installation in lower speed areas (45 m.p.h. or less) is a combined guardrail rubrail. This alternate could be used on the frongage road or backside of a noise wall. It involves blockouts mounted on the wall with a standard plate beam section or a 4" x 12" wood plank rail. For a wood noise wall the blockouts can be attached to the vertical posts if they are a minimum 6" x 6" post and not spaced over 8 feet apart.

10. Right of Way Fence

Since the primary purpose for erecting fences along highways is safety, the right of way fence can be eliminated when noise walls higher than 5 feet are constructed. The noise wall will generally prevent the hazardous intrusion of animals, people, and vehicles onto the highway. The elimination of the right of way fence make maintenance of the area behind the wall easier and can also lead to agreements for the municipality or community to maintain the area. Right of way fences will normally be required when earth mounds only are constructed; however, a low noise wall may be considered in lieu of the R/W fence.

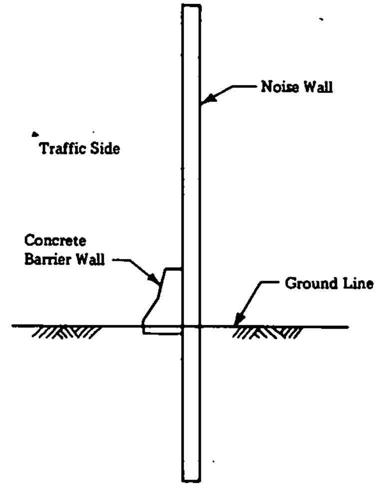
11. Summary

To ensure the safety of motorists, noise barrier design must incorporate all of the safety features used in the design of a roadway. Safety features such as location to provide the required clear area, side slopes of mounds, sight distances at terminals at cross streets, hazardous terminal ends, plantings, and transitions must all be studied and solutions worked out. Safety must be considered as one of the primary considerations.

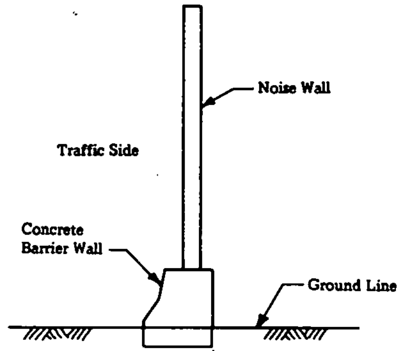
E. Design Procedure

1. General

Figure F illustrates steps which are necessary to develop an approved set of construction plans for a noise abatement project at an existing highway location. The procedure shown applies to non-major actions. Where noise abatement is constructed as part of a major action (new construction or major upgrading), the Action Plan procedures will apply.

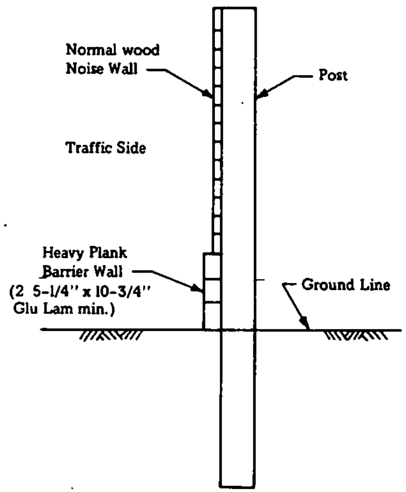


Concrete barrier wall in front of noise wall

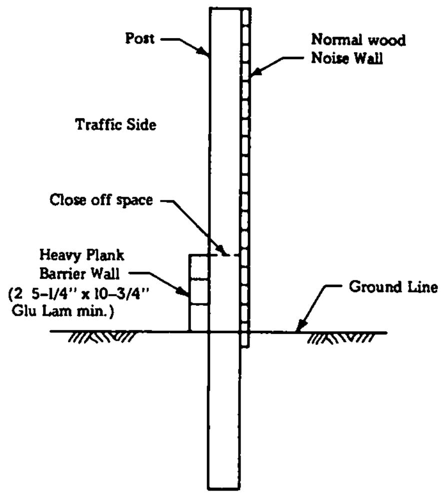


Concrete barrier wall as lower portion of noise wall

FIGURE D 5-291.567

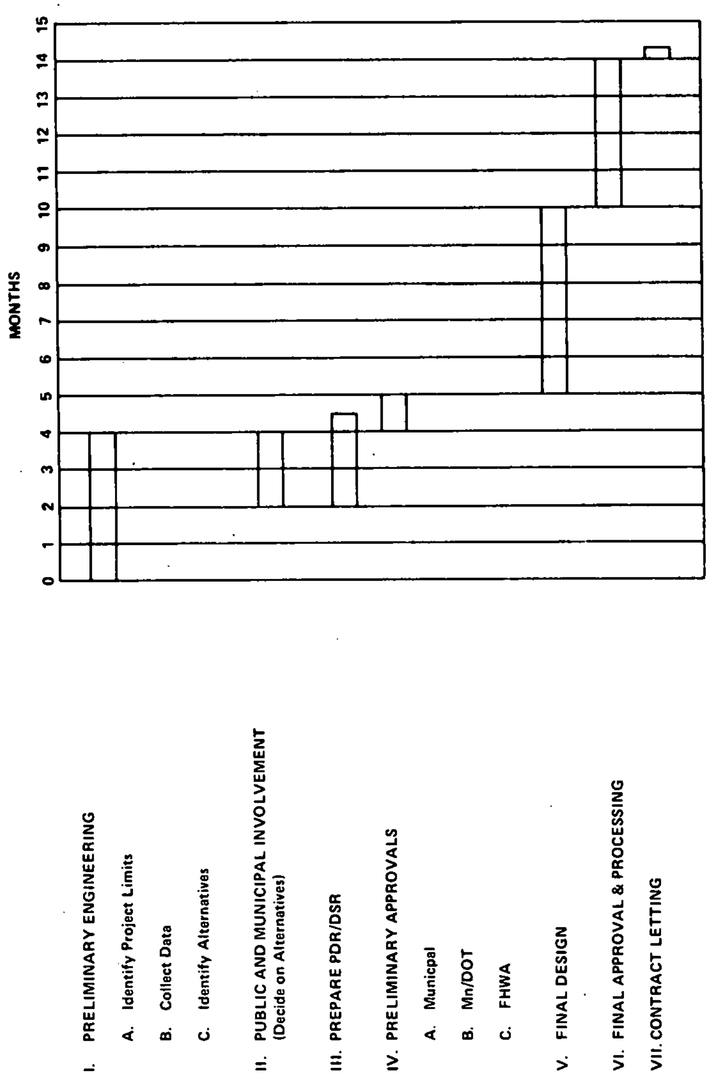


Wood noise wall on traffic side of posts



Wood noise wall on resident side of posts

FIGURE E 5-291.567



PROJECT DEVELOPMENT TIME SCHEDULE
(Example Only)
For Non-Major Noise Abatement Projects With No New R/W Required

2. Specific Comments on Project Development Steps are as follows:

a. Preliminary Engineer

Actions which occur in this phase include the

1) Noise abatement design (computation of wall heights, etc.).

2) Determine alternate methods of noise abatement (walls, mounds, combinations, etc.).

3) Determine possible alternate locations of abatement facility.

4) Determine alternate wall types (wood, concrete, etc.).

5) Prepare conceptual landscaping plan treatment for each alternate.

6) Prepare cost estimates of the various options.

Items which must be considered in selecting the proposed alternate include traffic safety, sight distance, drainage, maintenance, existing utilities, lighting, signing, potential soil problems, compatibility with surrounding terrain and land usage, and restrictions imposed by available right-of-way. Layouts, cross-sections, and barrier profiles should be prepared for each alternate.

Since it will normally be desirable to use the final plan base maps for noise abatement computations, identification of problem areas, and public informational meetings arrangements should be made in the initial month of project development to obtain the necessary topographical data and contour mapping. Aerial photography (Flight scale 1" = 250') contour mapping will normally prove sufficient accuracy for determining ground elevations needed in final design. However, supplementary field information should be requested where the work is in close proximity to buildings and where hydraulics problems or other conditions warrant.

Traffic, safety and sight distance considerations should be in accord with Section D, Safety Aspects.

Design should provide for positive drainage away from both sides of noise barrier walls, whenever possible (minimum slope of .04 Ft./Ft. away from wall). Where walls or berms will alter natural drainage patterns, provide adjacent drainage ditches and water way opening or culverts along and/or through the wall. Design should provide for a 50 year flood frequency discharge where flood risk damage potential warrants.

When selecting the barrier location, provide for winter snow storage (6' min. - 10' desired) and consider possible future construction such as sidewalks, recreational trails, ramp realinement etc.

The Environmental Services section should be consulted for preliminary input regarding the conceptual landscaping plan. Since the designer at this point is determining possible alternate schemes, it is expected that the environmental proposal will be somewhat general.

b. Public and Municpal Involvement

The intent of this step is to inform both local officials and affected citizens of the scope of the proposed work, including the alternate methods of achieving the desired noise abatement. Normally, Mn/DOT will make recommendations to the local council based on input received from the public. Local officials are responsible for selections and local approval of the final design scheme based on analysis of information obtained from the public and from Mn/DOT.

c. Prepare PDR/DSR

Preparation of the PDR/DSR is explained in detail in the Mn/DOT Action Plan. A layout with wall placement and profiles of ground line and top of wall should be included. Supplemental 1" = 100' or even 1" = 50' layouts for intersection sight distance requirements may be necessary.

d. Preliminary approvals

Local approval of the concept plan is needed to advance a project to final design. Consultation with the municipality in final selection of a noise abatement alternative should result in a resolution of concept approval at the municipal level. Where applicable (such as where the municipality already performs frontage road maintenance) a municipal resolution accepting maintenance responsibility for back slopes and/or areas on Mn/DOT right of way outside the noise abatement wall should be obtained at this time.

Following municipal concept approval, the PDR/DSR including a layout and profiles should be submitted to the Office of Technical Support Services (Design) for review and processing for Mn/DOT staff approval and FHWA approval.

e. Final Design

Standard plan sheets containing appropriate noise barrier wall details are available for use in the final construction plans. However, use of these sheets will require the following considerations:

1) Soils Information

The final design engineer should initiate a request to the district materials or soils engineer for soil recommendations at all wall locations.

The following items should be considered:

– The standard plan sheets provide for several soil and embankment conditions. The soils criteria for each condition are listed on the standard plan sheets. Recommendations from the soils engineer are necessary in order to select the appropriate design condition.

– Special wall designs are required when the soils conditions at the site are "worse" than the soils conditions described on the standard plan sheets. If walls are to be built in soils other than those described on the sheets, the designer must request a special design from the Bridge and Structures Section. The request should be made as early as possible in the final design stage.

– It is desirable to have sufficient soils information during the preparation of plans so that quantity estimate lists will be accurate and so contractors will be able to plan early material orders based on plan quantities. However, occasions may arise where the accurate determination of bottom of wall elevations cannot be made during design. In these instances, the contract must contain clauses restricting the contractor from ordering the affected materials until actual structure heights are known.

– Where a combination wall and berm is to be constructed, consider specifying an embankment material that will result in the most economical wall design. For example, construction of the upper portion of a berm using selected cohesive soil may be adequate to meet this recommendation.

– Embankment settlements of 6" or less are not considered detrimental with regard to altering the acoustical design. However, since differential settlement could cause rotation or tilting of wall segments, the soils engineer may elect to specify a time delay for settlement or construction using a more stable embankment material.

– Since the standard designs where no spread footing is provided depend on passive lateral earth pressure along a wall or at posts, the designer should furnish information regarding approximate depth of wall embedment to the soils engineer when requesting the soils investigation. The extent and shape of the soils investigation to be performed on each project will be as determined by the district soils engineer.

2) Wall alignment

The abatement scheme selected in the preliminary stage will not usually tie the walls to a precise location. In selecting the final wall alignment, the designer has some leeway in adjusting the location shown on the preliminary plan in order to provide for detail considerations. Adjustments may be warranted in order to fit standard panel lengths or standard materials sizes; to fit with existing trees, signs, lights and utilities; to better meet safety requirements, or drainage considerations.

When significant shifts in wall location are considered necessary, the change should be discussed with the preliminary design engineer.

3) Aesthetics and Environmental Factors

The final wall alignment scheme should be reviewed with the Environmental Services section so that final recommendations can be made regarding landscaping and special wall treatment.

4) Right of Way

After setting the final alignment, construction limits can be determined. A request for easements and/or additional right of way should then be conveyed to the district right of way engineer.

5) Special Structural Designs

Special designs will normally be warranted for any of the following situations:

– Where a barrier ties into a bridge abutment or retaining wall.

– Where the wall will be higher than provided for on the standard plan sheets.

– Where lights and/or signs are to be constructed integrally with the wall.

– Where the wall must serve as a retaining wall.

In any of these cases, the Office of Bridges and Structures should be requested to submit recommenddations and/or details regarding the special designs.

6) Final Design Public Meetings

In some cases the district may elect to hold public meetings in the final design stage to present detailed information to affected property owners. Meetings of this type would appropriately be held prior to finalizing the plans in order to incorporate acceptable changes into the plans before completing quantity lists.

f. Final Approvals

In addition to the normal Mn/DOT and FHWA final approvals, a resoltuion of plan approval is required from each municipality affected by the work

APPENDIX E

TECHNIQUES FOR MEASURING NOISE BARRIER EFFECTIVENESS (15)

5.0 BARRIER FIELD INSERTION LOSS DETERMINATION PROCEDURE

5.1 PURPOSE

This chapter provides procedures that can be used to determine the field insertion loss (IL) provided by a noise barrier. The field insertion loss is the difference in sound levels at a particular microphone location caused by the construction of a noise barrier. If the sound barrier could be constructed "instantaneously," determination of IL would be simple. In this situation, a "before construction" sound level measurement would be made, the barrier would be "instantaneously" constructed, and an "after construction" sound level measurement would be made. The difference between the two levels would be the IL. Because of the time involved in building a barrier, a number of factors are introduced for which corrections must be made. These factors include changes in traffic volumes, mix and speed, changes in emission levels, and changes in terrain. The procedures presented here for determining IL are based upon measurements to the maximum extent possible.

In addition to determining the IL, people are also concerned about the accuracy of the prediction models used in the barrier design. Too often the predicted IL used during the barrier design is compared with a measured IL obtained shortly after barrier construction. This comparison may be invalid if the predicted IL and the measured IL are based on different traffic conditions. For a meaningful comparison, the conditions under which the measurements were made must be used in the prediction model. Thus, a valid comparison may be made between a measured IL and a calculated IL. Users of these procedures are urged to use the FHWA Model (see FHWA Report FHWA-RD-77-108, "The FHWA Highway Traffic Noise Prediction Model") for these calculations.

Procedures are provided in this chapter for determining field insertion loss of noise barriers for two cases. Case 1 (section 5.4) is for existing highways where "before construction" measurements can be obtained. Case 2 (section 5.5 through 5.6) is for new highways or for existing noise barriers where "before" measurements cannot be obtained. Figure 12 illustrates the decision process for determining insertion loss as explained in sections 5.4 through 5.6.

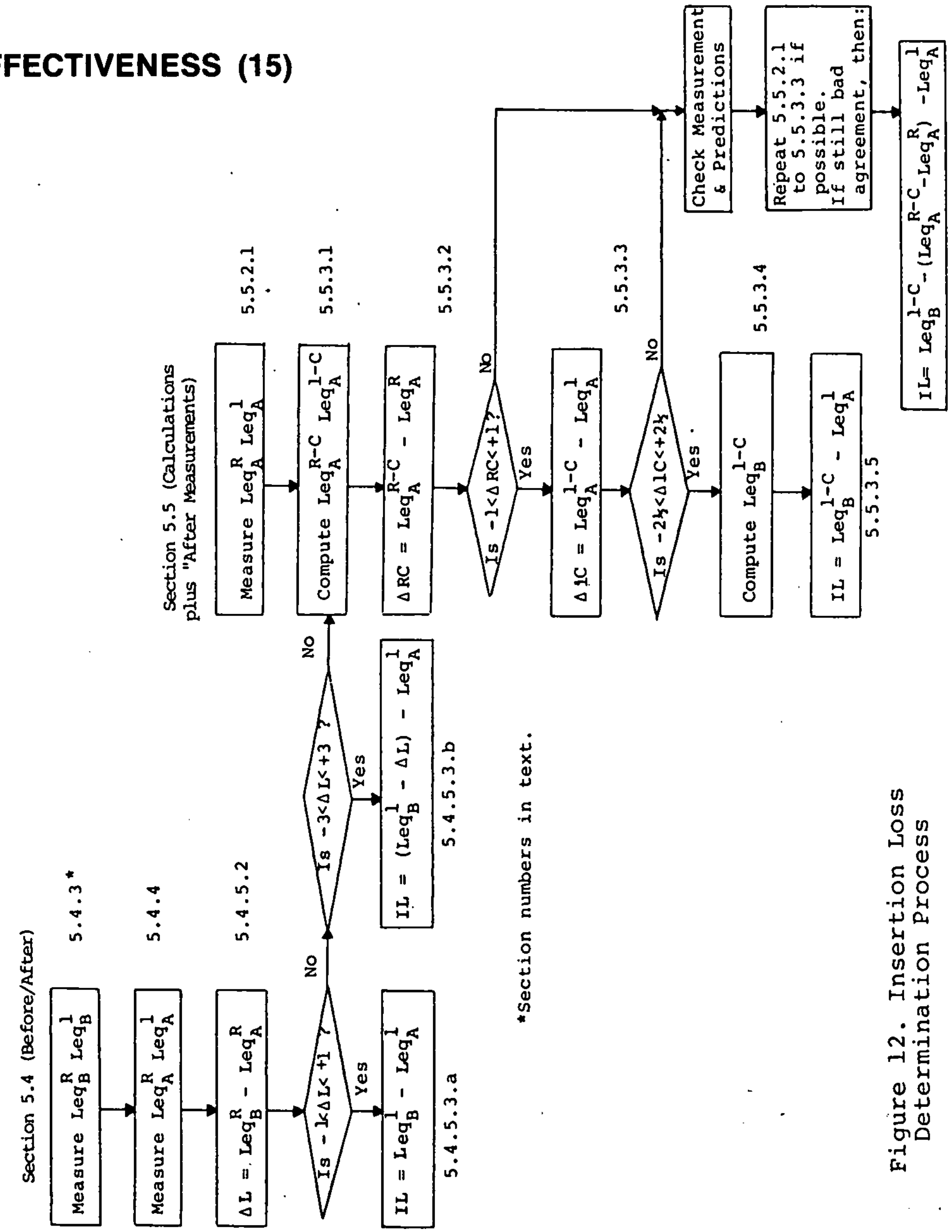


Figure 12. Insertion Loss Determination Process

5.2 INSTRUMENTATION

The following equipment is required:

- Sound Level Meters (Type 1 or 2) - 2
- Sound Level Calibrator
- Earphones or Headphones (Optional)
- Speed Detection Device (Radar)
- Stopwatches or Timers - 2
- Wind Speed Indicator
- Sling Psychrometer (Optional)
- Tripod - 2 (Optional)
- Data Sheets
- Microphone Cables - 2 (Optional)
- Windscreens - 2
- Spare Batteries

5.3 PERSONNEL

Two persons are needed to make sound level measurements. If the technique in section 5.4 is used, two other individuals will be needed to operate the speed detection equipment and to count the traffic. For the other two techniques, one person may be sufficient to count traffic. Familiarity with the FHWA Model is desirable.

5.4 TECHNIQUE FOR DETERMINING IL FOR EXISTING HIGHWAYS WHERE THE BARRIER HAS NOT BEEN BUILT

This procedure involves simultaneous measurements at "reference" and "study site" microphone locations. Two sets of measurements are made: one set before the barrier is built, and one set after the barrier is built. An adjustment is then made (if necessary) to the reference measurements, and the IL is calculated by subtracting the "after" measurement from the adjusted "before" measurement.

5.4.1 "Study Site" Microphone Location (Microphone #1)

1. Use maps and/or field reconnaissance to determine the desired "study site" location for the IL determination.

2. Once the location is selected, establish a baseline. The baseline is a line perpendicular to the centerline of the near traffic lane and passes through microphone #1. The reference microphone will also be located along this baseline. Record the exact location of the baseline and microphone #1 (distance and elevation). Another set of measurements will be made at the same location after the barrier is built.

3. Microphone locations should not be selected within 3 metres of any vertical reflective surface. Measurements should not be taken at locations or times where extraneous sounds such as aircraft, animals, children, or traffic on side streets could influence the measurements.

4. If a comparison will be made between the measured insertion loss and a calculated insertion loss, the geometry and terrain between microphone #1 and the roadway should be as simple and uniform as possible. This will simplify the input data needed for the prediction model.

5.4.2. Reference Microphone

1. The reference microphone is located on the baseline determined by section 5.4.1.2.

2. The location, length, and elevation of the proposed barrier must be known before the reference microphone may be located.

3. The reference microphone must have an unobstructed view of the roadway through a subtended arc of at least 160 degrees. Once this requirement is satisfied, any of three positions may be used.

   a. Position A (refer to Figure 13)--Between the roadway and the barrier provided that the microphone is at least 7.5 metres from the centerline of the near traffic lane, and at least 3.0 metres from any reflective surface (including the barrier).

   b. Position B (refer to Figure 14)--Directly over and 1.5 metres above the top of the barrier (still be at least 7.5 metres away from the centerline of the near traffic lane).

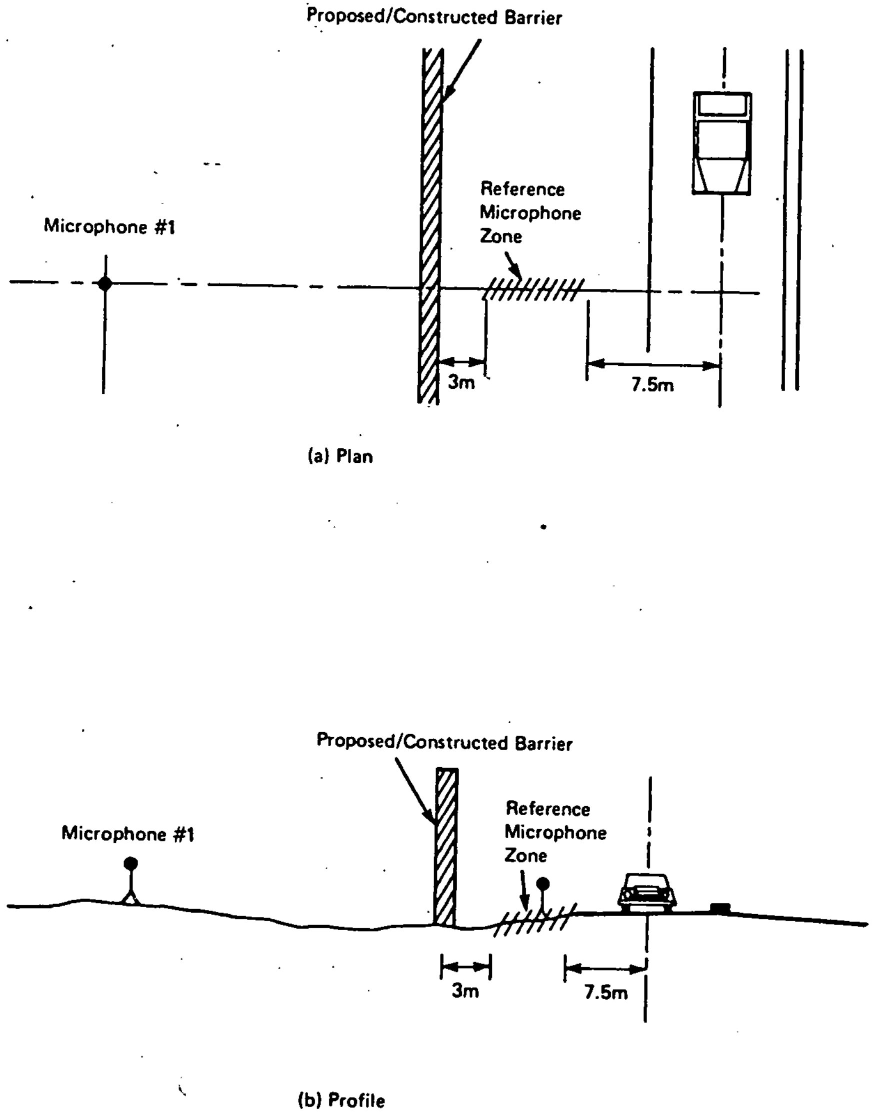


Figure 13. Reference Position A

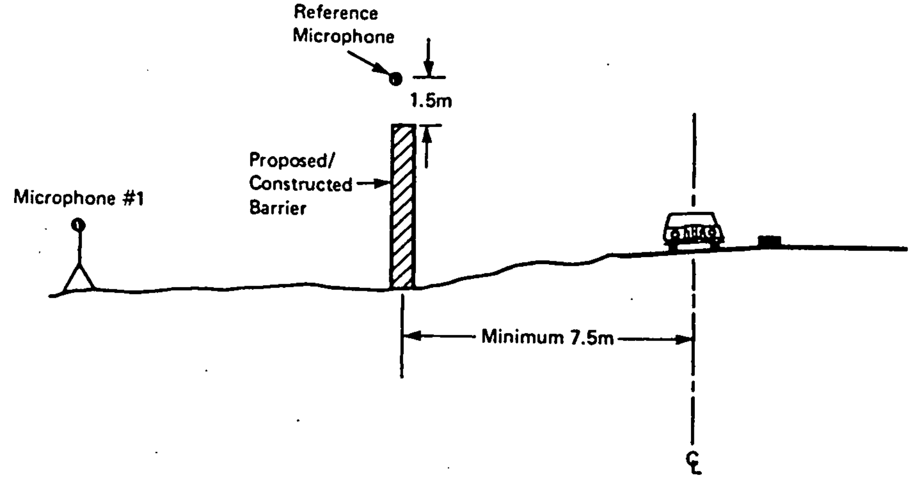


Figure 14. Reference Position B

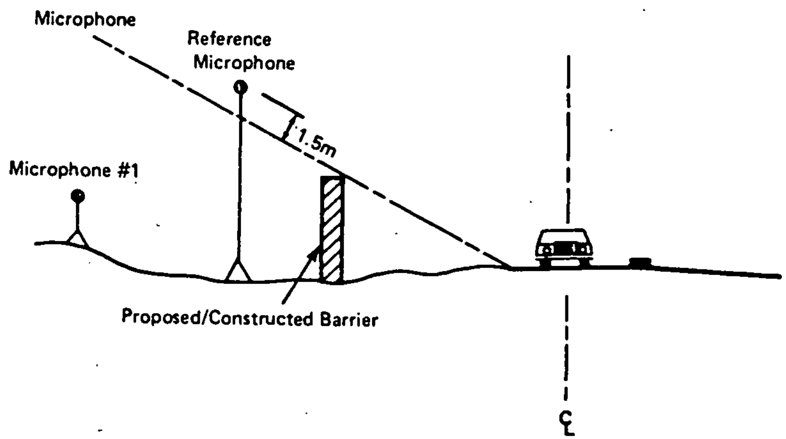


Figure 15. Reference Position C

c. Position C (refer to Figure 15)--Between the barrier and microphone #1. The reference microphone must be 1.5 metres higher (measured perpendicular) than a line drawn from the near edge of the pavement through the top front edge of the barrier.

4. If the measured IL is to be compared with a calculated IL, subsequent calculations will be simplified if the reference microphone location is exactly 15.0 metres from the centerline of the near lane.

5. Record the precise location of the reference microphone on the baseline. This location will be used for the "after" set of measurements.

5.4.3 <u>Measurement and Calculations for the "Before Construction" Condition</u>

1. <u>Sound Level Measurement</u>
Through simultaneous measurements, obtain sound level data at the reference microphone and at microphone #1. Minimum measurement period is 8 minutes and 20 seconds. Chapter 3 discusses a typical manual measurement procedure. Determine the "before" Leq(h) at the reference microphone, $Leq(h)^R_B$, and at microphone #1, $Leq(h)^1_B$. Record these values. After the barrier is built, these values will be used to determine the measured IL.

2. <u>Traffic and Environmental Data</u>
Concurrently with the sound level measurements, the traffic data must be measured. Vehicles must be separated into the three classes shown in Figure 16. Two-axle buses go into the medium category and three-axle buses go into the heavy category. Traffic counts volumes must be obtained for both directions of flow. Obtain representative speeds for each vehicle class (in both directions, if possible). Also, obtain information on the ground conditions, wind speed and direction, and other climatic conditions.

5.4.4 <u>Measurements and Calculations for the "After Construction" Condition</u>

It is important that this second set of measurements be made as soon as practical after the barrier has been completed and normal traffic flow has been restored. This will help minimize changes in traffic characteristics that could significantly alter the sound levels.

1. <u>Microphone Location</u>
After the barrier has been built, use the information in sections 5.4.1 and 5.4.2 to establish both microphone locations in the field. Monitor the environmental conditions and, when these conditions are similar to those observed in section 5.4.3.2, make the second set of measurements.

2. <u>Sound Level Measurements</u>
Through simultaneous measurements, obtain sound level data at the reference microphone and at microphone #1. The minimum measurement period is 8 minutes and 20 seconds. Chapter 3 discusses a typical manual measurement procedure. Determine the "after" Leq(h) at the reference microphone, $Leq(h)^R_A$, and microphone #1, $Leq(h)^1_A$. Record these values.

3. <u>Traffic and Environmental Data</u>
Concurrently with the sound level measurements, the traffic data must be measured. Vehicles must be separated into the three classes shown in Figure 16. Two-axle buses go into the medium category and three-axle buses go into the heavy category. The traffic count must be according to the direction of flow. Obtain representative speeds for each vehicle class (in both directions, if possible). Carefully study the ground and vegetation conditions at the site. Record these conditions along with data on wind speed and direction and other climatic conditions.

5.4.5 <u>Computation of the Field Insertion Loss</u>

1. <u>Traffic Data</u> Compare the traffic data measured before and after barrier construction. If the traffic conditions change substantially, the procedures in section 5.5 may be needed to determine the IL.

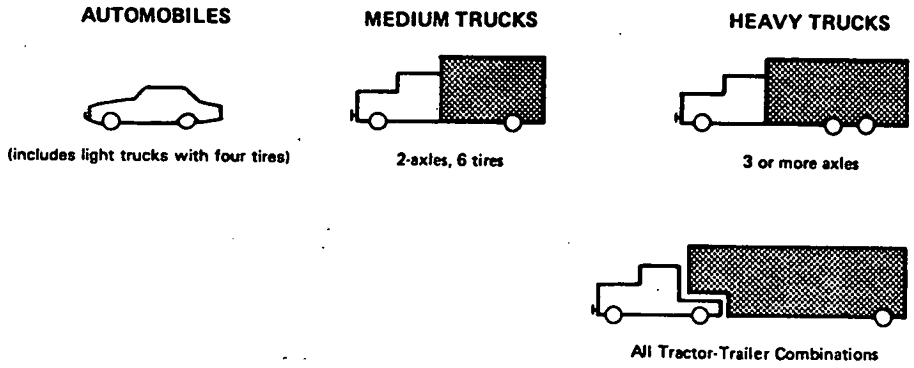


Figure 16. Vehicle Type Identification

Table 4. Criteria for Selection of Site Parameter

Situation	Drop-Off Rate
1. All situations in which the source or the receiver are located 3 metres above the ground or whenever the line-of-sight* averages more than 3 metres above the ground.	3 dBA ($\alpha = 0$)
2. All situations involving propagation over the top of a barrier 3 metres or more in height.	3 dBA ($\alpha = 0$)
3. Where the height of the line-of-sight is less than 3 metres and	
(a) There is a clear (unobstructed) view of the highway, the ground is hard and there are no intervening structures.	3 dBA ($\alpha = 0$)
(b) The view of the roadway is interrupted by isolated buildings, clumps of bushes, scattered trees, or the intervening ground is soft or covered with vegetation.	4.5 dBA ($\alpha = 1/2$)

*The line-of-sight (L/S) is a direct line between the noise source and the observer.

2. Reference Microphone Subtract the Leq(h) measured after the barrier was built from the Leq(h) measured before the barrier was built.

$$\Delta L = Leq(h)_B^R - Leq(h)_A^R \qquad (1)$$

where

ΔL is the difference in the Leq(h)'s

3. Microphone #1

   a. If ΔL is $\pm$ 1 dBA or less, compute the IL according to equation 2.

$$IL = Leq(h)_B^1 - Leq(h)_A^1 \qquad (2)$$

   where

   IL is the field insertion loss.

   b. If ΔL is $\pm$3 dBA or less, compute the IL according to equation 3.

$$IL = [Leq(h)_B^1 - \Delta L] - Leq(h)_A^1 \qquad (3)$$

   c. If ΔL is greater than 3 dBA, compute the IL according to the procedures in section 5.5.

5.5 TECHNIQUE #1 FOR DETERMINING IL FOR NEW HIGHWAYS OR EXISTING BARRIERS (CALCULATIONS PLUS "AFTER" MEASUREMENTS)

This procedure uses a combination of "after" sound level measurements and the FHWA model. Basically, a set of sound level measurements is made at two carefully selected locations. These measurements are used to calibrate the FHWA model. Once the calibration is completed, a "before" sound level is calculated. The IL is then determined by taking the difference between the calculated "before" and the measured "after" sound levels.

5.5.1. Microphone Location

See sections 5.4.1. and 5.4.2.

5.5.2. Measurement and Calculations Based on Existing Barrier

1. Sound Level Measurement
   See section 5.4.4.2.

2. Traffic and Environmental Data
   See section 5.4.4.3.

5.5.3. Computation of the Field Insertion Loss

1. Using the FHWA model, compute the calculated noise level at the reference microphone, $Leq(h)_A^{R-C}$, and at microphone #1, $Leq(h)_A^{1-C}$. Divide the roadway into at least two equivalent lanes, one for each direction of flow using the traffic data obtained in section 5.5.2.2. Use Table 4 and/or experience to determine the site parameter for the reference microphone and for microphone #1.

2. Compare the calculated traffic noise level at the reference microphone, $Leq(h)_A^{R-C}$, with the measured traffic noise level, $Leq(h)_A^{R}$. If the two values agree within ± 1 dBA, it can be assumed that the emission data in FHWA model correctly represents the traffic for this site and that the site around the reference microphone has been correctly modeled. If the two values do not agree within ± 1 dBA, refer to section 5.5.3.6.

3. Compare the calculated traffic noise level at microphone #1, $Leq(h)_A^{1-C}$, with the measured traffic noise level, $Leq(h)_A^{1}$. If the two values agree within ± 2 1/2 dBA, it can be assumed that the site has been correctly modeled. If the two values do not agree within ± 2 1/2 dBA, refer to section 5.5.3.6.

4. Using the FHWA model and traffic from section 5.5.2.2, calculate the noise level at microphone #1, $Leq(h)_B^{1-C}$, as if the barrier has not been built. Base the site parameter upon the conditions that would exist *if there were no barrier*.

   It is important to note that this calculation will be complicated for houses beyond the first row because they will receive some degree of shielding from the first row houses.

5. Compute the IL according to equation 4.

$$IL = Leq(h)_B^{1-C} - Leq(h)_A^{1} \qquad (4)$$

6. If the measured and calculated values do not meet the tolerance requirements ($\pm$ 1 dBA at the reference microphone and ± 2 1/2 dBA at microphone #1), locate the source of the discrepancies as follows:

   a. Check the computation of the measured Leq(h).

   b. Check the input data used in the FHWA model.

   c. If the tolerance requirement in section 5.5.3.6 still cannot be met, repeat the measurements in section 5.5.2.

   d. Repeat the steps in sections 5.5.3.1 through 5.5.3.3. If the error persists, compute the IL according to equation 5.

$$IL = \{Leq(h)_B^{1-C} - [Leq(h)_A^{R-C} - Leq(h)_A^{R}]\} - Leq(h)_A^{1} \qquad (5)$$

5.6 TECHNIQUE #2 FOR DETERMINING FIELD INSERTION LOSS FOR NEW HIGHWAYS OR EXISTING BARRIERS (UNSHIELDED LOCATION ALONG THE HIGHWAY)

One measurement is made at a noise sensitive site shielded by the barrier. A second measurement is made at a similar site along the highway where there is no barrier.

Figure 17 presents a sketch of appropriate measurement locations and specifies the geometry involved. If available, extra microphones could be used at each site at reference locations as a check on reference level similarities.

5.6.1. Microphone Locations

1. The microphone-to-roadway distance for each location must be identical ± 0.5 metres).

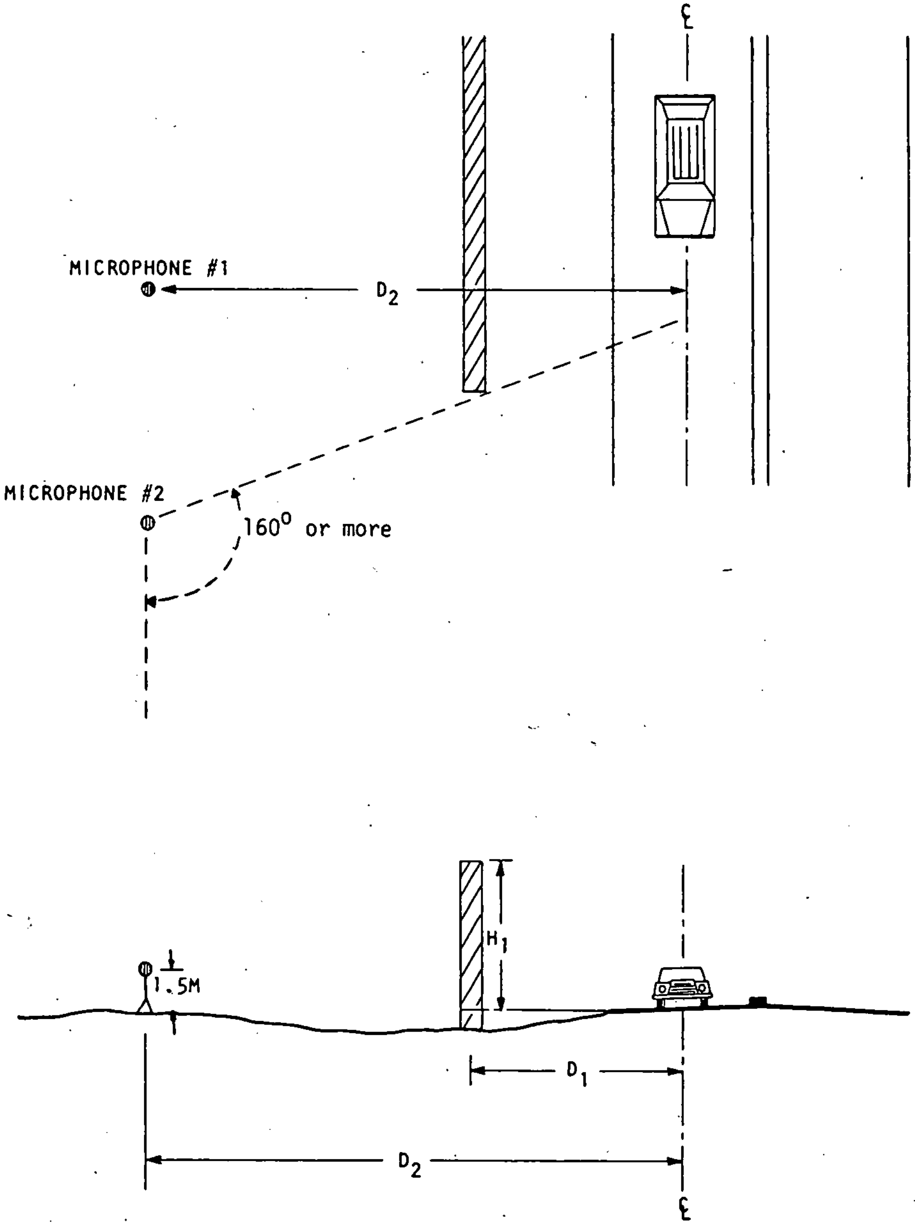


Figure 17. Microphone Locations for Simulated "Before" Site Method

2. The ground cover between the road and the microphone at each site must be similar.

3. The topography at each site should be similar.

4. The number of lanes and geometry of the roadway at each site should be identical. Road features such as median strips and guard barriers should be the same at each site.

5. Traffic flow conditions (vehicle/hour, mean vehicle speed) should be equivalent at each site.

6. The unshielded measurement location should have as great an angle of view of the highway as possible. An angle of at least 160 degrees is recommended. Both microphones are mounted on tripods at a height of 1.5 metres ±16 cm (5 feet ±6 inches) above the ground at the measurement point, or at the height of the receptor under study.

5.6.2. Measurements

1. Sound Level Measurement
Use the technique previously described in Chapter 3 to determine Leq at each microphone. Call the level at the unshielded site $Leq(h)^1_B$, and the level at the shielded site, $Leq(h)^1_A$

2. Traffic and Environmental Data
See section 5.4.3.2.

5.6.3. Computation of the IL

Use the procedure described in section 5.4.5, letting the unshielded site represent the "before" condition and the shielded site be the "after" condition. If the reference microphones were not used, the FHWA model should be used to compute the reference levels, $Leq(h)^R_B$ and $Leq(h)^R_A$. The IL will be the difference in levels at the two microphones, adjusted by differences in the reference levels.

APPENDIX F

TYPICAL SOCIAL SURVEY QUESTIONNAIRES

4S after survey

MINNESOTA DEPARTMENT OF TRANSPORTATION

NOISE BARRIER EVALUATION QUESTIONNAIRE

Please complete and return this questionnaire in the enclosed self-addressed and postage-paid envelope at your earliest convenience. Thank you for your assistance.

---

1. DO YOU OWN YOUR RESIDENCE, OR DO YOUR RENT? _____ OWN _____ RENT

2. PLEASE INDICATE TYPE OF DWELLING:
   - _____ SINGLE FAMILY HOUSE
   - _____ DUPLEX
   - _____ APARTMENT
   - _____ MOBILE HOME
   - _____ TOWNHOUSE/CONDOMINIUM

3. HOW MANY YEARS HAVE YOU LIVED AT YOUR PRESENT ADDRESS? _____ YEARS

4. DID YOU LIVE AT YOUR PRESENT ADDRESS BEFORE THE NOISE BARRIERS WERE CONSTRUCTED? _____ YES _____ NO

   (Answer parts a, b, and c only if you indicated <u>YES</u> to question 4.)

   a. WERE YOU SATISFIED WITH THE INFORMATION CONCERNING THE PROPOSED BARRIERS THAT WAS AVAILABLE PRIOR TO THE CITY COUNCIL DECISION TO CONSTRUCT THEM?

   (CHECK ONE)
   - _____ VERY SATISFIED
   - _____ SOMEWHAT SATISFIED
   - _____ NEITHER SATISFIED NOR DISSATISFIED
   - _____ SOMEWHAT DISSATISFIED
   - _____ VERY DISSATISFIED

   b. DID YOU AGREE WITH THE CITY COUNCIL DECISION TO CONSTRUCT NOISE BARRIERS AT THAT TIME?

   (CHECK ONE)
   - _____ YES
   - _____ NO
   - _____ HAD NO OPINION

   c. WERE THE BARRIERS EFFICIENTLY CONSTRUCTED SO THAT THEY CAUSED THE LEAST POSSIBLE DISRUPTION TO THE AREA?

   (CHECK ONE)
   - _____ VERY EFFICIENT
   - _____ SOMEWHAT EFFICIENT
   - _____ NEITHER EFFICIENT NOR INEFFICIENT
   - _____ SOMEWHAT INEFFICIENT
   - _____ VERY INEFFICIENT

5. IS THE BARRIER EFFECTIVE IN REDUCING TRAFFIC NOISE IN YOUR YARD?

(CHECK ONE)

- _____ VERY EFFECTIVE
- _____ SOMEWHAT EFFECTIVE
- _____ NEITHER EFFECTIVE NOR INEFFECTIVE
- _____ SOMEWHAT INEFFECTIVE
- _____ VERY INEFFECTIVE

6. ARE YOU SATISFIED WITH THE OVERALL LANDSCAPING ON THIS NOISE BARRIER PROJECT.

(CHECK ONE)

- _____ VERY SATISFIED
- _____ SOMEWHAT SATISFIED
- _____ NEITHER SATISFIED NOR DISSATISFIED
- _____ SOMEWHAT DISSATISFIED
- _____ VERY DISSATISFIED

7. ARE YOU SATISFIED WITH THE GENERAL APPEARANCE OF THE NOISE BARRIERS?

(CHECK ONE)

- _____ VERY SATISFIED
- _____ SOMEWHAT SATISFIED
- _____ NEITHER SATISFIED NOR DISSATISFIED
- _____ SOMEWHAT DISSATISFIED
- _____ VERY DISSATISFIED

8. IN YOUR OPINION, HAS THE CONSTRUCTION OF NOISE BARRIERS AFFECTED THE VALUE OF YOUR PROPERTY?

(CHECK ONE)

- _____ INCREASE VALUE GREATLY
- _____ INCREASED VALUE SOMEWHAT
- _____ NEITHER INCREASED NOR DECREASED VALUE
- _____ DECREASED VALUE SOMEWHAT
- _____ DECREASED VALUE GREATLY

9. INDICATE WHETHER YOU HAVE EXPERIENCED ANY OF THE FOLLOWING FREQUENTLY MENTIONED BENEFITS OF REDUCED TRAFFIC NOISE SINCE THE CONSTRUCTION WAS COMPLETED.

(CHECK ONE OR MORE)

- _____ CONVERSATION IS EASIER
- _____ IMPROVED SLEEPING CONDITIONS
- _____ MORE RELAXING ENVIRONMENT
- _____ OPEN WINDOWS IN SUMMER
- _____ USE YARD MORE
- _____ OTHER, ____________________
- _____ NONE

10. *INDICATE WHETHER YOU HAVE EXPERIENCED ANY OF THE FOLLOWING FREQUENTLY MENTIONED NON-NOISE RELATED BENEFITS SINCE THE CONSTRUCTION WAS COMPLETED.*

(CHECK ONE OR MORE)

_____ CLEANER AIR
_____ IMPROVED PRIVACY
_____ IMPROVED VIEW
_____ LAWN/SHRUBS GROW BETTER
_____ SENSE OF RURALNESS
_____ OTHER, ____________
_____ NONE

11. *INDICATE WHETHER YOU HAVE EXPERIENCED ANY OF THE FOLLOWING FREQUENTLY MENTIONED DISADVANTAGES OF NOISE BARRIERS SINCE THE CONSTRUCTION WAS COMPLETED.*

(CHECK ONE OR MORE)

_____ CREATES CLOSED-IN FEELING
_____ DESTROYS AREA ENVIRONMENT
_____ LIMITS/RESTRICTS VIEW
_____ MORE YARD MAINTENANCE
_____ VISUAL EYESORE; UNSIGHTLY
_____ OTHER, ____________
_____ NONE

12. *IN YOUR OPINION, DO THE BENEFITS OF CONSTRUCTING NOISE BARRIERS OUTWEIGH THE DISADVANTAGES?*

(CHECK ONE)

_____ VERY BENEFICIAL
_____ SOMEWHAT BENEFICIAL
_____ NEITHER BENEFICIAL NOR DISADVANTAGEOUS
_____ SOMEWHAT DISADVANTAGEOUS
_____ VERY DISADVANTAGEOUS

IF YOU HAVE ANY ADDITIONAL COMMENTS OR SUGGESTIONS ABOUT EITHER THE NOISE BARRIER PROGRAM OR TRAFFIC NOISE REDUCTION IN GENERAL, PLEASE FEEL FREE TO INCLUDE THEM HERE. THANK YOU. YOUR HELP IS SINCERELY APPRECIATED.

____

____

____

____

____

____

MINNESOTA DEPARTMENT OF TRANSPORTATION

NOISE BARRIER EVALUATION QUESTIONNAIRE Fridley after survey

Please complete and return this questionnaire in the enclosed self-addressed and postage-paid envelope at your earliest convenience. Thank you for your assistance.

EVALUATION SCALE

		VERY HIGH	HIGH	NEUTRAL	LOW	VERY LOW
1. HOW WOULD YOU EVALUATE THE AVAILABILITY OF INFORMATION ABOUT THE NOISE BARRIERS PRIOR TO THE CITY COUNCIL DECISION TO CONSTRUCT THEM:	(Circle one)	5	4	3	2	1
2. HOW WOULD YOU EVALUATE THE EFFICIENCY OF CONSTRUCTION ON THE NOISE BARRIERS IN ORDER TO CAUSE THE LEAST POSSIBLE DISRUPTION TO THE AREA?	(Circle one)	5	4	3	2	1
3. HOW WOULD YOU EVALUATE THE EFFECTIVENESS OF THE NOISE BARRIERS IN REDUCING TRAFFIC NOISE FROM THE FREEWAY?	(Circle one)	5	4	3	2	1
4. HOW WOULD YOU EVALUATE YOUR SATISFACTION WITH THE LANDSCAPING THAT WAS INCLUDED WITH THE NOISE BARRIER CONSTRUCTION?	(Circle one)	5	4	3	2	1
5. HOW WOULD YOU EVALUATE YOUR SATISFACTION WITH THE DESIGN AND GENERAL APPEARANCE OF THE NOISE BARRIERS?	(Circle one)	5	4	3	2	1

(Each question above is followed by: COMMENTS: ______________________________)

6. IN YOUR OPINION, HOW HAS THE CONSTRUCTION OF NOISE BARRIERS AFFECTED THE VALUE OF YOUR PROPERTY? (Check one)

- ____ INCREASED VALUE GREATLY
- ____ INCREASED VALUE SOMEWHAT
- ____ NOT AFFECTED VALUE
- ____ DECREASED VALUE SOMEWHAT
- ____ DECREASED VALUE GREATLY

COMMENTS: ______________________________

7. WHICH OF THE FOLLOWING FREQUENTLY MENTIONED BENEFITS OF REDUCED TRAFFIC NOISE HAVE YOU EXPERIENCED SINCE THE CONSTRUCTION WAS COMPLETED?

(Check one or more)

COMMENTS:______________________________

____ CONVERSATION IS EASIER
____ IMPROVED SLEEPING CONDITIONS
____ MORE RELAXING ENVIRONMENT
____ OPEN WINDOWS IN SUMMER
____ USE YARD MORE
____ OTHER, ________________
____ NONE

8. WHICH OF THE FOLLOWING FREQUENTLY MENTIONED NON-NOISE RELATED BENEFITS HAVE YOU EXPERIENCED SINCE THE CONSTRUCTION WAS COMPLETED?

(Check one or more)

COMMENTS:______________________________

____ CLEANER AIR
____ IMPROVED PRIVACY
____ IMPROVED VIEW
____ LAWN AND SHRUBS GROW BETTER
____ SENSE OF RURALNESS
____ OTHER, ________________
____ NONE

9. WHICH OF THE FOLLOWING FREQUENTLY MENTIONED DISADVANTAGES OF NOISE BARRIERS HAVE YOU EXPERIENCED SINCE THE CONSTRUCTION WAS COMPLETED?

(Check one or more)

COMMENTS:______________________________

____ CREATES CLOSED-IN FEELING
____ DESTROYS ENVIRONMENT OF AREA
____ LIMITS OR RESTRICTS VIEW
____ VISUAL EYESORE: UNSIGHTLY
____ OTHER, ________________
____ NONE

10. IN YOUR OPINION, DO THE BENEFITS OF CONSTRUCTING NOISE BARRIERS OUTWEIGH THE DISADVANTAGES?

(Check one)

COMMENTS:______________________________

____ YES, ARE VERY BENEFICIAL
____ YES, ARE BENEFICIAL
____ NEUTRAL
____ NO, ARE NOT BENEFICIAL
____ NO, ARE VERY UNBENEFICIAL

IF YOU HAVE ANY ADDITIONAL COMMENTS OR SUGGESTIONS ABOUT EITHER THE NOISE BARRIER PROGRAM OR TRAFFIC NOISE REDUCTION IN GENERAL, PLEASE WRITE THEM ON THE REVERSE SIDE OF THIS SHEET. THANK YOU. YOUR HELP IS SINCERELY APPRECIATED.

California Department of Transportation 2I
Transportation Laboratory

QUESTIONNAIRE *

1. Has the noise in your neighborhood environment changed since the freeway noise barrier was built?

   ☐ much less noise ☐ less noise ☐ same ☐ noisier

2. Has your awareness or notice of the freeway noise changed since the noise barrier was built?

   ☐ same ☐ somewhat less aware ☐ much less aware

3. Check those items which may have improved since the building of the barrier.

   ☐ sleep ☐ ease of conversation ☐ use of TV/stereo/radio

   ☐ use of telephone ☐ reading ☐ use of yard ☐ relaxation

   ☐ general peacefulness other ____________________

4. Now that a noise barrier has been erected, how do you rank the annoyance of the following freeway features? (Put in numerical order with 1 being most annoying.)

   ____ air pollution ____ total traffic noise ____ congestion ____ truck noise

   ____ accidents ____ dust/dirt other ____________________

5. How do you rank the annoyance of the following environmental noises now that there is a barrier? (Put in numerical order with 1 being most annoying.)

   ____ neighborhood noises (children, stereos, dogs, lawnmowers, etc.)

   ____ airplanes ____ freeway noise ____ sirens ____ city street noise

   ____ industrial other ____________________

6. Which best describes your neighborhood now?

   ☐ very quiet ☐ quiet ☐ a little noisy ☐ noisy ☐ very noisy

*After Noise Barrier Construction Questionnaire

7. Do you find the barrier acceptable in appearance?

☐ very acceptable ☐ O.K. ☐ no

If not, why? ______________________________

8. Has the barrier met your expectations in improving the neighborhood?

☐ yes ☐ no ☐ undecided

If not, in what way? ______________________________

9. Do the advantages of the barrier outweigh the disadvantages?

☐ yes ☐ no

10. How do you feel about the barrier overall?

☐ like ☐ dislike ☐ neither (neutral)

11. Did you respond to the questionnaire sent before the barrier was constructed?

☐ yes ☐ no

12. Other comments ______________________________

____

____

____

____

____

NOTE: If you need more information or clarification of questions, please call (916) 739-2400 collect, and ask for Mr. Mas Hatano or leave a message for him.

PROPOSED QUESTIONNAIRES (*16*)

Suggested questionnaire for survey before construction of a noise barrier (instructions to interviewer in italics or brackets).

Hello. I am from the (state) Department of Transportation, which is concerned about problems that may be affecting people such as yourself who live near major highways. We are actively considering solutions to some of the problems in your neighborhood. We would very much appreciate a few minutes of your time to answer the following questions.

1. What are the most important things you dislike about living in this area?

Write down the exact thing(s) said, for later coding. Probe slightly: "Is there anything else you dislike?" Focus on the residential environment of a few surrounding blocks. Whether or not road-related problems are mentioned, use the following transition phrase to move to the next question: "The Department of Transportation is particularly interested in things you dislike that may be related to living near a highway."

2. Here is a list of problems other people have mentioned. Please rate each of them with regard to how great a problem it is for you and your family while you are at home.

Read question stem at left and each response as written.

	not a problem at all	a minor problem	a moderate problem	a major problem or	an extremely bad problem?
Is highway dust and dirt	___	___	___	___	___
Is headlight glare	___	___	___	___	___
Is litter from vehicles	___	___	___	___	___
Is highway noise	___	___	___	___	___
Is vibration from the road	___	___	___	___	___
Are fumes from the road	___	___	___	___	___
Are there any other road-related problems? Name? Severity?	___	___	___	___	___

3. How often does the noise from the road interrupt you during any of the following activities?

	never	only occasionally	several times per week	several times per day	almost all the time
Conversation indoors	___	___	___	___	___
Conversation outdoors	___	___	___	___	___
Use of telephone	___	___	___	___	___
Watching television	___	___	___	___	___
Relaxing indoors	___	___	___	___	___
Relaxing outdoors	___	___	___	___	___
Sleeping	___	___	___	___	___

4. How often do you or members of your family use your yard for relaxing or playing during warm weather?

___ every day ___ once or twice a week
___ several times a week ___ less than once a week

5. a. Have you regularly been forced to close your windows because of traffic noise?

Yes___ No___

b. [If yes] How often would you say this happens?

___ once or twice a month ___ several times a week
___ once a week ___ most of the time

6. Have you made any modifications to your house or yard because of the traffic noise?

Yes___ No___ [If yes] What?

7. Are there any other problems associated with living near the highway that you would like to mention? Yes___ No___

List responses.

8. How long have you lived at this address? ___

9. Would you or other members of your household be interested in attending a public meeting about possible solutions to some of the problems mentioned earlier?

Yes___ No___

10. And now, a few questions about yourself, to assist us in contacting you personally for a possible follow-up survey.

If name is offered by respondent at this point, write it down, and do not ask remaining items.

a. Sex [Do not ask.] male___ female___

b. How old are you?___ years

c. What is your main occupation (that is, what sort of work do you do)?

___

Thank you for your assistance.

Suggested questionnaire for survey after construction of a noise barrier (instructions to interviewer in italics or brackets).

Hello. I am from the (state) Department of Transportation. Last year we spoke to a person in your household about problems that may be affecting people who live near highways. The person we spoke to was *(describe, from question 10 data)*. Is he/she available?

If the appropriate person is not available, try to find the best time to call back when he/she will be available.

Now that we have completed our work on the project in this area, we would like to know how the highway is affecting people here.

1. Here is a list of problems that were mentioned in last year's survey. Please rate each of them with regard to how great a problem it is now for you and your family while you are at home.

Read question stem at left and each response as written.

	not a problem at all	a minor problem	a moderate problem	a major problem or	an extremely bad problem?
Is highway dust and dirt	___	___	___	___	___
Is headlight glare	___	___	___	___	___
Is litter from vehicles	___	___	___	___	___
Is highway noise	___	___	___	___	___
Is vibration from the road	___	___	___	___	___
Are fumes from the road	___	___	___	___	___
Are there any other road-related problems? Name? Severity?	___	___	___	___	___

2. How often does the noise from the road interrupt you during any of the following activities?

	never	only occasionally	several times per week	several times per day	almost all the time
Conversation indoors	___	___	___	___	___
Conversation outdoors	___	___	___	___	___
Use of telephone	___	___	___	___	___
Watching television	___	___	___	___	___
Relaxing indoors	___	___	___	___	___
Relaxing outdoors	___	___	___	___	___
Sleeping	___	___	___	___	___

3. How often do you or members of your family use your yard for relaxing or playing during warm weather?

___ every day ___ once or twice a week
___ several times a week ___ less than once a week

4. a. Have you regularly been forced to close your windows because of traffic noise?

Yes___ No___

b. [If yes] How often would you say this happens?

___ once or twice a month ___ several times a week
___ once a week ___ most of the time

5. 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
___	___	___	___	___	___	___

6. What effect do you feel the barrier and its associated landscaping have had on the general appearance of this residential area?

considerable improvement	moderate improvement	slight improvement	no effect	slight deterioration	moderate deterioration	considerable deterioration
___	___	___	___	___	___	___

7. Are there any suggestions you have regarding noise barriers we may build in the future in other areas, to improve their appearance or effectiveness?

Thank you for your assistance.

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