181

National Cooperative Highway Research Program

NCHRP Synthesis 181

In-Service Experience with Traffic Noise Barriers

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Synthesis of Highway Practice 181

In-Service Experience with Traffic Noise Barriers

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, 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 useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on 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 these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to highway environmental engineers, noise analysts, design engineers, maintenance personnel, planners, administrators, and others responsible for the design, selection, and maintenance of noise barriers or other traffic noise abatement policies. Information is provided on current state practice associated with noise abatement techniques and on the various products that are used.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available 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 reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This synthesis describes the state of the art with respect to traffic noise abatement procedures, especially noise barriers. This report of the Transportation Research Board provides information on the design, construction and maintenance of both new (Type I) and retrofit (Type II) noise barriers. The design elements that are addressed include materials, the selection process, service life, foundations, drainage, aesthetics, and safety. The construction section covers technical problems related to surface effects, durability, snow damage, and costs. Other noise abatement measures such as insulation and highway design alternatives are also addressed. The issue of public demand and availability funding is included, and recommendations are made to improve the situation.

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.

CONTENTS

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Special appreciation is expressed to Dr. William Bowlby, P.E., Associate Professor, Department of Civil and Environmental Engineering, Vanderbilt University, who was responsible for collection of the data and preparation of the report.

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W. Campbell Graeub, Engineer of Public Transportation, Transportation Research Board, assisted the NCHRP 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

IN-SERVICE EXPERIENCE WITH TRAFFIC NOISE BARRIERS

SUMMARY

The purpose of this synthesis is to assess the state of the practice used by state highway agencies related to the design, construction, and maintenance of traffic noise barriers. It was initiated, in part, because nearly a decade has passed since a previous synthesis of practice on noise barriers was published and major changes of many types have occurred.

There were four areas of interest in the state-of-the-practice assessment:

- State highway agency administrative and programmatic issues related to noise abatement;
- Noise barrier design, construction, and maintenance problems, solutions, and needs;
- Other recent noise abatement strategies used by state highway agencies; and
- Traffic noise barrier research.

Information was gathered from the literature and from surveys of state and provincial highway agencies. The key findings from the research and the 51 survey responses include:

- The demand for traffic noise abatement is growing throughout the country, even in some of the more rural states.
- This demand is especially strong for Type II projects along existing highways (A noise abatement project on an existing highway is called a "Type II" project by the Federal Highway Administration (FHWA); a "Type I" project is construction or reconstruction of a highway that adds lanes and as a result could create noise impact that would warrant abatement.)
- State highway agencies, in general, cannot meet this demand with the current funding mechanisms.
- There is a need for more research, development, implementation, and technology transfer to better understand the cost, benefits, and trade-offs of various noise abatement strategies, to reduce abatement costs, and to improve analysis techniques.
- While much has been learned, state highway agencies are still experiencing many problems related to the construction and maintenance of noise barriers.
- The new American Association of State Highway and Transportation Officials (AASHTO) noise barrier design specifications have allowed state highway agencies to reduce wind loadings and save costs; however, some state highway agencies view the flexibility built into the specifications as ambiguity that could lead to design of barriers that do not meet requirements.

The primary noise abatement measure used by state highway agencies is the noise barrier. By the end of 1989, 39 states and Puerto Rico had constructed more than 720

miles of barriers at a cost exceeding $635 million (in 1989 dollars). The state highway agencies indicated that they plan to spend between $130 and $147 million per year over the next 5 years for barriers as part of new roadway construction or major reconstruction. Additionally, Ontario plans to spend about $4 million (Canadian) per year on similar projects.

Twelve states indicated spending an average of $75 million per year over the next five years for Type II barriers on existing highways (one-third of that in California alone), and Ontario plans to spend $30 million (Canadian) on retrofit projects. California voters recently passed Proposition 111 which increased the state gas tax. Part of Proposition 111 stipulated that $150 million in new money be directed to its Type II program over the next 10 years. Several agencies noted that implementation of a good project prioritization procedure is an important part of a Type II program.

A third of the state highway agencies have tried other abatement strategies, such as sound insulation of public facilities, depressing the highway, and shifting the alignment. Many states also indicate a willingness to allow privately funded or locally funded barriers erected on the state right-of-way, but are reluctant to obtain easements to place their barriers off the right-of-way, where in certain situations they would be more effective. States are also generally reluctant to soundproof private facilities or reduce speeds on roads to reduce noise. There is much interest in "quiet pavement" research, but little implementation yet.

In summary, the public demand for abatement is increasing in many states while the resources—funds, staff, executive management support, legislation, regulations, and technical tools—are inadequate or need improvement. Source control through vehicle emission level restriction is generally beyond the jurisdiction of state highway agencies, yet the U.S. Environmental Protection Agency (EPA) programs on source control and technical assistance to local governments have been virtually nonexistent since funding was cut in the early 1980s. Source control through use of quiet pavements is one area, however, that offers promise to state highway agencies. Control at the receiving land use is also largely beyond the jurisdiction of the state highway agencies, yet effective land use compatibility planning, zoning control and physical noise mitigation techniques could prevent many future noise problems from arising. Control along the path is the main option available to state highway agencies, yet work is needed on issues such as abatement cost and cost effectiveness, and analysis tools for special situations.

The challenge of obtaining funding, especially for adding noise barriers to existing highways, seemed to be a common thread throughout the state highway agencies. In most states, however, traffic noise, while very serious, competes with other issues often given higher priority within an agency. Noise impacts can be severe, but probably do not affect a large enough population for focused statewide legislation to succeed. Lacking such a voice, the affected public must rely on the various branches and levels of government to protect and enhance the environment while carrying on the mission of providing safe, efficient, and economical transportation.

CHAPTER ONE

INTRODUCTION

BACKGROUND

A state legislator recently wrote to the Washington State Department of Transportation (WSDOT):

"Traffic noise will grow as a transportation problem as the level of use of our older freeways and state highways in the Seattle area and other urban areas continues to grow. Citizens will increasingly demand that the current noise problem be fixed before we address the need for the greater utilizaton of the existing roadways or additional roadway capacity."

Traffic noise analysis and control grew as both an art and a science in the late 1960s and early 1970s in response to national environmental and highway legislation and resultant federal regulations. Since those early years, noise abatement strategies traditionally have been divided into three categories: source control, path control, and receiver control.

Source control efforts on a national level focused on emission level regulations for newly manufactured trucks and motorcycles and on maximum operating emission levels of trucks and buses engaged in interstate commerce. State and local source control focused on enforcement of the federal in-operation regulations, state and local "nuisance" and "muffler" ordinances, and on traffic management strategies such as truck re-routing, curfews, and bans.

Path control efforts have concentrated on blocking the path by which the noise reaches the receiver or on increasing the path's length. The focus has been the construction on the highway right-of-way (ROW) of traffic noise barriers between source and receiver. Additionally, shifts in the vertical alignment of the road have been used to provide a shielding effect. The Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) have sponsored or conducted numerous research projects since the mid 1960s to develop and refine or revise mathematical models to predict traffic noise levels and to design noise barriers. Most of the use of these models and implementation of path noise control have been done by state highway agencies with certain notable exceptions, such as in California where private residential developers must provide abatement with review and approval by local government.

Receiver control includes two categories. The first includes administrative strategies such as zoning, building codes, subdivision laws, municipal ownership or control of land, and financial incentives for compatible use. The second category includes physical methods, such as site planning, architectural design, and acoustical construction (sound insulation). Most of the strategies in both categories fall under the jurisdiction of local government or indirectly on state highway agencies. Also, some state highway agencies have carried out sound insulation projects for public buildings, such as the comprehensive California School Noise Abatement program.

Much of the research, development, and technology transfer for these strategies was done in the 1970s when federal emphasis was strong. In the 1980s, the U.S. Environmental Protection Agency (EPA) program was phased out and the EPA Office of Noise Abatement and Control (ONAC) was closed. Also, Federal Highway Adminstration (FHWA) programs shifted from active research, development and implementation to a maintenance effort, as administration priorities shifted. Some new research was funded (construction noise modeling, sound-absorptive barrier literature review, traffic noise modeling, and an experimental noise barrier evaluation) but there was limited implementation or dissemination of the results.

However, interest in noise control remained high within many state highway agencies, often spurred by emphatic citizen demands. Several states have had active programs in providing noise control along existing highways, and all states must abide by federal legislation and regulations when building or rebuilding federal-aid roads. Professional interest through organizations such as the Transportation Research Board (TRB), among others, remains strong.

Yet, much remains to be done. While a great deal has been accomplished in traffic noise control both in North America and abroad, there have been few attempts at reviewing this work in a comprehensive manner. An assessment of current noise abatement practices is essential for state highway agency noise analysts and administrators who need the latest information as they determine where to direct future efforts in terms of policy, legislation, implementation, and research. The aforementioned state legislator from Washington described exactly the problem that many states are facing and will face in the coming years: citizens recognize that traffic noise can and should be controlled and that their voices will be heard by their legislators.

PROCEDURES

The information gathering and analysis for this synthesis involved a two-part approach: first, the relevant literature was reviewed; and second, contacts were made with state highway agency noise analysts via a survey and telephone follow-up. The survey was prepared and conducted as part of a separate study for Washington state DOT (*1*). The survey was sent to the main office environmental unit of all 50 state highway agencies plus Puerto Rico and the Canadian province of Ontario. Questions dealt with abatement measures, abatement expenditures, communication techniques, legal decisions, research, land use and local coordination issues, staffing, analysis tools, and issues and problems. The questionnaire may be found in Appendix A. Follow-up contacts were made by telephone for additional information.

Detailed conversations were held with representatives from a dozen state highway agencies to focus on specific issues related to noise barrier design, construction, and maintenance. Field visits to Connecticut, California, Washington, Maryland, New Jersey, and Ontario also provided important information. Noise analyst contacts in these and other state highway agencies may be obtained from TRB Committee A1F04, Transportation-Related Noise and Vibration.

SYNTHESIS OBJECTIVES

This synthesis has two objectives: (1) to review and evaluate the state of the practice in traffic noise barrier design, construction, and maintenance, especially as related to in-service experiences; (2) and to synthesize the information and package the results into a report useful to the state highway agency noise analysts and transportation administrators.

The survey of transportation agencies provided a national perspective of noise abatement programs in the United States. Chapter Two presents this broad view of how state agencies are addressing issues of funding, policy, administration, and research. Chapters Three, Four, and Five focus on noise barrier design, construction, and maintenance, respectively, as reflected in common practice. Examples of unconventional design and use are given Chaper Six. Chapter Seven presents conclusions drawn from the synthesized information and recommendations based on the noise abatement issues that continue to challange highway agency personnel. The appendixes provide design guidelines from Caltrans and Ontario, as well as the survey questionnaire.

CHAPTER TWO

NATIONAL PERSPECTIVE ON TRAFFIC NOISE ABATEMENT

This chapter presents a broad picture of the size and scope of the state highway agency noise abatement programs in the U.S. Some current practices related to noise barriers are also highlighted.

Constructed noise barriers can be categorized by types that are referenced throughout this synthesis. A **Type I** barrier is built during the construction of a highway on new location or during the physical alteration of an existing highway that significantly changes either the horizontal or vertical alignment or increases the number of through-traffic lanes. A **Type II** barrier is one built to abate noise along an *existing* highway. Please note that all sound levels, unless otherwise noted, are A-weighted sound levels in dB.

PAST NOISE BARRIER CONSTRUCTION

Traffic noise barrier construction began in earnest in the United States in the mid-to-late 1970s, driven by federal requirements for Type I barrier studies and the ability to use federal-aid funds for Type II projects. Figure 1, based on data in a 1991 FHWA analysis (*2*), shows the annual combined Type I and II barrier construction in miles per year and the annual expenditures (in 1989 dollars). Figure 2 shows the cumulative growth of Type I, Type II, and combined barrier mileage, based on the same analysis. Figure 2 includes both federal-aid and fully state-funded projects. When the first NCHRP Synthesis on noise barriers was published in 1981 (*3*), a total of approximately 200 miles of noise barriers was reported through 1980. Eighty-five percent were in nine states. (California had the most, followed by Minnesota, Colorado, Virginia, Oregon, Arizona, Washington, Massachusetts, and Connecticut.)

In 1986, FHWA (*4*) provided data on noise barrier construction, a good summary of the general nature of the traffic noise problem in the United States, a brief summary of land use planning and control and source control, and a discussion of the FHWA noise abatement procedures. The barrier construction summary data were taken from an article by Weiss of FHWA (*5*). As of 1986, nearly 500 miles of noise barriers had been constructed with highway funds at a cost exceeding $338 million. More than 350 of those

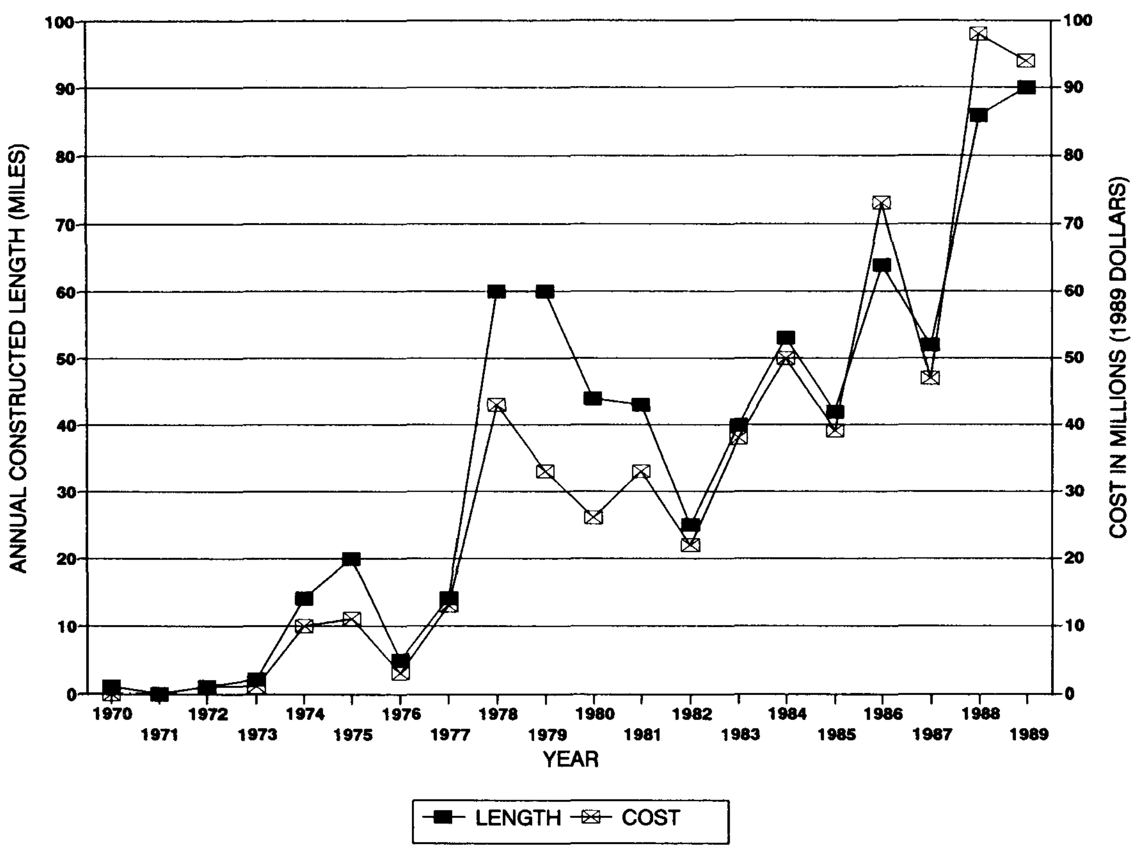

FIGURE 1 Annual U.S. barrier construction by mileage and cost (1989 dollars) (from *2*).

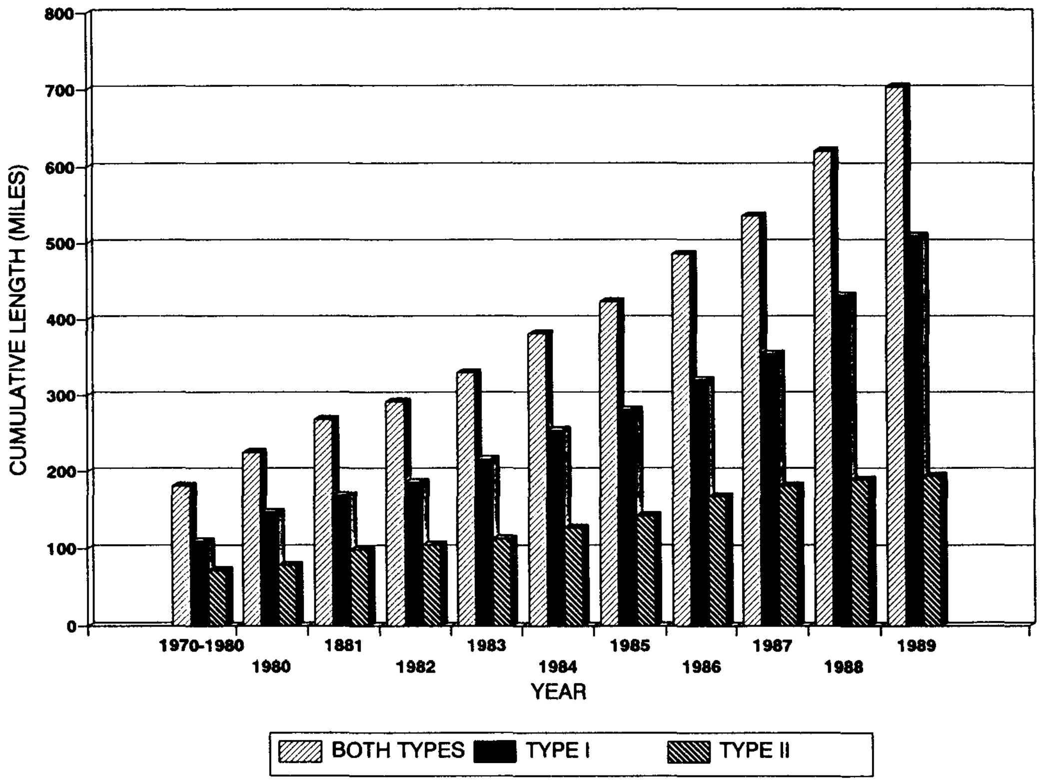

FIGURE 2 Historical trends in Type I, Type II, and combined barrier construction for federal-aid and state-funded projects (from *2*).

miles (75 percent) were constructed by ten states (California, Minnesota, Colorado, Virginia, Oregon, Michigan, New York, Arizona, New Jersey, and Washington). California alone accounted for over 30 percent of the total construction. Another FHWA document published in 1986 examined the national Type II program and included detailed discussion of the priority systems in California, Michigan, and Massachusetts (*6*). As of 1986, fifteen states had constructed more than 157 miles of Type II noise barriers at a cost exceeding $139 million (in 1986 dollars).

Finally, in 1989 FHWA updated the previous inventories (*7*). As of the end of 1989, over 720 miles of barriers had been constructed by 39 states and Puerto Rico at a cost of more than $635 million in 1989 dollars ($555 million in actual dollars). Figure 3 presents those data on an annual basis, broken out by Type I and II, where all construction prior to 1980 is grouped together. Figures 1 and 2 show that the annual *rate* of barrier construction has been increasing. Figure 3 indicates that the growth has been with the Type I program, while Type II construction has been decreasing after a peak in 1986. The data should be considered in view of the fact that by 1989 California accounted for 25 percent of the Type I construction and 57 percent of the Type II construction. Table 1 presents FHWA data in terms of the states with the greatest barrier lengths and costs. Table 2 lists states that have built Type II barriers (although not all of these states should be considered as having a formal program).

BARRIER COSTS

Problems with Barrier Costs

Weiss (*5*) and the 1991 FHWA analysis (*2*) presented a variety of views on the barrier cost data. Of interest were the findings that the "average" barrier was approximately 12 ft high and cost about $12/ft^2 in 1986 dollars. Weiss also looked at trends in the quantity and cost of noise barriers over time. According to FHWA, "the cost data . . . should not be used to draw conclusions about which states construct the most or least expensive barriers . . . [comparable] cost data are difficult to obtain for many barrier installations. . . ." Part of the problem in presenting or comparing costs is the many variables that go into determining cost, as well as the inconsistencies in reporting cost. The variables include cost of labor (union versus non-union), the cost of transportation of materials, foundation costs based on soil types and prevailing economic conditions, how a contractor puts the bid package together, and others. For those reasons, it is essential that individual state noise analysts develop their own cost data for use in barrier design and costing.

Several attempts have been made to analyze barrier unit costs or cost per linear foot for use in the FHWA OPTIMA noise barrier design computer program (*8*). One such effort considered data for more than 700 barrier projects in 37 states (*9*). Regressions of cost per linear foot as a function of barrier height were derived for 520 of the projects. Ninety-six percent of the data were for barriers between 5 and 20 ft in height. Use of these, or any, summarized cost data should be done with caution.

The California Department of Transportation (Caltrans) developed a set of cost data for use in its computer modeling. However, Caltrans main office staff report that district office designers often use their own cost data, which are more specific to their region and practices.

Life Cycle Costs

Other states have examined their own cost data independently. Of note, Colorado computed the annualized cost of various barrier

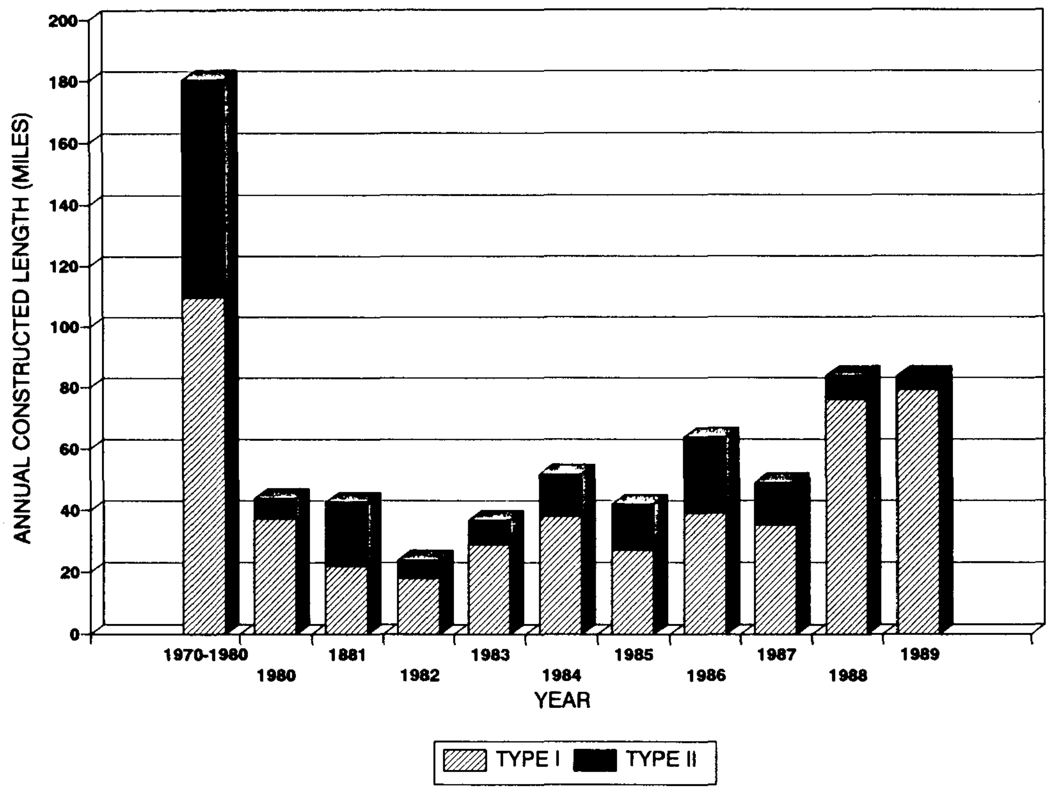

FIGURE 3 Annual construction of Type I and Type II barriers in the U.S. (from *2*).

TABLE 1
THE TEN STATE HIGHWAY AGENCIES WITH THE GREATEST LENGTHS OF AND EXPENDITURES FOR TYPE I AND TYPE II NOISE BARRIERS (*7*)

State	Miles	State	Actual Cost Millions	State	1989 Dollars Millions
California	242.9	California	180.0	California	205.3
Minnesota	56.9	New Jersey	61.1	New Jersey	62.8
Pennsylvania	41.1	Pennsylvania	59.3	Pennsylvania	60.8
Colorado	40.9	Maryland	40.4	Minnesota	47.8
New Jersey	35.4	Minnesota	32.5	Maryland	42.7
Oregon	29.1	Michigan	25.2	Virginia	29.7
Michigan	28.3	Virginia	22.2	Michigan	29.0
Virginia	26.8	Connecticut	18.6	Connecticut	20.3
Connecticut	22.7	New York	12.6	Colorado	14.5
Maryland	20.9	Colorado	12.2	Tennessee	14.2
10 State Total	545.0	10 State Total	465.5	10 State Total	527.1

system alternatives and life cycle cost analysis for nine types of noise barriers. Four of these barriers were constructed. The following describes the Colorado life cycle cost analysis for a barrier 10 ft tall. Annual costs were calculated over a 40 year analysis period using a "real" interest rate of 4 percent. A salvage value was assumed for products replaced during intermediate years, and which had not reached their design life. The computations assumed service lives of 15 years for wood, 30 years for masonry (based on the Colorado Masonry Institute) and 40 years for post and panel concrete (based on bridge life). Not included was the potential disposal

TABLE 2
TYPE II NOISE BARRIER CONSTRUCTION BY STATE BY TOTAL BARRIER LENGTH (*7*)

State	Length in miles	Actual cost (millions)	Cost in 1989 dollars
California	113.4	90.4	107.7
Minnesota	26.2	17.7	29.0
Michigan	15.3	11.9	14.6
Colorado	12.9	4.6	5.4
Maryland	12.2	26.6	28.2
Connecticut	3.2	2.1	2.9
Wisconsin	3.0	5.3	5.7
New York*	2.7	2.9	3.2
New Jersey	1.3	3.0	3.2
Louisiana	1.0	0.2	0.3
Washington	0.9	0.9	1.0
Oregon	0.8	1.0	1.1
Iowa	0.7	0.4	0.5
Georgia	0.6	0.5	0.5
Massachusetts	0.2	0.7	0.8
Ohio	0.2	0.2	0.2

* Total through 1986

cost of placing the chemically treated wood in non-standard (permitted) landfills.

The resulting annualized costs may be segregated into three general price ranges—less than \$5/linear foot (l.f.), from \$5 to \$10/l.f., and over \$10/l.f., as shown in Table 3. Colorado found that the cost for wood, concrete, and masonry are all within about one dollar, being approximately \$4/l.f. per year.

Colorado's initial costs have run about \$35-45/l.f. (based on a 10-ft height) for the materials and installation. Figuring in other costs such as design, seeding, and landscaping (but not right-of-way acquisition) raises that cost to about \$70/l.f. A post and panel concrete wall atop a safety shape crash barrier was recently priced at about \$85/l.f. and the mineralized wood-shavings sound-absorbing barrier panel at \$120/l.f. (for a height of 7.5 ft above the top of the crash barrier). Approximately \$2/ft^2 of that cost was attributable to transportation of the panels from the manufacturing site.

Other Unit Costs

The average cost for California's masonry block barriers has been \$12/ft^2 for just the barrier system. No other costs are included in that figure, and an estimation of the cost for mobilization and contingencies was 20 percent above that value. The cost for precast concrete systems was \$18/ft^2. In Districts 7 and 12 in southern California, noise barrier costs have been running about \$1 million per mile (\$228/l.f. barriers along the shoulder and \$200/l.f. for barriers at the right-of-way line). Most of that cost is associated with the footings, although exact percentages were not available.

Typical construction costs in Michigan have been \$275/l.f. of noise barrier. This includes all costs associated with the barrier including land clearing, maintenance of traffic, and others. Arizona cites an average installed noise barrier cost of \$10/ft^2 for masonry and cast-in-place barriers, but notes difficulties in determining the true cost of the noise barriers when they are one of many items in a bid package. However, cities in Arizona have reported an average cost of only \$5/ft^2 for their masonry walls; the difference is attributed to the city-built walls not being as strong in terms of reinforcing steel and footings.

The average unit cost for barrier installation in Oregon is running about \$14–15/ft^2. No breakdown of that cost by various components is available, although Oregon typically includes 20 to 30 percent of the cost for "engineering contingencies," which cover unforseen problems during construction. Based on a comparison of 30 barriers installed to date, the average in-place cost in Florida is also \$14–15/ft^2. Virginia uses a figure of \$16/ft^2 for use in its cost effectiveness calculations. This typical barrier cost is for materials only. Connecticut has found that the installed costs for its timber walls is approximately \$6–8/ft^2. This low cost is attributed to contractor experience with the system gained over several years of installations.

Typical construction costs have been identified for concrete and steel in Massachusetts. These costs are averages based on the installation on a prepared surface. The cost for concrete has been \$14/ft^2, while the cost of steel has been \$17/ft^2 (whether free-standing or installed on a structure).

Maryland State Highway Administration (SHA) staff completed an analysis of the bid costs for its Type I and Type II noise barrier projects completed by the fall of 1990. For nine Type I projects, the average cost for materials was \$17.83/ft^2, based on 7.9 miles of noise barriers including over 650,000 ft^2 of regular barrier, 7,500 ft^2 of sound-absorbing barrier, and 15,000 ft^2 of barrier on structure. This cost is for materials only, because the SHA found it too difficult to separate out other costs from the bids.

For its Type II barriers, Maryland SHA was able to do a much more detailed analysis of the costs for precast concrete systems, as shown in Figure 4. Costs were categorized as follows: drainage (pipes and inlets, and sediment and erosion control), barrier system (panels, posts and foundations), fencing (Jersey safety barriers and safety guard rail), landscaping, utilities, preliminary engineering (mobilization, maintenance of traffic, clearing and grubbing, and office time), and excavation. The total average cost per square foot was \$26.17 (in actual dollars). The analysis was carried out for nine projects whose bid prices totalled over \$16 million, but did not include \$740,000 for retaining wall construction on one of the projects.

PLANNED NOISE BARRIER EXPENDITURES

In the previously mentioned WSDOT survey, the state highway agencies were asked to comment on their anticipated expenditures per year on noise barriers over the next five years for Type I projects (involving highway construction) and Type II projects (noise barriers on existing highways). Fifty-one responses were received from 49 states plus the commonwealth of Puerto Rico and the Canadian province of Ontario (the most active of the Canadian provinces in traffic noise abatement). The responses are presented in Table 4. Planned expenditures, of course, are subject to evolving and changing state policies and programs.

The planned expenditures varied widely. The states with the largest "planned" expenditures for Type I projects were California, (\$30–40 million per year), Texas (\$30 million per year), and New Jersey (\$15–20 million per year). The anticipated annual total expenditures for Type I noise barriers range between \$130 million and \$147 million per year, excluding possible projects in eight states that did not provide data. Several of those states not providing

TABLE 3
COLORADO DEPARTMENT OF HIGHWAYS ANNUALIZED BARRIER COSTS BASED ON 10-FT HIGH BARRIER

Barrier system	Design Life (years)	Annual Cost (per linear ft)	Initial cost (per linear ft)	Sound transmission coefficient	Noise reduction coefficient
Concrete (3-5" thick)	40	$ 3.54*	$ 70.00	47 dB(A)	N/A
Wood	15	3.84*	40.63	16-27	N/A
Masonry (8" thick hollow)	40	3.54**	70.15	Ordinary 43-45 Soundbox 49	Ordinary N/A Soundbox .65-.75
Durisol (5 1/4" thick)	40	8.08***	160.00	32	.70-.85
Poured-in-place concrete (7" thick)	40	10.25***	203.25	56	N/A
Aluminum/ Honeycomb aluminum (5" high)	40	11.72**	231.38	28-35	N/A
Steel/Mineral wool/steel (2" thick)	30	10.30*	175.00	28-44	1.0-1.1
Plastic/ mineral wool	25	17.68***	270.00	27	Unknown but greater than 0.65

* Based on manufacturer/contractor supplied cost quote.
** Based on actual project cost in Colorado.
*** Based on cost from other states from the June 1989 FHWA report "Unusual Features of Noise Barriers and Other (Non-Barrier) Measures Implemented by December 31, 1988."
Source: Flodine, R., *Internal Report on Noise Barrier Analysis and Comparisons*, Colorado Department of Highways.

an estimate, notably Arizona, Connecticut, Georgia, Minnesota, and Pennsylvania have already constructed many miles of noise barriers.

California has programmed $130 million to be spent for Type II projects over the next five years, with an estimated need of $240–275 million to complete the statewide retrofit program. New Jersey has indicated a need for over $100 million for barriers. Recently $33 million was approved for Type II barriers for three projects in FY 92, four more projects, at a total cost of $40 million, will be in design soon. Ohio also reported that $5 million was authorized for a Type II program by the legislature, but this was later removed, and thus is not listed in Table 4.

In Maryland, of the original 26 projects in its Type II program, eight remain to be built at a cost of approximately $29 million. However, the Type II program was seriously affected in 1986 when $47.8 million in Interstate Replacement (I-4R) funds was cut by 20 percent to $38.4 million. More recently, the entire Type II program was put on hold and is now being reevaluated because of the state's financial situation. Maryland also estimates that there is the potential for nearly 50 miles of noise barriers (at a cost of $120 million) in areas where noise abatement has been requested by citizens or legislators, but it has been denied because the qualification criteria were not met, coupled with limited funds.

Connecticut completed a reevaluation of its retrofit noise abatement program in 1986 and developed a 10-year, $125 million program (in 1987 dollars, reflecting an inflation factor of 5 percent

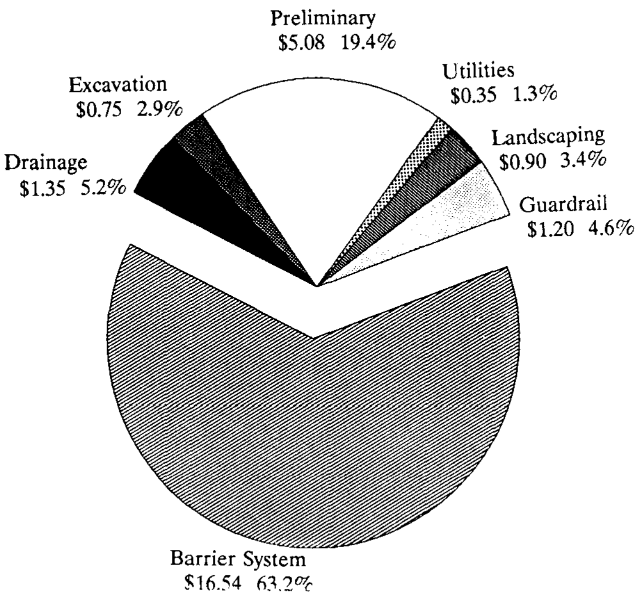

FIGURE 4 Bid costs for Type II noise abatement, breakdown by category. Courtesy of Maryland State Highway Administration.

per year) (*10*). In its reevaluation, Connecticut noted that current DOT staffing would not allow for initiation of such a large long-term program. The state estimated the need for 10 additional staff positions in both acoustics and structural engineering during the 10-year period.

Colorado redid its Type II noise barrier priority list when a change in administrative philosophy was made not to be simply reactive to complaints. The number of projects on the Type II list increased from 50 to 140. Over 50 of these sites had a one-hour average sound level L_{eq} equal to or exceeding 71 dB. The priority list included sites with L_{eq} as low as 64 dB, (the calculated levels were based on traffic projections out to 20 years to accommodate the increase in noise levels). The priority list would require an average expenditure of $2.5 million per year for 20 years.

As a final example, Utah reported the need to spend $1 million per year for Type II projects, although only one-half of that amount was indicated to be more realistic. No formal Type II program exists in Utah at this time, but studies along the urban interstates show extensive needs for abatement. Coupled with a recent large increase in noise complaints, Type II funding appears to be likely in the near future. The state is also contacting local authorities about developing land use compatibility ordinances in conjunction with a barrier program.

Excluding Ontario, the average annual planned expenditures for Type II barriers is over $75 million per year.

STATE HIGHWAY AGENCY POLICIES AND PROCEDURES

The policies and procedures used by state highway agencies in their noise analysis and abatement programs have evolved continually over the years, although inconsistencies and differences still abound. The latest in a series of field reviews conducted by FHWA headquarters staff provides a perspective (*11*). Eight highway agencies were visited; the selected agencies included some that had not built any traffic noise barriers as well as some that had. The review found a wide variation in the interpretation of the Noise Abatement Criteria (NAC) in the FHWA Noise Standards (FHPM 7-7-3) (*12*). Some states still view the NAC as either a federal standard, desirable noise levels, or design goals for barrier construction. The proper interpretation is that the NAC are levels that indicate serious enough impact to warrant consideration of abatement. Abatement should attain a substantial noise reduction, usually 5–10 dB. The criteria are displayed in Table 5.

The FHWA found that the eight visited states defined "substantial increase" in the existing noise environment as either 10 dB, 15 dB, or on a sliding scale combining the increase in level with the value of the levels themselves. Other aspects of the field review dealt with "reasonableness" and "feasibility" of abatement measures, the existence of formal written state noise policies, efforts at coordinating with local officials, addressing the "likelihood" of noise abatement in the final environmental document, and the need to consider public attitudes toward highway traffic noise. Regarding the last point, FHWA notes:

> Highway traffic noise is one of the pervasive noise sources in society today. From peaceful, rural roadways to busy urban freeways, traffic noise is ever present. [State highway agencies] . . . make decisions on whether it is reasonable and feasible to implement abatement measures. Public reaction to the problem of traffic noise plays a large role in the implementation decision. In several densely populated states, the citizens have come to expect and almost demand that abatement of traffic noise be a very high priority in the highway program. Citizens in almost all states expect that traffic noise abatement be part of the highway program—that is, it should not be overlooked or avoided. . . . Per the FHPM 7-7-3, the view of the impacted residents should be a major consideration in the decision to implement traffic noise abatement measures on new highway construction projects. The will and desires of the general public should be an important factor in dealing with the overall problems of highway traffic noise, particularly the decision to implement Type II noise abatement. State highway agencies should incorporate traffic noise consideration in their ongoing activities for public involvement in the highway program.

A different perspective on state highway agency practices may be gained from two reports prepared for Maryland DOT. The reports were based on a survey of state highway agencies on a number of noise policy issues of interest to Maryland as it developed a state noise policy (*13,14*). The survey focused on the following areas: policy, funding, Type I criteria, Type II eligibility and prioritization, abatement goals, construction criteria, construction costs, alternative methods, abatement monitoring and model calibration, and court action. Table 6 provides summary information from that survey on the following subjects:

- What constitutes a "substantial" increase if comparing "build" and "no-build" alternatives,
- The cutoff date for new residential developments for eligibility as Type I projects,
- Insertion loss goals when providing noise abatement (insertion loss is the difference in noise levels at a receptor before and after installation of a barrier),
- Cost per residence criteria in judging reasonableness for abatement, and
- Average installed unit costs for noise barriers.

TABLE 4
PLANNED ANNUAL EXPENDITURES FOR NOISE BARRIERS 1991–1996 (from *1*)

None planned	Less than $1 million	$1 - 5 million	More than $5 million	Not determined
		TYPE I PROJECTS		
Alabama	Alaska	Florida	California	Arkansas
Delaware	Iowa	Illinois	Colorado	Arizona
Idaho	Missouri	Kentucky	New Jersey	Connecticut
Indiana	Nevada	Louisiana	Ohio	Georgia
Kansas	South Carolina	Maryland	Texas	Maine
Massachusetts	Vermont	Michigan	Virginia	Minnesota
Minnesota		New Mexico		North Carolina
Montana		New York		Pennsylvania
North Dakota		Oklahoma		
South Dakota		Oregon		
West Virginia		Puerto Rico		
Wyoming		Tennessee		
		Utah		
		Washington		
		Wisconsin		
		Ontario		
		TYPE II PROJECTS		
36 states	Michigan	Colorado	California	None
	Washington	Massachussetts	Connecticut	
		New York	Maryland	
		Puerto Rico	New Jersey	
		Utah	Ontario	
		Wisconsin		

The first set of data shows that the most commonly used criterion for judging a "substantial" increase in noise levels is an increase of 10 or more dB (i.e., "greater than 9 dB"). It should be pointed out that this question did not inquire as to an increase in the existing levels over the "build" levels (which is called for in FHPM 7-7-3), but referred to a comparison of future "no-build" and "build" cases. The data also show that the most commonly used cutoff date for new developments to qualify for Type I treatment is the location approval of the proposed project. The third set of data shows a wide range in noise abatement goals. While many of the respondents tried to achieve 7 or more dB insertion loss, the most commonly cited range was 5–10 dB. Two states showed extremely low goals of 3–5 dB.

The data on cost per residence also showed a wide spread in the values, ranging from $8,000 per residence (Washington) to $40,000 (Maryland). Only one state (Oregon) expressed its criterion in terms of dollars per residence per dBA loss. Use of this latter criterion may be a better way of accounting for differences in marginally effective and very effective noise barriers. The barrier unit cost data tend to confirm the recent FHWA finding of an average cost of $12/ft^2.

Two examples of application of criteria follow: Caltrans acoustical design criteria include achieving at lease five dB insertion loss, reducing the L_{eq} at the receivers to under 67 dB and breaking the line of sight to an average truck exhaust stack height of 11.5 ft. Physical criteria include a minimum height of 6 ft and a maximum height of 16 ft on the ROW or 14 ft if on the edge or shoulder.

The current eligibility criteria for a Type II barrier in Maryland are as follows:

- A majority of the impacted residences must have preceded the highway;
- Noise levels must exceed the impact threshold level of 67 dBA;
- Costs must be reasonable; cost per impacted residence that is protected may not exceed $40,000;
- Construction of an effective noise barrier must be feasible;
- Seventy-five percent of the impacted residents must favor the project; and
- Funds must be available.

Additional information on state highway agency noise policy definitions was published in 1991 by FHWA (*15*).

TABLE 5
NOISE ABATEMENT CRITERIA [Hourly A-Weighted Sound Level — (dBA)[1]] (12)

Activity Category	Leq(h)	L_{10}(h)	Description
A	57 (Exterior)	60 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 (Exterior)	75 (Exterior)	Developed lands, properties, or activities not included in Categories A or B above.
D	---	---	Undeveloped lands.
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

[1] Either L_{10}(h) or Leq(h) (but not both) may be used on a project.

TYPE II PROGRAM ADMINISTRATION

Interest continues to grow in the subject of Type II noise barrier programs as many states complete their interstate construction programs and look toward fixing existing noise problems. States with Type II programs were contacted with regard to five items:

- Reasons for development,
- Funding mechanisms,
- Funding from local governments or affected citizens,
- Actions by local government in support of a project, and
- Prioritization methods.

Reasons For Development

As described earlier, twelve states indicated that they have constructed Type II barriers. The most common reason given for starting a Type II program was a response to citizen complaints. New Jersey also cited a 1977 community lawsuit. Legislative complaints, requests, and inquiries were also a common beginning point for the programs. Six states cited legislative action: California, Connecticut, Massachusetts, Minnesota, Utah, and Wisconsin. Hawaii also noted that the legislature recently asked for a pilot noise study along a one-mile section of one of its freeways.

Connecticut began a Type II program in 1973 using Federal-aid Interstate (FAI) construction funding with 90 percent federal participation. Between 1973 and 1982, 122 areas were prioritized and six noise barriers constructed. Since 1982, Connecticut constructed only three other retrofit noise barrier projects because of lack of funds. Connecticut notes that it has a "deferred" file of more than 50 noise complaint locations that has grown between 1981 and 1986. These complaints, coupled with legislative interests, led to the passage of Special Act 85-107, which directed the department to revise the noise barrier priority listing and develop a ten-year plan for installing noise barriers, including cost estimates.

The California Type II program began as a voluntary effort, but was formalized through state legislation as Section 215.5 of the State of California Streets and Highways Code, Priority System for Noise Barriers (*16*). Section 215.5 required the department to develop and implement a system of priorities for ranking the need for retrofit noise barriers along California freeways. The legislation specified prioritization criteria and directed the department to include in its proposed State Transportation Improvement Program a program of noise barrier construction beginning with the highest priority sites. The department was directed to prepare a priority list on an annual basis. Appendix B provides the text of the Caltrans guidelines for traffic noise abatement and an informational brochure on the Caltrans noise barrier program in District 7 (Los Angeles) is used to answer citizens' questions.

The 1987 Wisconsin Act 27, s.3052(3g)(b), required that state to develop criteria and procedures for siting noise barriers. The department responded with Administrative Rule TRANS 405, approved by the legislature in 1989. Finally, Massachusetts completed

TABLE 6
STATE HIGHWAY AGENCY NOISE ABATEMENT PROGRAM PRACTICES *(13,14)*

"Substantial Increase" if Comparing No-Build and Build Alternatives	Number of States
> 5 dB	3
> 7 dB	2
> 9 dB	14
> 14 dB	9
Cut-off Date for Type I Eligibility for New Developments	**Number of States**
Location Approval	11
Design Approval	4
P S & E	5
Public Hearing	2
"Time of Investigation"	1
Abatement Insertion Loss Goals (dB)	**Number of States**
3-5	2
5	6
6,6-7,8	1 each
5-10	12
7-10	2
8-10	1
10	5
8-15	1
20	1
Cost per Residence Criteria for Justifying Abatement*	**Number of States**
$ 8,000	1
$ 15,000	3
$ 16,500	1
$ 20,000	2
$ 25,000	2
$ 30,000	1
$ 37,000	1
$ 40,000	1
$ 3,000/dB	1
Average Barrier Construction Cost Range	**Number of States**
$ 5-10/ft^2	10
$ 10-15/ft^2	15**
$ 15-20/ft^2	6***
Over $ 20/ft^2	1

a Type II Noise Attenuation Study in 1988. The first public meetings on proposed Type II barrier projects were held in the summer of 1990 to determine the residents' reactions.

Funding Mechanisms

The 1982 Surface Transportation Act eliminated the use of Federal-aid Interstate money for Type II noise barriers, stating that Federal "4R" (Resurfacing, Reconstruction, Restoration and Rehabilitation) funding could be used for Type II noise barriers. In many states, this smaller funding source was generally already earmarked for other 4R projects. The lack of a separate federal funding source specifically dedicated to Type II projects has been cited by many states as their primary reason for not having such a program. When asked about funding mechanisms, the majority of the responses identified regular 4R highway funds.

On one project in 1984, Connecticut used the Interstate Trade-in Program set up in the 1982 Act, which was structured to allow a high level of local input by eligible communities for setting priorities for the use of trade-in funds. The town of Wethersfield chose installation of a noise barrier on I–91 as its highest priority.

Colorado is investigating several different funding scenarios, including using a fixed percentage of their construction budget. Assigning one percent of the construction budget for noise barriers on existing highways, with the federal/state funding ratios depending on the type of highway, is being considered. Colorado notes that many of its severe noise problems are on six- to eight-lane primary highways, since most of its Interstate problems have already been treated. Colorado staff expressed optimism that the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) will give flexibility in the use of funds.

The California Type II program began as a volunteer program with a volunteer funding level, but as noted in the previous section, was subsequently legislated via Section 215.5 of its code. In June of 1990, the voters approved a five cents per gallon gasoline tax increase under Proposition 111 (increasing to nine cents in four years). One part of Proposition 111 stipulated that the Type II noise abatement program shall receive an additional $150 million over the next 10 years. Prior to Proposition 111, the annual funding level was reported as barely keeping up with inflation. This new money would be in addition to the 1988 State Transportation Improvement Program (STIP) budget of $75 million over five years (the 1990 STIP stated a need for $180 million over seven years).

Minnesota currently has a legislative moratorium on its Type II program after major expenditures in the 1970s for Type II barriers in Minneapolis-St. Paul area funded largely by a one-quarter of a cent per gallon state gas tax set-aside.

Oregon considers all levels of government — federal, state, county and city, as well as Local Improvement Districts (LIDs)— as potential Type II funding sources. The city and county funds are sometimes requested as "local match" to supplement regular 4R or FAI state/federal funds.

As an alternative to barrier construction, Maryland is investigating a "resale assurance" program similar to that adopted by Baltimore-Washington International Airport (BWI). In this program, the state would pay the difference in the selling price of a house versus its appraised value, with the sale being handled by the property owner and the state reimbursing for certain settlement costs on a new home. Some maximum "cap" would be placed on the difference (e.g., 15 percent) and an easement would then be placed on the property preventing future actions by future homeowners regarding noise control. The amount spent would be limited to an annual budgeted amount and would be for those impacted areas beyond the current commitments.

Funding from Local Government or Affected Citizens

Several states have sought or indicated that they would seek funding from local government or the affected citizens for their Type II Programs. Wisconsin seeks this extra funding on projects where barrier costs exceed $30,000/dwelling unit. Oregon will sometimes seek 25 percent of the project cost if the local government is partially responsible for the noise problem, such as when they design and build a road without following the National Environment Policy Act (NEPA) process or when a city allows development along an existing highway.

In Virginia, for traffic noise abatement on non-federal aid projects, the local jurisdiction must pay 50 percent of the abatement cost. The local jurisdiction must also have an ordinance requiring developers to include noise abatement in their plans for developments along highway corridors.

Colorado is also addressing the issue of cost-sharing in barrier construction by municipalities, however, the issue of equity is of concern. Colorado is considering allowing a community to pay the cost above and beyond a standard design for desired aesthetic enhancements. Illinois, Michigan, Oregon, and Utah are other examples of states that seek funds in certain cases from local sources. On the other hand, Connecticut analysts believe that the solicitation of funds does not generate a positive attitude about funding.

California does not actively seek this type of local funding, but will accept local participation. This then enhances project priority, since, if the cost is reduced, the prioritization goes up. State legislation stipulates that the state will pay the party back with no interest in the year that the wall is scheduled to be built. However, it is possible that funding levels may change. As a result, that wall might keep getting pushed back in funding priority. Additionally, if a wall is only partially funded, then there is no pay-back by the state. Most projects on which local funding is provided are built by cities or counties.

In Maryland, on one project along I–95, Howard County contributed $200,000 of the $730,000 cost for a barrier. On a planned project in Montgomery County along I–95, the citizens will be paying for a large portion of the wall through a tax surcharge over a 20–year period. The state agreed to pay up to one-half of the then current $20,000 per residence criterion (since raised to $40,000). The county would initially contribute the additional money and the surcharge would be based on the amount of benefit received by each house.

Actions of Support by Local Government

Concurrence with the planned abatement project is asked of local governments by a number of states including New Jersey, Massachusetts, New York, Wisconsin, Colorado, Connecticut, Michigan, and Virginia. Michigan asks local governments to change their zoning policies as a condition to building Type II noise barriers. Wisconsin has an administrative rule that requires documentation of noise-compatible land use control adjacent to all freeways and expressways before any Type II barriers will be built.

Colorado invites local and county agencies to meet with the Planning Division of the Department of Highways to present information on a prioritized Type II set of projects. The department then studies all presentations and incorporates the selected projects into the five-year plan.

Utah is pursuing a program of having local governments develop land use compatibility ordinances for land abutting state highways. Minnesota and Connecticut look to see that the people in question indeed want the barrier. Iowa also wants any projects to be consistent with local planning, and looks to local government for aesthetic considerations.

Connecticut has formalized a process of obtaining signed agreements with affected citizens who oppose construction of a barrier planned for their area. The agreements state that the citizen "shall never directly or indirectly ask, request, petition or otherwise seek the erection, construction or maintenance of a noise barrier within state limits." Elimination of a proposed project can be accomplished only through a consensus of the residents and property owners who would receive primary benefit from the barrier. The agreement must be executed by each of the benefitting property owners, with authorized concurrence from the FHWA and the local government, in accordance with FHWA requirements. A sample agreement may be obtained from Connecticut (Florida has similar agreements available).

Project Prioritization

Each of the states with a Type II program has some method for prioritizing among potential projects. The methods vary, but most have a common thread, a prioritization index of some sort. Factors typically include: (1) cost, (2) dwelling units affected, (3) noise level, and (4) achievable reduction. In general, eligibility is pegged to the 1976 change in FHPM 7–7–3 and whether or not the development was in place prior to 1976.

Details on several older prioritization methods were presented in NCHRP Synthesis 87, (3) including those for California, Connecticut, Georgia, Maryland, Michigan, Minnesota, and New York. Also, as noted earlier, FHWA has published detailed discussions of the priority systems in California, Michigan, and Massachusetts (*6*).

Since those publications, Wisconsin DOT developed a complex ranking procedure that includes the following variables: (*17*)

- Average sound energy, averaged over all modeled receptors,
- Traffic exposure (the average daily traffic divided by 24 times the level of service (LOS) volume where LOS is an hourly vehicle rate, depending on density of traffic),
- An age factor (an average of the ages of the residences weighted by the difference in ages between the residences and the freeway), and
- The cost effectiveness of the barrier (total barrier cost divided by number of residences divided by average noise reduction).

Using this procedure, a score was computed by summing the four factors using weights of 50 percent, 25 percent, 15 percent, and 10 percent, respectively. Finally, according to Wisconsin DOT, "the ranking of each noise barrier relative to the other barriers was performed by normalizing each of the barrier factors using standard deviation techniques and summing all four factors with the appropriate weighing factor for each barrier to arrive at a score." Wisconsin used a cutoff of an L_{eq} of 67 dB for inventorying its needs. According to the FHWA noise abatement criteria (Table 5), 67dB is the level at which noise abatement should be considered to mitigate the effects of highway-generated noise in the vicinity of residences.

Also, Washington State DOT (WSDOT) Directive D22-22 (*18*) gave a procedure to inventory and prioritize the noise abatement sites and presented a Type II noise barrier priority listing of 28 projects. The inventory procedure first identified all highway sections where an L_{eq} of 67 dB or greater occurred at the right-of-way line. A second screening eliminated highway sections without residential development, with physical restrictions on practical solutions, or where roadside development, including access driveways, precluded noise barriers. After an on-site inspection, a second, more detailed prediction phase to determine a benefit/cost computation led to an expression of a noise impact and a noise barrier priority number.

The procedure makes a point to carefully note that sections excluded from the priority listing be documented with reasons for their exclusion. Such documentation is essential when responding to requests for abatement measures. The procedure also uses the philosophy of only listing those areas exceeding an L_{eq} of 67 dB. (Another philosophy is to prioritize below the 67 dB level to a value of 55 dB, for example.) This ranking establishes impacts without regard to feasibility of abatement. The advantage is that many more sites are listed, providing visible evidence as to why certain sites are unlikely to receive abatement. Once this ranking of impacts is available, the consideration of feasibility, effectiveness, and cost of abatement can be introduced to produce the barrier construction priority list.

The WSDOT procedure also groups the impacted residences by noise level rather than counting all people who receive some benefit equally. However, the procedure does not make provision for special noise-sensitive land uses, such as parks, and other areas included in FHWA Activity Category A (57dB).

Another WSDOT document, *WSDOT Noise Abatement Program* (WSDOT, unpublished, 1989), expanded on the procedures in Directive D22-22. Seventy-seven sites were listed in the priority ranking for noise abatement. However, only two of the projects were funded and built between 1986 and 1989. The document analyzed the types of funding sources available for highway noise abatement under current state and federal legislation. It also analyzed the costs for each priority site in terms of these various funding mechanisms. The department's concern for traffic noise mitigation must compete for funds with other departmental needs, such as maintaining and improving the existing highway system, and with other environmental mitigation projects that the department is committed to construct. The document notes that "demand for funds in other critical areas absorb funding allocations, especially state funds."

RESEARCH RELATED TO NOISE BARRIERS

Eighteen states have performed traffic noise research in the last 10 years, while 11 indicated that work was planned in the next five years. A list of recent Highway Planning and Research (HP&R) studies related to noise barriers is presented in Table 7. Fourteen of these state highway agencies have been involved in a National Pooled-Fund Study on parallel barrier effectiveness (the "Dulles noise barrier project") (*19*). These states are: California, Connecticut, Florida, Georgia, Hawaii, Iowa, Maryland, Massachusetts, Michigan, New Jersey, New York, Ohio, Pennsylvania, and Virginia. The pooled fund study is being conducted by the USDOT Transportation Systems Center under the guidance of FHWA and the states.

Noise barrier research focuses on four areas:

- Improving prediction modeling, including calculation of multiple diffraction and interaction with excess ground attenuation, and developing CAD and expert systems techniques for noise analysis and barrier design,
- Evaluating noise barrier performance,
- Analyzing multiple reflection effects between parallel noise barriers, and
- Investigating meteorological effects on traffic noise propagation, especially in the presence of barriers.

For example, California converted its mainframe noise prediction programs to microcomputer programs for use by consultants (*20*) and is researching the use of expert systems for noise barrier design. New Jersey is also studying the use of expert systems for noise barrier design through a project-related study. Colorado has already used computer imaging for one project to show views where high occupancy vehicle lanes being added along I–25 required changes to the existing noise barriers. The computer images gave residents a view of the noise barrier, any traffic that could be seen above it and the Denver skyline. Additionally, an interactive graphics program for STAMINA 2.0 file creation, editing and three-dimensional display running within the CAD software was recently developed. (*21*)

Florida has researched the effective height of noise sources to use in prediction models. The initial research results indicated that source heights currently used for medium and heavy truck noise predictions are higher than the data indicate they should be (*22*).

The subject of multiple reflections between parallel noise barriers has received a great deal of attention. Previous work in Japan and Europe has shown that large reductions in the insertion loss can occur (*23*). Work in the United States has focused on field evaluations of this problem. The National Pooled-Fund study showed effects of 2-6 dB (*19*). However, a 1987 study by Iowa showed minor increases in noise under actual traffic on I–380 (*24*). California also studied the effectiveness of adding sound absorbing panels to one wall of the parallel barrier system in an attempt to appease homeowners living more than 1,000 ft from the road who complained of increased levels after the "far-side" wall was built (*25*). Because of the wide separation between the barriers relative to the barrier heights, little benefit was expected and little was found. California also recently completed a much more detailed study, involving no barrier, single barrier and parallel barrier areas along a single roadway (*26*). Again, however, the barrier height to barrier separation ratio was very small, about one-to-fifteen. Wind speed and direction had greater effects on insertion loss at the study site than did multiple reflections.

Another aspect of the National Pooled-Fund study was to evaluate the performance of two parallel noise barrier prediction programs, IMAGE-3 (based on research described in (*23*)) and Barrier 2.1 (based on research described in (*27*)). The study also aimed at assisting in the evaluation of the American National Standards Institute (ANSI) method for measuring noise barrier effectiveness (*28*), and has led to a number of recommended changes to the standard regarding use of controlled and artificial sources, adjustments to reference levels atop the barrier, and wind effects. A more comprehensive analysis of state highway agency noise measurement equipment and procedures for studying barrier effectiveness and other subjects may be found in *Transportation Research Circular 288: Environmental Noise Measurements*, published in 1985 (*29*).

Additional studies of noise barrier effectiveness have been conducted by Florida (I–275, I–95), Kentucky (I–471), California (a number of sites), and Tennessee (I–440). Kentucky used a combination of "before" predictions and "after" measurements, finding that the barrier was indeed effective and that the predicted STAMINA 2.0 levels with the barrier agreed quite well with the measured levels (*30*). Florida also found that the barriers in its study were as effective as predicted in all cases, and slightly more effective than

TABLE 7
SUMMARY OF FEDERALLY FUNDED RESEARCH ON NOISE BARRIERS SINCE 1982

Project Title	Sponsoring Organization	Type of Funding	Beg. Date	End Date
Evaluation of Honeycomb Sound Barrier, I-280, Harrison, N.J.	NJDOT	HP&R	7/79	10/84
Determination of Insertion Loss and Evaluation of Traffic Noise Barrier Design Method, Rt. 444 (Garden State Parkway)	NJDOT	HP&R	7/79	10/84
Program Computer to Optimize Noise Barrier Design	Caltrans/ Translab	HP&R	6/81	6/82
Standard Test Procedure for Evaluating Noise Barrier Effectiveness	FHWA and TSC	Admin.	6/81	7/91
Determination of Insertion Loss for Traffic Noise Barrier Along I-676, Camden, N.J.	NJDOT	HP&R	1983	10/86
Investigation of Structural Design Criteria for Noise Walls	FHWA	Admin.	8/84	5/86
Parallel Noise Barrier Prediction Procedure	FHWA	Admin.	1/85	5/87
Evaluation of Innovative Noise Barriers	NJDOT	HP&R	5/85	--
Determination of Noise Source Height of Vehicles on Florida Roads	FDOT	HP&R	8/86	6/89
Effect of Vegetation on Noise Barriers	NJDOT	HP&R	9/86	---
Evaluation of Performance of Experimental Highway Noise Barrier	FHWA	Pooled-Fund Studies	1/87	9/91
Investigation of the Effectiveness of Noise Barriers Along I-275 and I-95	FDOT	HP&R	3/87	2/88
Public Response to Noise Barriers	NJDOT	HP&R	3/87	2/89
Alaskan Way Viaduct Traffic Noise Abatement Plan	WSDOT	HP&R	11/88	11/90
Field Eval. of Reduction in Acoustic Performance of Parallel Noise Barriers	Caltrans	HP&R	3/89	6/90
Design of Noise Barriers Using Artificial Intelligence	Caltrans	HP&R	5/89	6/91
Specialized Noise Barriers for Use on Bridges	NJDOT	HP&R	11/89	9/91
Comprehensive Systemwide Noise Mitigation Strategies	WSDOT	HP&R	4/90	10/91
Extension of Reference Emission Factors for STAMINA Model to Include 55-65 m.p.h. Range	FDOT	HP&R	7/90	12/91

predicted in several locations (*31*). California found that the FHWA model predicted 3 to 4 dB higher than the measured noise levels, but that the calculated barrier noise attenuation averaged about 1 dB lower than measured attenuation (*32*). Use of California vehicle noise emission levels cut the overpredictions in half (*33*). A study for Tennessee DOT on the I–440 barriers in Nashville showed a 2.5 dB overprediction of levels behind the barriers (underprediction of insertion loss) averaged over 40 sites (*34*). Iowa has also studied the effects of a noise barrier on community noise levels and air quality, finding that the barrier reduced noise levels and did not much change measured pollutant concentrations (*35*).

Both Pennsylvania and Michigan plan to study the effectiveness of some of their noise barriers, as well as a house insulation project along I–696 in Michigan. Florida also hopes to do field studies of noise barrier effectiveness, and California is researching sound propagation rates over various ground surfaces (*36*).

Wisconsin completed a study of the freeway locations with the potential for Type II noise barriers (as noted earlier). Also, Illinois DOT (IDOT) is developing procedures to consider and reduce existing freeway noise in northern Illinois, partially in response to the increased citizens' demand for noise abatement to be a high priority in the highway program. IDOT will investigate other states' Type II programs to identify areas of significant impact through a field review.

Washington has initiated several HP&R projects dealing with noise abatement. One project examined the state of the art in source, path, and receiver control in the federal, state, local, and private sectors (*1*). It then related its findings to current policy initiatives in Washington state and made recommendations to WSDOT for its noise abatement program. A follow-up effort for this project is focusing on motor vehicle noise reduction strategies and costs, successful community noise reduction programs, and a matrix of system-level abatement strategies comparing costs and benefits. A second project examined propagation and reflection of traffic noise off the superstructure of an old decked freeway in Seattle, the Alaskan Way Viaduct. Additionally, barrier-related research has been proposed by WSDOT on measurement of the effect of highway noise barriers on air pollutant concentrations, free-field performance of absorptive materials used in noise barriers, and field evaluation of noise barrier effectiveness.

It is interesting to note that in a 1987 TRB survey, state highway agencies identified some 50 items of needed research (*37*). Despite the work that has been done or is being scheduled, the list of needs is long. A recent updating of the survey identified the following five top-priority needs (Polcak, Maryland SHA, unpublished):

- Multiple reflections model,
- Multiple diffraction in the FHWA traffic noise prediction model,
- Compiled data on vegetation effects,
- Cost-effectiveness of absorptive barriers, and
- Insertion loss model, propagation over many surfaces.

PROBLEMS AND ISSUES

State highway agencies were polled on traffic noise issues and problems as part of the WSDOT survey (*1*). The agencies were asked:

- What are the issues of concern to the agency on traffic noise policy, program administration, analysis, or funding?
- What are the key issues in noise control at the source, along the path, and at the receiver?
- What is the agency's biggest problem or challenge concerning traffic noise?

Some of the issues related to noise barriers are described below. For other details, please refer to the WSDOT report (*1*). Probably the most serious issue and challenge is lack of funding for noise abatement, especially for Type II projects. Eight states noted funding as the primary problem within their noise programs, four of these mentioning Type II projects specifically. One state noted a 15–20 year waiting list for Type II projects at the current level of funding. Another noted the challenge of balancing the great need for abatement against very limited available funds. A third called for dedicated federal funds for Type II projects that are not tied to the 4R program. Competition for funding between noise abatement and highway construction is another concern. Also noted was lack of funds (as well as potential locations) for noise barrier product evaluations and experimentation.

Several states noted an "increasing demand by the public and politicians" or "great need" for noise abatement on the existing highway system, but complained of lack of executive management support or state-level funding and policies for such abatement. Traffic noise control is not listed as high on the priority list in the upper management of several responding states. One respondent also noted frustration with political pressure to circumvent current Type II policies by requiring special analysis on previously studied areas. Increasing public and legislative pressure for abatement is coupled with the increase in noise levels as traffic volumes grow.

Another administrative challenge included inducing local government to consider traffic noise in decisions affecting future development and to prevent uncontrolled development along roads (lack of state legislation on the subject was also cited as a problem), and dealing with the public whose demands for abatement might be termed excessive in terms of current federal and state policies or in terms of physical or economic feasibility.

Technical issues of concern regarding noise abatement include:

- Cost effectiveness of barriers,
- Expense of noise barriers per protected residence,
- Cost increases due to conservative design by structural engineers,
- The need for improved capabilities for analyzing sound reflection situations (buildings and parallel barriers), and
- Development of aesthetics acceptable to the public, not only for residents but for the motoring public, especially visitors in tourism-oriented states (the "view from the road").

Additional issues regarding noise control along the path between source and receiver include:

- Providing effective barriers while maintaining access and sight distance (one state requires barriers to be placed at the right-of-way line for safety, which generally makes them infeasible because of the needed height and associated cost), and
- Dealing with barrier maintenance (including development of graffiti-resistant surfaces), landscaping, snow removal, and the loss of view by residents, and making better use of earthen berms on new construction.

Among the specific items mentioned, California noted needs for the development of a relocatable wall, which would be important in areas where provisions for future widening of the road are required, and an inexpensive wall system (especially important in the Los Angeles area because of the extremely large number of planned barrier projects). Virginia indicated a need for more research to determine when absorptive barriers are needed including the effect of using an absorptive barrier as compared to a reflective barrier in single wall applications. Should the absorptive barrier prove to be more effective, a cost savings could be a benefit associated with its use.

CHAPTER THREE

NOISE BARRIER DESIGN

This chapter examines the materials and systems used by state highway agencies and reviews practices in the design, construction, and maintenance of traffic noise barriers. This discussion focuses on conventional barriers owned by the state highway agency and located on the state ROW; discussion of other types of barriers is in the next chapter.

MATERIALS AND SYSTEMS

Table 8 presents a listing of total barrier lengths by material type as of the end of 1989 (*7*). This section looks briefly at the experiences, practices, and preferences of ten states with regard to the use of these materials.

Connecticut DOT has used a number of different noise barrier systems, including wood post and plank, free-standing precast concrete panels, plastic panels inserted between steel posts, earth berms, and one test section of a masonry barrier. The state has standardized the wood post and plank concept and, as a result, has seen a decrease in cost as construction contractors gained experience in streamlining fabrication and installation.

Pennsylvania has used a variety of materials in its designs, but has tended to stay away from metal barriers for aesthetic reasons. PennDOT had developed a standard wood barrier design for structures and has avoided tropical hardwoods (despite use on one I–78 project).

Arizona makes extensive use of masonry, precast and cast-in-place concrete, and earth berms. ADOT will not use wood noise barriers because of the extremes in temperature experienced in the state which can cause warping and cracking problems. ADOT has built only one metal barrier. Erected in the late 1970s, this barrier protected a school in a remote part of Arizona, which ADOT felt to be too far removed from the normal supply for masonry barriers.

Minnesota does not have a standard materials system for all projects, nor are there specific barrier systems set aside for applications such as edge of shoulder installation, top of cut, ROW line, and bridges. Minnesota has used both wood barriers and concrete barriers. Only one steel barrier has been installed; its expense resulted in the removal of steel barriers from the state's approved list.

The most commonly used material in Florida is concrete. The system favored involves the use of precast panels, largely because of the fast installation time, which results in minimum interference to the public. By contrast, concrete block barriers require a longer installation time and, therefore, an increased presence in the backyard of the residents. Some materials are not used at all; however, this depends on individual districts and their experiences and preferences.

Earth berms have been used in Florida in only one case and probably will see little or no use in the future. This is due to the terrain in Florida in which there are essentially no cut and fill operations, and typically, limited ROW is available. While absorptive barriers have not been used in Florida, a "modified reflective" wall is being used. This is a concrete barrier with a fractured finish on the highway side. The surface involves grooves $1\frac{1}{4}$ in. deep and 3–4 in. on center in width. No acoustical benefit of this design is claimed.

Barrier systems used in Florida vary according to different installation situations. Edge of shoulder installations use a concrete safety shape barrier base incorporated with a wall. The casting of both the base and the wall are done in one unit at the same time. Barriers that are away from the shoulder can use other systems such as concrete block.

In Colorado, most of the early barriers were made out of wood posts and planks. However, the state is making a transition to masonry block or post and panel concrete walls. Colorado has installed one concrete post and panel design atop a safety shape crash barrier on a bridge that involved widening and rebuilding. Colorado prefers to place noise barriers near the right-of-way line to preserve future highway widening options without disturbing the barrier.

The most commonly used system in Virginia is precast concrete. The state feels that there is more control available in the manufacturing process of precast concrete compared to cast-in-place barriers. No concrete block barriers have been built. While steel barriers have seen much use in Virginia, there is concern about the ability of some designs to meet the 23 dB transmission loss requirement that the state has adopted. Transmission loss is a measure of how much the sound level is reduced in passing through the barrier material. This problem has been observed for lower frequency noise only. While wood barriers have also been used, they are not

TABLE 8
TOTAL NOISE BARRIER LENGTH BY MATERIAL TYPE AS OF 1989 (*7*)

Single Material Barriers		Combination Barriers	
Material	Length In Miles	Material	Length In Miles
Block	229.3	Berm/Wood	22.2
Concrete/Precast	147.6	Berm/Concrete	19.0
Berm Only	50.5	Wood/Concrete	16.9
Wood/Unspecified	39.2	Concrete/Brick	12.2
Wood/Post & Plank	36.4	Wood/Metal	7.4
Concrete/Unspecified	29.8	Metal/Concrete	7.0
Metal/Unspecified	27.2	Berm/Block	6.5
Wood/Glue Laminated	25.0	Concrete/Block	6.3
Brick	6.9	Wood/Block	4.5
Other	7.2	Berm/Metal	3.5
		Berm/Wood/Block	3.1
		Berm/Wood/Metal	3.0
		Other	10.8
Total	599.1	Total	122.4

currently being considered. The problem with wood barriers has been warping and cracking that require increased maintenance.

Massachusetts has installed 20 noise barriers throughout the state. Eight of the barriers have been wood or a combination of wood and berm. One barrier each of polycarbonate, precast concrete, and steel on a berm has been installed, as well as seven barriers using a proprietary free-standing concrete panel system.

Earth berms are the most desirable form of barriers in Michigan, due to perceived effectiveness and low maintenance. However, concrete block has become the standard based on both initial cost and the expected life of the barrier. Materials that have seen little use in Michigan are wood and steel. While treated wood has been used on structures due to its weight advantage, it has not been used in typical noise barrier applications due to perceived durability problems. Furthermore, steel has been used in only one application because of concern over longevity. Interlocking steel panels were expected to corrode in the overlap area in spite of manufacturers' claims of the effectiveness of galvanizing processes and coatings. While the results of the one project were judged very pleasing aesthetically, state designers see a 20-year life as a maximum for steel coatings. Overall, they would prefer to see a 50-year life for barrier materials.

Michigan is considering a system combining a retaining wall with an earth berm. The retaining wall would be used on the residential side of the barrier with the corresponding berm being visible on the freeway side. This arrangement has been recommended by the architectural staff as being the most aesthetically satisfying for all those viewing the barrier.

California has made few changes in noise barrier design specifications since 1981. Designs are included for barriers made out of masonry, precast panels, steel, plaster, and wood. A framed plywood wall is planned for use in the San Jose area and the Caltrans designers are examining their specification for wood noise barriers. However, masonry block is the most commonly used material in California. In fact, due to the large number of projects in California, masonry block composes thirty percent of all square footage of noise barrier materials used by state highway agencies in the U.S.

BARRIER SELECTION PROCESS

Methods of selecting the barrier material or system to be used on a project vary among the states. Several methods are summarized in this section.

The usual process for barrier selection in Massachusetts involves an initial selection of several alternatives by the agency, followed by discussions with residents near the proposed barrier locations. Most often residents have preferred wood barriers. Due to this high public acceptance and the cost advantage of wood, a large number of wood barriers have been constructed. However, certain contracts have allowed more than one option to the contractors. In a number of these cases, a free-standing concrete panel design was chosen.

In Type II situations in Minnesota, residents affected by the barriers are shown alternatives and, in general, the choice made by the residents is used for that particular application. In Type I situations, generally the same procedure is used; however, special conditions may require preselecting the alternative. For instance, if a retaining wall is to be built at a certain location, its presence may dictate the type of barrier to be mounted on top of it.

The decision to use various barrier systems or materials in Michigan is based on a three-part approach. First, the landscape in the area is considered, and second, the type of community where the barriers are to be located is evaluated. Landscape architects look at these first two considerations and make a series of recommendations. In the third step, the community evaluates the final selection of material and barrier system.

In Florida, the process to decide what barrier systems and materials are to be put in the plans, specifications and estimates (PS&E) begins with options determined by the districts where noise barriers are to be located. This choice is based on the nature of the area and the type of terrain and landscaping along with climatic conditions that favor some systems over others. A second step in the process involves public workshops to solicit input from the community where the noise barriers will be installed. Finally, the information from the public workshops is reviewed and, if possible, the preferences from the public workshops are followed for the PS&E.

A team approach is used in Virginia to plan and design barriers using a multidisciplinary committee. Once the general barrier system has been decided, input is received from the citizens who will be affected by the noise barriers.

One concern in California deals with walls built by cities or counties on state ROW as part of the state Type II program. Caltrans has a payback program by which a local government can install a noise barrier and then be reimbursed later by the state when that site is reached on the priority list. Any plans for work on the state ROW must be reviewed by the Permit Review section. However, there have been occasions when the review has not been as rigorous as might be desired. In one instance, a masonry wall that was built by a city atop a concrete safety shape barrier without any steel reinforcing, collapsed during an earthquake. Concern was also expressed that developers installing noise barriers on their own property are not required to meet statewide requirements or standards of quality, appearance, or sound level reduction. While some cities, such as Cerritos, have detailed specifications, others seem to have no requirements. The need for a more uniform noise barrier program by local governments was identified.

BIDDING DOCUMENTS

Questions often arise regarding the specification of a barrier design in a bid document package, especially as related to including alternative designs or allowing a contractor to propose an alternative. Several examples are discussed below.

While alternatives have been allowed in the bidding documents package for noise barrier construction projects in Michigan, the specifications are very narrow. For example, a different material cannot be substituted in the barrier design and no unspecified alternatives are allowed in the bidding. No proprietary products have been specified; however, one precast concrete panel system has been allowed as an alternative in a number of cases. Specific systems that fall under the category of "footingless walls" are not approved for use in Michigan, nor are those barrier types that are convoluted in plan view or use other shapes to provide stability.

Generally, Colorado will specify a particular type of design in bid packages. The agency allows alternative designs, but contractors have not come forward with any to date. Alternatives would require review by the in-house staff and, if approved, would be added to the bid package so that others could bid on them as well.

In Minnesota, contractors are not allowed to bid unspecified alternatives. The specifications are relatively tight regarding the barrier system and type; however, any number of manufacturers might be able to produce a product within those specifications. Proprietary products are not specified in the project plans.

In Florida, options are available in the bid package provided that the contractor meets the general requirements specified. While proprietary products have not been called for by name, under certain circumstances tight specifications have been given and product brand names have been provided as examples. In one case, a relocatable wall was specified; the material could be chosen from wood, steel, or concrete. Proprietary metal and concrete walls have been used in Florida.

Virginia has developed a list of acceptable suppliers of noise barriers. During the bidding process, contractors are allowed to propose systems from this approved list. In its bid documents, Arizona specifies barrier height and length and surface treatment (per community preferences). Contractors may bid on specified alternatives as long as they can meet the specifications. Oregon will generally include alternatives in the bid package, although no special provisions or allowances are made for these alternatives in terms of cost when selecting the winning contractor.

NEW PRODUCT REVIEW

Another important issue is how state highway agencies deal with newly proposed barrier materials or systems. This section describes several approaches.

Washington state DOT has a Products Committee for the testing and approval of proposed systems. The committee includes members of the materials lab and the structures office. The materials lab can conduct accelerated weathering tests, freeze-thaw cycle tests, ultraviolet radiation tests, and aging tests on the wood or concrete coloring stains.

WSDOT installed its first project using a patented precast panel system along I–5 in Olympia. According to the manufacturer, this system offers ease of construction and minimal site preparation. The panels, which have openings cast in their bases, are set in a trench atop pier blocks with vertical reinforcing steel running through each panel and each opening, and down through the bottom of the panel to the ground line. Concrete is then poured to fill the trench and pass through the openings in the bases of the panels. Formliners are used to provide a concrete safety shape crash barrier on the roadway side. New Jersey has also expressed interest in this product for situations where the presence of rock presents difficulties in drilling holes for posts. NJDOT structural engineers are evaluating the structural aspects of the product.

PennDOT uses an in-house Product Evaluation Board, which recently approved a lightweight architectural panel product for use on structures. The panels, which look like concrete, slip between steel posts that are attached to the bridge structures. Several have been installed on the I–78 project. Connecticut has also used this product as a temporary barrier on one road relocation project.

In Oregon, new designs that might offer cost savings would be reviewed by the Design Office. If approved, it would not be specified as a proprietary system in the bid package, but the desired properties would be described to not preclude others from bidding on the same specifications. One instance dealt with a product described as an "artistic fence," which was a concrete post and panel design with a shiplap construction where the panels were slid between posts. Based on a standard design for a 6-ft high fence, the company initially quoted a cost of $65/l.f. for a 10-ft high wall, which was less than one-half the price that ODOT typically paid for barrier installation. However, serious problems were encountered in the construction of the posts. As a result, the actual price was on the order of $100/l.f., meaning that the savings compared to the standard design were not significant.

In Florida, there are plans to provide a review of barrier systems through seminars in which several vendors of noise barriers could present their products to the designers. This process would broaden the designers' exposure to the options available in the marketplace.

SERVICE LIFE

A very important issue, often overlooked in estimating the costs of a barrier system, is system service life. Different materials have different service lives, and even the same material will behave differently in different regions of the country.

Engineers in Oregon estimate that the service life for wood in western Oregon is one-half of that for concrete due to the dampness of the climate. They expect 45 to 50 years service life for concrete (and for wood in the dryer, eastern part of the state) but only 20 to 25 years for wood in the western part of the state. However, the timber manufacturers claim that, with proper sealing, the timber walls should last 50 years. The expected life of the barriers, largely made of wood, in Minnesota has been estimated to be 30 years. The oldest barrier was built in 1972 and is currently holding up very well.

The oldest barriers in Michigan date back to about 1975, with the oldest one being a creosote wood wall. It has required little maintenance and caused little trouble. There have been no maintenance problems associated with the oldest concrete barrier, which dates back to about 1978. An earth berm barrier built in 1975 is performing well and, aesthetically, is the most pleasing of any Michigan barrier because its function is disguised by abundant vegetation.

The expected life of the concrete barrier systems is 50 years in Florida. The oldest barriers date back to 1976 and are still in very good condition. In Virginia, the expected life of most of the barriers has been estimated at 20 years. The oldest barriers are 13 to 14 years old and show few, if any, problems.

AASHTO DESIGN SPECIFICATIONS

In 1986, the AASHTO Subcommittee on Bridges and Structures Ad Hoc Task Force on Sound Barriers was created. Lacking a specific sound barrier design specification, designers had previously relied on related documents such as building codes or the *AASHTO Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. In 1989, AASHTO published the *Guide Specification for Structural Design of Sound Barriers* (*38*) to provide consistent design criteria for the preparation of plans and specifications.

During the preparation of the AASHTO specification there was some disagreement as to how explicit or how flexible it should be. The final document was developed to give designers as much flexibility as possible. However, this "flexibility" has been viewed by some as "ambiguity" that could lead to misinterpretation and improper application of the specification. One example was cited where a reviewer would not approve several projects because the state was not using the lowest allowable wind speeds. The designers felt that higher speeds were warranted, but a different interpretation by the reviewer caused a serious problem.

The Caltrans structures office had a key role in the preparation of the AASHTO sound barrier design specifications. The masonry barrier specification in the AASHTO document is a generalization of the Caltrans masonry specification. Caltrans uses a more detailed specification for its own masonry barriers tailored to California conditions. Appendix C contains the Caltrans Memo to Designers 22-1, dated July 1, 1989, which details the Caltrans noise barrier design criteria.

Colorado formerly used the AASHTO sign specifications, but has adopted the AASHTO sound barrier specifications and has found that this has allowed them to reduce design wind loads tremendously. As a result, caisson depths have been reduced significantly (in the past, these were 14 to 15 ft deep; now a maximum depth of 8 to 9 ft is used), resulting in a savings of 30 to 40 percent in foundation costs. Additionally, they are now using higher strength reinforcing steel in the foundations (going from an allowable stress of 20,000 psi to 24,000 psi), which has also allowed a reduction in caisson sizes and costs. Engineers in Arizona have also expressed concern about past overdesign of their barriers.

Virginia uses design specifications that were developed through years of building barriers. They have looked at the AASHTO noise barrier specifications, and have revised their wind load specifications as a result. Washington state structural engineers have expressed some concern about the specifications, especially regarding use of the Exposure B wind loading. This is a wind category that includes urban and suburban areas with closely spaced obstructions the size of single-family dwellings upwind from the noise barrier. The degree of openness in the terrain helps determine minimum wind pressures. The engineers feel that one cannot simply assume that Exposure B will be adequate, especially for the crest of a hill or for masonry walls. On several bridge projects they have used a loading of 50 lb/ft^2.

Florida DOT uses the AASHTO barrier specifications; in addition, some of the southern Florida building code is referred to regarding wind loading and some other features for barrier design. One comment received was that the wind load charts are somewhat difficult to work with. FDOT also has a set of draft specifications that are continually being developed as experience is gained from previous barrier designs.

Minnesota DOT has developed a set of standard plans and specifications for noise barrier design. While the AASHTO noise barrier specifications have been provided to the barrier designers, Minnesota engineers expressed a desire for more detailed specifications. Only minor changes in Minnesota design specifications have been made; a list of acceptable barrier systems and materials has been approved for Minnesota.

The relatively small number of barriers built in Massachusetts, coupled with the long time span over which they have been built, has hindered the development of design criteria. However, there is currently an effort to work on producing specifications in light of a new project pending on I–93. While AASHTO noise barrier specifications have not been evaluated in depth, they will be used on a planned Type II project.

Michigan has developed its own specifications for a number of barrier designs including wood, concrete block, brick, and several insert type panels such as brick. Steel barrier specifications have generally been provided by the manufacturer of the steel barrier system. The AASHTO noise barrier specifications have been reviewed, but not fully evaluated by Michigan.

OTHER DESIGN SPECIFICATIONS

Design standards have evolved over the years in many transportation agencies. Presented below are examples from several agencies.

The standard barrier design in Connecticut is timber using cylindrical southern yellow pine or Douglas fir poles with 2- x 8-in. x 12-ft tongue and groove planks nailed to the poles as shown in Figure 5. The wood panel walls are assembled by nailing the planks in a jig on the ground, then lifting the resultant panels and power-nailing them to the poles. The bottommost planks are then attached by hand.

The wood is treated in one of two ways: chromated copper arsenate (CCA) in accordance with American Wood Preservers Association (AWPA P-5), or pentachlorophenol in accordance with AWPA P-9, Type B (L.P.G.). All material must have a minimum treatment of 0.5 lbs/ft^3 for the pentachlorophenol, and 0.4 lbs/ft^3 for the CCA (with 0.6 lbs/ft^3 for the poles), conforming with AWPA C-2 for planks, panels, and battens, and AWPA C-4 for poles.

Connecticut also has three standard designs for using hardwoods (with bongossi [*Lophira alata*] for posts and bonalim [*Dinizia excelsa*] for panels). The hardwood material must be naturally fire-resistant without the use of fire retardant preservatives. Flame spread indices and smoke developed values are given based on testing in accordance with ASTM E-84-81a.

For all Connecticut wooden noise barriers, the posts are buried in concrete piers, and crushed stone is placed to a minimum depth of 2 in. above the bottom of the highest panel to permit drainage under the wall. Additionally, based on earlier experiences, Connecticut has increased the depth of the tongues on their planks to a minimum height of $^3/_4$ in. and a minimum width of $^5/_8$ in.

The philosophy and practices of the Maryland SHA have evolved as experience has been gained with their Type II program. The first walls were constructed to provide a totally flat surface on the highway side regardless of the material. The original installation was a wooden glue-laminated barrier.

After this first installation, a concrete manufacturer proposed an exposed aggregate surface that the citizens and SHA officials liked even though the design violated the flat-surface philosophy. The initial exposed aggregate walls used very large washed river gravel, which proved to be too big. The state went to smaller stones to allow the exposed aggregate surface to be applied easily to both sides of the panels. Maryland's next barriers were a proprietary concrete panel product, installed on I–495. The panels were stacked 3 or 4 high in a "deep fan" design. There had been concerns about use of this design where the grades are too variable or where there are steep cuts, although the manufacturer developed newer techniques for using the product on slopes. While most of the Maryland barriers have steps in the barrier tops as elevations change, these barriers have a smooth line along the barrier top through the use of specially cast top panels. Doors have been built into the barriers to provide access.

Based on earlier experiences, a standard system evolved in Maryland consisting of a steel H-post and concrete panel design with exposed aggregate on both sides of the panel. The highway side of each panel is indented on a bevel to give a smoother look to the posts. In many of its designs, Maryland ends a barrier with a sharp diagonal cut on the last panel rather than any gradual stepping down in height. The main alternative to this design is another proprietary concrete wall product, which has an integral post and panel element. The Maryland SHA structures group was concerned about making adequate field-checks of the welds on the posts and caissons for

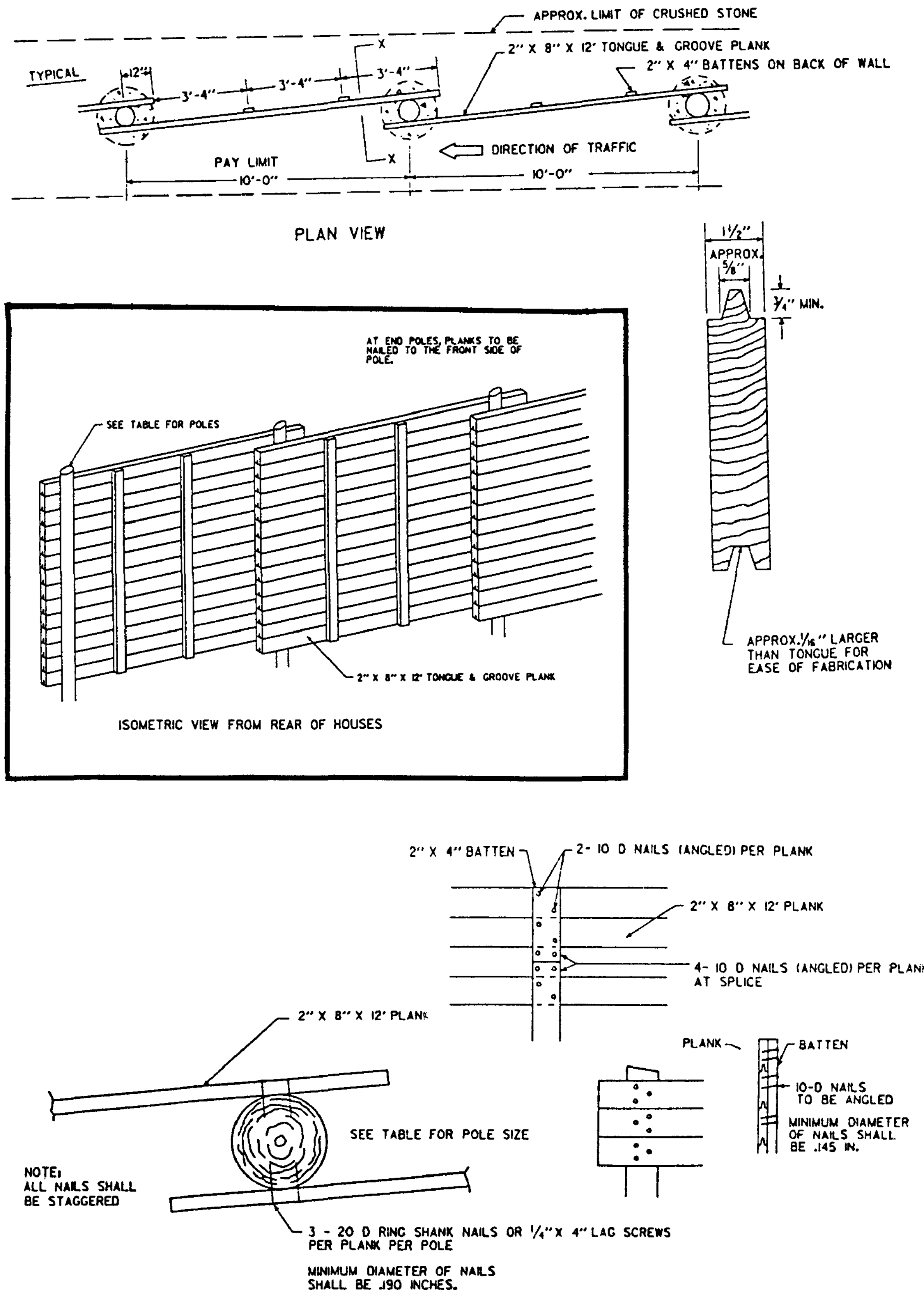

FIGURE 5 Connecticut DOT timber wall design details.

this product, so the manufacturer developed a bolted design. Other variations on the standard design include exposed aggregate on concrete posts.

The American Plywood Association (APA) had worked with Washington state DOT in developing pressure-treating specifications. The ground contact specification for the treatments calls for 0.6 lb/ft^3 of preservative and the penetration depth is checked by field borings. Moisture content is controlled via a certified APA percentage stamp on the wood.

In the case of wooden noise barriers in Minnesota, the required size of wooden posts became very large for some high walls. The use of reinforced concrete posts in these situations was a more efficient alternative to very large wood posts.

Ontario has a great deal of experience in noise barrier construction. Its earliest barriers of precast concrete, cast-in-place concrete, and earth berms date back to the early 1970s. Design standards for the Ministry of Transportation have evolved over the years. Draft materials specifications and construction specifications have also been prepared, as were instructions for designers on how to prepare a noise barrier contract bid document package. Appendix D contains the final draft of the materials specification.

Several European countries have developed their own specifications. One example is ZTV-LSW 81. In particular, Germany has issued three sets of guidelines related to: (1) acoustical design of length and layout of barriers (*39*); (2) physical design recommendations (*40*); and (3) other technical and acoustical requirements for reflective and sound absorbing barriers, linings, and coatings (*41*).

DESIGN CHALLENGES

Bridges

Bridges pose a unique set of problems to designers, including wind loading, method of attachment, weight, safety, and type of material. Different state practices are outlined below.

California uses specially reinforced masonry barriers on bridges, a change from earlier projects in which only cast-in-place concrete atop a safety shape concrete barrier was used. On bridges, the masonry blocks are grouted solid for the first three courses and then vertical reinforcing is placed in every block (on 16-in. centers). There is a concern about adding barriers to existing bridges and retaining walls that occasionally cannot accommodate the extra load, either necessitating a setback or a lighter weight material. When retrofitting existing bridges where weight is a concern, Caltrans has used steel barriers but has set them back at least one foot from the parapet for safety.

Maryland has used only metal for noise barriers on bridges. That decision was made after an accident where a roll of aluminum fell off a truck and knocked out 100 ft of a 10-ft high concrete barrier across a bridge. Steel barriers have also typically been used in Massachusetts on structures for Type II applications. In the past, Colorado has used an aluminum sandwich panel product. Oregon has also used metal barriers in two instances over bridges, where a lightweight product was needed. The panels were bolted into the bridge. For new bridge construction, ODOT would consider using an extended safety shape crash barrier.

In Type I situations where walls must be installed on structures, Florida DOT uses cast-in-place concrete walls. The wall itself is cast into the handrail section of the bridge framework to anchor the wall. In the case of precast panels that have been attached to bridge structures, an arrangement to bolt the panels to the side of the bridge has typically been used.

For barriers across bridge overpasses, Connecticut has developed a system that requires no bolted supports on the outside of the bridge. Instead, a 1- to 1 ½-ft deep hole is cast into the concrete parapet and a steel H-column is inserted and cemented in place. Then, the wood planks are bolted to the flanges of the H-column with face plates on either side of the flange-plank assembly. A second Connecticut method, where the posts are inserted and bolted into collars, which are bolted to the bridge, is shown in Figure 6.

In Michigan, wood barriers are typically used on structures. Two types of wood barriers have been used in these applications. The first type uses ⅝-in. tongue and groove plywood installed in 4- x 8-ft panels which are framed with 2- x 4-in. wood sections. The second type of wood barrier uses a double wall composed of horizontal 2- x 6-in. tongue and groove wolmanized boards. Barriers attached to bridges generally involve drilling holes in the sides of the bridge, inserting anchors, and attaching the barriers with bolts.

Foundations

Foundations pose another challenge to designers. As noted above, the new AASHTO specifications have allowed some states to reduce their designs and save substantial amounts of money. Some other observations are presented below.

In Minnesota, foundation design for noise barriers has generally been quite straightforward. Special anchoring was required, however, where noise barriers were added above existing retaining walls.

Connecticut has experienced settling problems which caused some freestanding, footingless barriers to lean.

FDOT has successfully developed a new system of foundation for barrier posts where groundwater is a problem. Many sites in Florida have groundwater within 3 to 4 ft of the ground surface. The solution to the problem of water filling the caisson holes has been to use an "auger-cast" pile. With this method, as the hole is bored for the caisson, an auger with an internal passage is used to force pressurized concrete into the hole. As the auger reaches the bottom of the hole, pumping of concrete begins, and the auger

FIGURE 6 A Connecticut DOT method of attaching timber wall to bridge.

continues in rotation while being removed. In this way, concrete under pressure is pumped into the hole, preventing water from entering the hole. Precast posts with extended reinforcement bars are then placed in the newly poured concrete. The whole process takes approximately one-half hour per post.

Drainage

Special consideration has been given to drainage in several states. In Michigan, a number of problems have occurred where the barriers have prevented adequate drainage from private property. The typical solution is to direct the water laterally along the barrier to a drain. However, some situations have required installing small holes (typically a diameter of 2 in. at the base of the barrier). While this is a very small hole when compared to a normal drain opening, this size maintains the acoustical integrity of the noise barrier. The property owners are required in these cases to maintain clearance for water to drain through the small hole.

In Virginia, in some cases a grate is used with drains that pass under the barrier; in other cases, an opening in the base of the barrier is used. These drain openings are often put in at transition sections, where the barrier is not parallel with the roadway. This placement has been thought to reduce any acoustical problems of having the drain holes in the barriers.

In Minnesota, drainage is generally handled through the use of small weep holes at the base of the barriers, or in some cases, the water is diverted to collection basins and channeled under the barriers. As noted earlier, Connecticut routinely leaves a gap below its bottom panels that is then backfilled with gravel.

Most barrier installations in Florida have been in situations where drainage has not been a problem. One method being considered in Florida is to cast drain holes in the panel itself at the lower portion of the panel where it is below grade. The area surrounding this hole would then be filled with gravel to allow adequate percolation of water behind the barrier to flow through into the highway side or vice versa. However, in one project the method chosen by the barrier manufacturer resulted in holes in the wall above grade. Since these holes would degrade the acoustical performance of the noise barrier, different solutions were considered. One idea was the installation of louvres or a hinged flap on the highway side of the barrier. However, it was suspected that a flap might work erratically and possibly not open when necessary for water flow.

Another solution, which is used in California, would be to cover the hole on the highway side with a barrier that acts as a block for sound while further acting as a baffle to water flowing from the backside of the barrier. This solution would probably result in the lowest maintenance activity and the fewest problems.

A unique solution to the concern of flood waters ponding between parallel barriers in a low-lying loading section was developed in Ontario. The bottom panels of a precast concrete panel wall were hinged so that the pressure of any built-up water would swing the panels outward, releasing the water. The heavy panels would swing back into place after the pressure was relieved. Figure 7 shows the bottom panel in the normal closed position.

FIGURE 7 Ontario panel hinged to release floodwaters trapped on road side of barrier.

Nailing

A Noise Barrier Task Force in the Connecticut Design Office investigates problems with noise barriers. One major problem with wood barriers has been with the nails used to attach the planks to the poles. A straight-line nailing pattern initially caused problems with nails pulling out of the planks and poles splitting. On several projects that used electroplated nails, corrosion caused nail heads to pop off, requiring renailing in the field. There was also concern that the copper in the CCA preservative was a corrosive agent attacking the double-dipped galvanized nails being used on other projects. Accelerated tests by the American Plywood Association showed these corrosion problems, although the Task Force had pulled nails from barriers that were 6 to 7 years old and found no such evidence. Nonetheless, as a result of an investigation by the Task Force, Connecticut has changed its nailing pattern to a triangular arrangement (see Figure 6), specified a larger 20-penny nail, and plans to use stainless steel material. Use of the stainless nails, while more expensive initially, will provide much longer life.

Also, in its initial designs, Connecticut used felt strips between the poles and the planks to eliminate air gaps that might allow sound to pass through. The state stopped using the felt strips because of doubts about their effectiveness. However, the strips may have actually helped to reduce the nail corrosion problem.

Post Design

PennDOT has experienced a problem with a precast concrete post and panel wall where too much "play" was allowed between

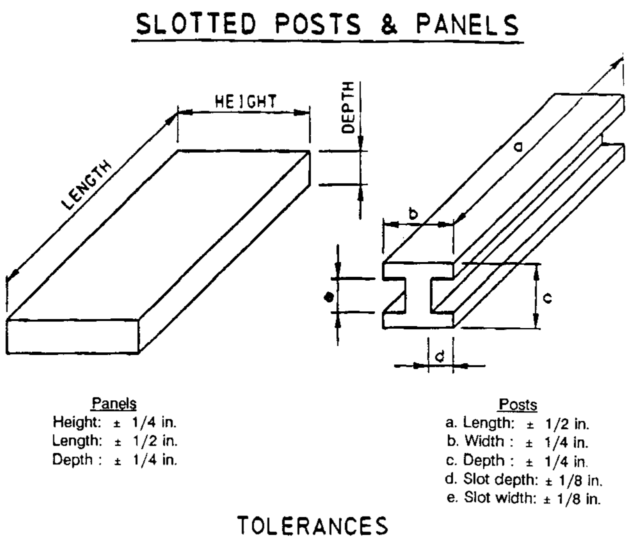

FIGURE 8 Details of tolerances for concrete post and panel noise barriers in Pennsylvania.

the posts and panels. An in-house review indicated that there was insufficient reinforcing steel to take up the stress of the panel rocking back and forth and there was concern about concrete spalling off of the posts. A retrofitting of the posts was necessary. Figure 8 shows PennDOT's revised tolerances and reinforcing for post and panel design.

For a project on I–95, the "Remedial Group" in the Maryland SHA Bridge Design Office is investigating problems with the concrete posts similar to those experienced in Pennsylvania, and plans to go back and wrap the posts with cables.

Overhead Obstructions

One problem that has been encountered in Florida noise barrier construction is the presence of high voltage wires. Depending on the size of the panels that must be lowered in place between the concrete posts, cranes may be impeded by high voltage wires. One solution to this problem has been to advise barrier designers of the potential problem. As a result, barrier designers have taken steps to ensure adequate clearance in these situations. Another result of this awareness has been to reduce the heights of precast barrier panels, which reduces the amount of overall boom height required to place the panels in position.

Where there is limited room for installation or where overhead power lines are a factor, Oregon might specify masonry as the only option.

Access

Access through a barrier is often needed for maintenance crews or for firefighters. Several examples are described below.

Maintenance staff in Oregon have requested that access be provided in several instances, leading to overlapping barrier sections or the inclusion of metal doors. Arizona DOT maintenance people have also asked for access through the barriers for long sections. As a result, several different access strategies, such as doors in the walls, gates in the chain link fences on the right-of-way, and overlapping barrier sections, have been tried. No maintenance access has been provided in the existing barriers in Florida; however, a "design checklist" requires its consideration for any new barrier. Special details have been developed in Michigan for fire hose access but not for maintenance access. There has been reluctance to install doors and gates in deference to aesthetic considerations. In Minnesota, only one maintenance access door has been provided (to accommodate grass mowing equipment).

Virginia will continue to use access doors that serve both for maintenance and fire hose access if required. Caltrans also routinely provides fire hose access and maintenance access. In several instances they have had to provide a door in the barriers large enough to allow a utility truck to pass through (10 ft x 16 ft). Caltrans also provides access for maintenance by extending one barrier section past the end of another to form an overlapping area through which vehicles could pass; in these cases, a 2 ½ to 1 or 3 to 1 overlap ratio is used.

In Colorado, details such as fire hose and maintenance access are normally handled in the field and are not included as standard design specifications. In a recent project at the I–25 and I–70 interchange, where mineralized wood-shaving, sound-absorbing barriers were added as a median barrier between two parallel walls, emergency access was provided with 4-ft wide steel doors in the panels.

For fire hose access, Florida had a design for a removable plug. However, this design was not used due to the possibilities of the plug jamming during removal, or conversely, being too easily removed by vandals. A second design uses a circular heavy gauge PVC flap anchored with a bolt. This arrangement allows the flap to swing from side to side for access to the 10-in. fire hose hole. Caltrans' standard design specifications for fire hose openings is based on use of a sliding redwood door. Maryland has installed standard fire hose connectors into most of its barriers, allowing hoses to be connected on either side of the wall. Figure 9 illustrates this method on a barrier along I–68. This design could require standardization in connectors from one municipality to another.

Minnesota provides fire hose access in its noise barriers, although the specific design details vary by district. The details are not included in the Minnesota standards. Furthermore, fire hose access tends to only be used on the higher walls.

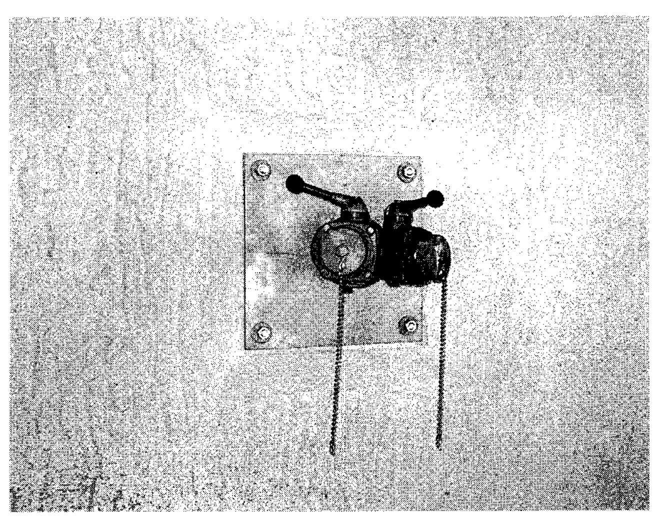

FIGURE 9 Maryland I–68 noise barrier fire hose connector.

Barrier Aesthetics

Appearance has always played a critical role in the acceptance of noise barriers, although enough attention has not always been given to the subject. Two schools of thought seem to exist and are beginning to be verbalized. One is to hide the barrier—make it blend into the highway environment as much as possible. The second is to make the barrier an aesthetic feature that stands out on its own. This approach is more evident in Europe, as noted in the excellent collection of information on European noise barrier concepts produced by the Danish Ministry of Transport (*42*). Another publication on noise barrier aesthetics was prepared to provide guidelines and suggestions to the Wisconsin DOT for traffic noise barrier design (*43*). Aesthetic treatments are perceived to be expensive and are often first to be cut when budgets are tight. But, a commitment to good design should include all aspects of design, including noise barriers. Of importance are the material type, color and texture, and landscaping. Several states increasingly emphasize aesthetics in their barrier designs. Some examples are described below.

New Jersey is moving away from the use of smooth surfaces because they show deficiencies and defects too easily; rough surfaces hide such problems. There is also a concern about the height-to-width ratios of the barrier designs (from post to post), and an interest in applying principles of aesthetically pleasing proportions in their dimensioning. Of concern are the effects on the apparent final height-to-width ratio of plantings growing at the bottom of the barrier.

In one instance, New Jersey will be using the outline of tree silhouettes cast into the face of the noise barrier with formliners. In another project, they are considering casting the top of the barrier to give a silhouette representing the roof lines of the two-story houses being protected by the barriers. Florida has also used formliners on a barrier system on I–95 to cast images of seabirds, sailboats, and lighthouses into the concrete, as illustrated in Figure 10.

Generally, Arizona tried to provide patterns that match the styles of the neighborhoods in which the barriers are located. Both vertical and horizontal striations, as well as a block look, have been used. Additionally, ADOT has recently experimented with designs based on the Hohokam Indians native to the area.

Maryland developed a "route theme" approach. First, it established a preferred noise barrier treatment in priority order of: (1) earth berm, (2) earth berm/wall combination and (3) wall. Then, design themes were established for each major roadway corridor. For example, along the Baltimore Beltway and the Capitol Beltway in Prince Georges County an exposed aggregate finish with a tan earthtone color is being used. On the Capitol Beltway in Montgomery County, an exposed aggregate finished with a dark brown earthtone color has been used. The I–270 corridor uses an ashlar stone formliner which gives a simulated cut stone block appearance (see Figure 11).

The idea of corridor themes is being considered in Minnesota and New Jersey as well, where consistency (and relevancy to the environs) is important for the noise barriers and other physical elements of the highway.

Washington has established an Architectural Review Team consisting of people from the architecture and landscape architecture offices, and an expert local architect to address many of the issues regarding appearance. A guideline booklet on good highway architecture is planned.

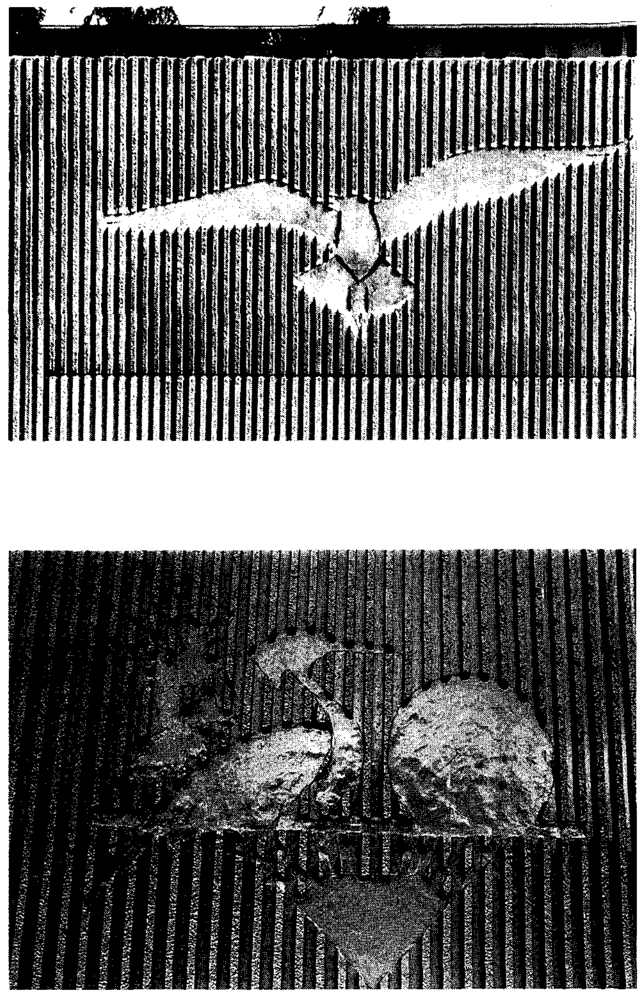

FIGURE 10 Seascape graphics cast into surface of precast concrete noise barrier with fractured fin finish on I–95 in Florida.

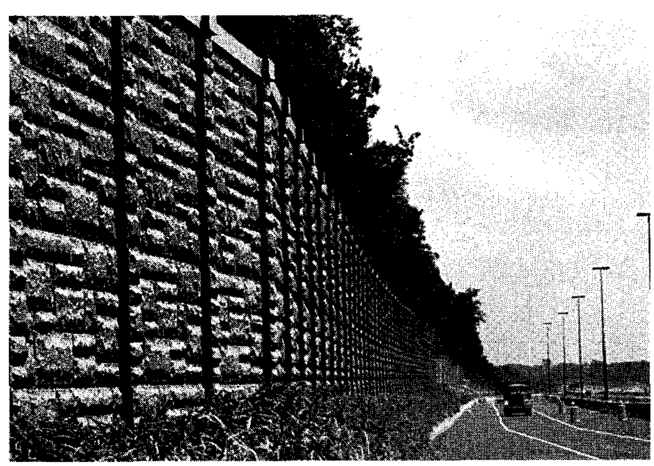

FIGURE 11 Ashlar stone finish on precast panel wall in Maryland.

Separate from the issue of aesthetics are other concerns regarding noise barrier acceptability. These include blocking the view of the road or from the road, blocking breezes that provide natural ventilation and blocking sunlight from reaching gardens. Among the benefits associated with noise barriers are a greater sense of privacy for residents and a perception of increased security from motorists whose vehicles have broken down or from other intruders.

Safety

One of the major safety concerns of all state highway agencies is vehicle strikes against the barriers. In California, most of the noise barriers are at the ROW line, with no other fence. This location allows any locally built walls to be taken down or tied into the state's wall. If a barrier is located within 15 ft of the edge of pavement, it must be placed atop a safety shape crash barrier. Barriers between 15 and 30 ft from the pavement edge require a box-beam guardrail.

An inspection of 90 sites in the Los Angeles area with reported truck accidents revealed damage at six sites (although one had a fatality). At many of the sites, there was no evidence that there had been a crash.

Wooden rails have been installed on some wooden barriers in Minnesota to prevent the possibility of a vehicle crashing through the boards and hitting the barrier posts. Beyond this, no crash attenuation has been provided for noise barriers except for impact attenuators in gore areas.

Crash attenuation for barrier ends has been accomplished in Florida in several cases by either curving the walls at the ends of the barriers or tapering the top of the wall downward to a reduced wall height. In some cases, the curvature has a built-in safety shape barrier at the base. However, no special crash attenuators have been used.

In Michigan, crash attenuators are installed at the ends of barriers near service roads. In addition, Michigan requires that all barriers have a guardrail (typically a safety shape barrier) installed between the roadway and the barrier. Crash attenuators have been used in certain situations in Virginia where they were deemed necessary. If noise barriers are installed relatively close to the pavement, safety shape barriers are used to protect the noise barriers.

Colorado has several safety concerns associated with construction of noise barriers; vehicles striking the barrier itself, snow drifting caused by the barrier, and shadows that can affect roadway icing have all caused problems. Barriers placed within the clear zone must be protected by guardrail per standards. But, all barriers, regardless of material, can be expected to cause major damage to vehicles striking them. Colorado does not have a reliable way of predicting drifting snow problems associated with the noise barriers. Having the maintenance personnel review the placement of the barrier is considered to be one of the better ways to address the problem. Shadowing of the roadway can cause sudden changes from wet or dry pavement to pavement that is ice covered, snow packed or wet, leading to loss of control of the vehicle causing an accident. Colorado strives to limit the shadow to the shoulder areas whenever possible.

CHAPTER FOUR

CONSTRUCTION

Good construction practice is essential for noise barriers because of the ability of sound to "leak" through gaps, cracks, and openings to degrade the acoustical performance of the barrier. However, good construction practice is not always achieved. This chapter describes some problems and solutions.

EFFLORESCENCE

New Jersey and Virginia report significant efflorescence problems that can occur following the cure of the concrete, where alkaline salts migrating to the surface of concrete barriers give them a chalky, stained appearance.

A team from the structures, landscape, and materials offices in NJDOT assembled to study this problem believes that one cause is the high alkalinity of the specific cement used. Contractors use this cement to provide a higher strength concrete that will allow precast panels to be pulled out of forms more easily. There may be additional problems with too much water in the mix and with curing panels outside where they are often rained on. Solutions used in architectural designs, such as acid cleaning or indoor storage during curing, are viewed as too costly. The NJDOT is considering putting additional limits on the strength of the concrete or restrictions on the cement being used as a means of requiring the contractors to leave panels in the forms longer.

Virginia also believes the solution to this problem is to tighten the construction specifications. In addition, its concrete barriers have been stained to hide the effect of the efflorescence problem. California has also experienced problems with the grout used in concrete block wall joints.

COLORATION

The other main construction problem experienced by NJDOT deals with any coloring used for concrete. The coloration problem has occurred with attempts to either tint or stain the panels. Early designs used tinting, but the efflorescence problem led NJDOT to move to stain. Initial staining was done at the precast yard, although significant field retouching was often needed due to damage to the finish during transportation and installation. However, field application of stain (especially if by roller) led to different colors and appearances than the precast yard staining. Additionally, recent laws against emission of volatile organic compounds (VOC) have forced NJDOT away from solvent-based coatings and stains toward water-based materials. Once the efflorescence problem is solved, New Jersey expects to return to using color admixtures during the casting process. They feel that use of the integral color is no more expensive than field application of stain when the labor costs associated with the latter approach are considered.

Dark brown crushed stone in the surface of the panels was used on some barriers in Maryland. However, color consistency of the exposed aggregate could not be obtained. Problems with blotched surfaces led the department's landscape architects to visit the casting yard with the construction inspectors to gain a better understanding. Ultimately, the problem was resolved by staining with a dark stain.

QUALITY CONTROL AND INSPECTION

Caltrans and other states noted that the main problems encountered during the construction of noise barriers, particulary on Type II projects, have been the presence of utilities, culverts, sewer lines, and occasional high groundwater, which involve unique construction solutions.

The most prevalent complaint from field personnel in Virginia during construction has been the inferior quality of precast panels that arrive at the site, resulting in a large number of rejects. Tennessee reported similar quality problems on its I–440 project. Virginia has installed one sound absorbing barrier which used foamed concrete, but curing problems occurred when the panels were cast in the field. Two more absorptive barriers are under construction, using proprietary systems. An early project in Maryland used glass fiber reinforced concrete (GFRC), which was painted a very dark brown. The GFRC barrier consisted of 1 ½-in. fibers in a cement matrix sprayed into a mold to produce 1-in. thick panels without steel reinforcing. The material did not live up to the manufacturer's claims, with panels breaking out of the frame.

Many of the precast panels on one Washington state project had indentations on the surfaces outlining the location of the reinforcing steel within them. The problem was caused by the contractor's use of a steel drum roller to push the concrete under the rebars after pouring into the formliners. While the contractor was willing to tighten his specifications, WSDOT felt that the best solution was to have full-size control panels cast and approved on future projects. Another problem in Washington occurred with the casting of concrete safety shapes on the noise barrier at an improper height on the panel. The safety shape concrete had to be removed from the panels, new rebars had to be grouted to the panel, and the safety shape had to be recast.

In New Jersey, a key part of the quality control problem deals with inspections of panels delivered to the job site. NJDOT requires the contractor to assemble four panels from four different days of production at the precast yard for approval by the state. While New Jersey has problems with insufficient numbers of inspectors (plus the occasional use of certification acceptance), they feel that the test panels should help the inspectors in gauging the acceptability of the final product.

No special training has been given to barrier construction inspectors in Virginia because of the limited number of barrier installations in many of the districts. Generally, a member of the design committee checks the barrier installation at some point and this has been satisfactory for the barriers installed to date. Minnesota has reported no special training for state barrier construction inspectors, nor any specific guidelines or standard practices for barrier construction beyond what is listed in the standard plans. Barrier construction problems have been minimal in Minnesota.

Florida, however, has workshops for its barrier construction inspectors to teach them noise barrier concepts and to provide a basis for understanding the checklist of items that could cause acoustical problems. In the past, a number of these problems have been ignored because the inspectors were unaware of the impact of changes. The training alerts them to potential problems which they can refer to the FDOT environmental office for advice. One problem that has occurred during construction has involved bolt hole alignment on structures. Installers of barriers have found it difficult to match the holes provided in the bridge structure for attaching the barriers.

Connecticut installed a sound-absorbing plastic panel wall on one parallel barrier section on Route 15 where multiple reflections were going to be a problem. In one section, the barriers are on fill at the edge of the roadway shoulder, while in another area they are on a bridge overpass. Two problems have occurred. Movement at the bridge expansion joints led to several panels falling out. The state had to add bolted plates over the panel edges at the H-columns in which the panels were set. There was also a problem with deflection of the bottom channel on which the panels rested between each post. Center footings between each post were installed on the edge-of-shoulder barrier, and center stiffeners were spot welded on the bridge.

Stacking precast panels has caused some appearance problems when the joints between the panels do not line up from one section to the next. Projects in Maryland (Liberty Road) and Tennessee (I–440) have had this problem.

On precast panel walls, Washington has used adhesive-backed foam gaskets to seal openings between panels, but has had problems with durability and getting the desired compression. On future projects, grouting will be used or foam rope will be inserted and caulked into the caps.

Both Connecticut and Washington have accelerated the construction process for their wooden plank walls by assembling the planks in a jig to create large sections, which are then lifted and nailed into place. While no major construction-related problems have been identified in Arizona, there has been some concern as to when in the project construction process the barriers should be built. Construction of the barriers early in the project would protect the communities from construction noise, but could limit access to the site.

Ontario's major problem concerns the quality of noise barriers being constructed by private developers. Presently, there are no controls or inspection of these barriers for effectiveness or quality of design, materials, or installation. There have been efforts over the years to bring about a consensus between the local government and the provincial Ministries of the Environment and Housing regarding the dangers of this lack of controls. The Transport Ministry must usually fund repairs or rectify the shortcomings of installations. The Ministry is finally gaining support, nationwide, to develop national and provincial designs, material and construction specification. A Canadian National Standard on material and construction specifications is now being developed. Pennsylvania has also prepared a barrier construction specification.

CHAPTER FIVE

MAINTENANCE

State highway agencies are concerned about maintenance related to noise barriers. Concerns include the barrier surfaces themselves and the ground areas on either side of the barriers. However, not enough attention has been paid to the long term maintenance consequences of decisions made during material selection, design, and construction. This chapter addresses these issues.

DURABILITY

The primary maintenance problem faced by many states has been with the durability of wooden barriers. For example, in Colorado, some wooden barriers are 17–18 years old and need major rehabilitation. The original wood walls used butt joints with no laps, and as the wood aged, shrinkage and warping occurred. The allowable moisture content was 19 percent. There is now consideration of reducing that figure to 15 percent on new construction, despite the increase in capital cost. Additionally, there is some sagging at the center of the sections. The original design called for a concrete footing between the posts, but somewhere along the way, this footing was eliminated. The 2- x 6-in. rails laid horizontally between the posts carry all the load, which results in sagging. A larger section for the rails is being considered.

In Colorado, poor drainage that leads to ponding has caused wood posts to rot. Future designs may include a better water sealant. The designers are also looking to change their standard to place the rails 2 in. above the ground, but need to consider drainage and possible leakage of sound under the barrier. Colorado also experienced some problems originally with the cement-coated galvanized nails rusting; now, the use of ring-shanked nails has eliminated that problem.

The acoustical effectiveness of the wooden noise barrier design used in Colorado is susceptible to degradation as it ages. Shrinkage cracks can be expected to allow up to 8 per cent of the surface area to become potential noise leaks, yielding a decrease in effectiveness of "up to 60 percent." *(44)*

The major maintenance problem in Minnesota has also occurred as a result of warping and cracking of wooden barriers. Several approaches have been tried to alleviate this problem. The cracked and warped boards in some cases have been covered with plywood to maintain the acoustic performance of the barriers. In other cases, where the cracks and gaps are not too large, a tubular foam material has been forced into the openings of the barrier to seal the gaps. Once the problem was recognized, tighter specifications on the moisture content of wood were specified and maintained.

Washington has also had some negative experience with several wooden barriers, both glue-laminated panels and plywood walls. Problems have been experienced with the pressure-treated wood, including some ground line rot. In general, the WSDOT environmental and architectural groups were disappointed in the wooden walls and are looking to use other materials in the future.

The wood barriers in Massachusetts, in spite of the wide public acceptance, have resulted in numerous maintenance problems. The major problem encountered with wood barriers has been due to shrinkage, which has created gaps and holes in the wall. In one case a wooden barrier caught fire.

SURFACE TREATMENTS

Most of the timber barriers in Connecticut are colored green, using a stain that penetrates the exterior. The state has had problems in some instances getting the stain to adhere; some peeling and wash-out has occurred. The problem appears to be in getting the stain to adhere to the CCA-treated wood.

Washington state found from accelerated weatherometer tests that the ammoniacal copper arsenate (ACA) preservative treatment did not age well. Additionally, the use of pentachlorophenol and oil resulted in a splotchy appearance. Some coloration problems occurred, attributed to the sapwood and the heartwood absorbing the treatment differently. Accelerated lab tests showed that about three years was needed to age the two types of wood so that they would look the same. Quality control problems associated with plywood walls were made evident by some ground line rot.

Some problems in Washington also occurred with concrete stain fading and peeling. Discussions with stain manufacturers led to a recommendation that the concrete walls should not be stained for at least a year after curing.

The major maintenance problem in dealing with Michigan noise barriers is the presence of graffiti on the noise walls. The general approach to reducing this problem has been to make the surface of concrete walls very rough to discourage potential vandals. Coated surfaces that provide easy cleaning are used on steel barriers to address the graffiti problem.

Colorado recommends that barriers should not be painted if at all possible to eliminate the necessity for maintenance of these surfaces. If color is desired, the staff recommends that the color be an integral part of the material or that a baked enamel finish be used. Both Colorado and FHWA have expressed concern about the shininess of aluminum panels used for noise barriers on bridges. These panels cause some glare and they stand out much more than the normal wooden wall.

Connecticut also reports some concern over a glare problem due to reflection of the sun off plastic panels. Headlight glare off metal walls has been reported in several states.

While Connecticut has used a number of precast concrete barriers in the past, it is moving away from that material for three reasons: (1) the extra initial cost compared to timber installations, (2) the severe problems with graffiti on concrete walls, and (3) the replacement costs from vehicle hits, (both a wood wall and a concrete panel wall were crashed into by vehicles; the repair costs for the wood wall were less than for the concrete.) Connecticut paints over graffiti on wood walls, although some trouble in matching the paint has been reported.

Arizona reported little graffiti on the older noise barriers. More graffiti have been reported on the newer ones, requiring sandblasting or painting to cover them. Graffiti in California also required either sandblasting or painting. In some cases, ivy planted on the homeowner's side has grown to cover the wall surface. Massachusetts also sees allowing vegetation to cover the barriers as a possible solution. The graffiti problem in Florida has not been as great as was originally anticipated; one approach used by FDOT is to plant vegetation and to provide landscaping treatments to make it difficult to put graffiti on the walls. Virginia also mentions graffiti as a problem, but Maryland and New Jersey report that their rough-textured surfaces tend to be less prone to graffiti.

STOCKPILING REPLACEMENT MATERIALS

Some states have concerns about replacing materials when noise barrier panels or sections are damaged. For example, Connecticut has stockpiled replacement panels for its plastic barriers for approximately two years at a maintenance yard. There has been no problem in deterioration of the sound insulation bags inside the panels or the green coloring of the panels themselves. In Virginia, there have been at least one or two cases of damage to steel barriers from accident. However, no parts have been stockpiled as replacements, and as a result, six months were required in one case to get replacement panels. While boards and posts for Minnesota's walls have been replaced from time to time due to accidents or other situations, there has been no stockpiling of materials. Replacement boards for wood panels are bought locally. Because of the relatively few problems and the fact that it uses a standard design, Oregon does not maintain material stockpiles for replacements.

Caltrans notes that the city of Huntington Beach will be stockpiling extra panels for replacements for the polycarbonate wall in that city.

AREA BETWEEN RIGHT-OF-WAY LINE AND BARRIER

Another maintenance problem involves the area behind the wall. Typically, an area between the ROW line or the property line and the wall is provided to allow maintenance at the back of the wall. However, this area is difficult to maintain. In Michigan, it has been suggested by the maintenance departments that the walls be put at the ROW as a solution to this problem. There has been a reluctance to do this because of other problems that would arise, such as the need for easements.

In Massachusetts, chain link fences are built at the ROW. Noise barriers are not built at the ROW but some distance away, creating a gap between the chain link fence and the barrier. Typically, this gap provides an area for uncontrolled vegetation growth which results in a maintenance problem. Noise barriers also act as trash collectors if the right-of-way fence is left in place. They may also cut off access to portions of the right-of-way.

The area between the back of a noise barrier and the ROW line has been a continual maintenance issue. In Florida, Maryland, New Jersey, and Minnesota, the solution to this problem has been to allow the property owners free use of the land between their property and the barrier in exchange for their maintaining the land. This saves the state maintenance money while providing increased yard area for the property owners.

In Arizona, one other concern is the maintenance of landscaping. For those barriers with landscaping, flora with low water consumption and low maintenance characteristics are used. Additionally, drip irrigation systems have been installed after the roads have been built and the barriers installed. In Washington, the landscape architects have identified the rugosa rose as a low maintenance planting. On some projects, WSDOT has installed an irrigation sprinkler system to provide adequate moisture to the plantings. They estimate approximately three years for landscaping to become established.

SNOW DAMAGE

Noise barriers have posed some maintenance problems regarding snow. As mentioned earlier, Colorado notes that drifting snow has caused problems at some barriers. Colorado has also found that snow plowed against the aluminum panel walls on bridges can deform the aluminum, causing the holes to stretch and the connections to fail.

In Ontario, several metal walls located close to the roadway had severe denting and bending in the lower parts of the panels due to snow being plowed and stored against them.

MAINTENANCE COSTS

Very limited data on maintenance costs were available from the state highway agencies.

The only systematic cost review reported was done in Colorado, where wooden barriers cause a considerable expenditure of resources to maintain their effectiveness. A breakdown of the repair costs by year of more than 118,000 l.f. of wooden noise barriers in Colorado District VI showed the average cost per year to maintain was $19,765 (*44*); the average cost in 1989 was $15.08/l.f. As the wood ages and cracks, there is more damage due to wind each year. Approximately 45 percent of total damages over the past five years has been reported as resulting from vehicle accidents.

Caltrans has estimated the maintenance cost for the polycarbonate wall in Huntington Beach at approximately $1,500 per year to wash the glass (once per month) using a water truck and nozzle with de-ionized water that should drip clear for drying. The city will maintain the wall.

CHAPTER SIX

NOISE BARRIERS OTHER THAN CONVENTIONAL WALLS ON STATE RIGHT-OF-WAY

While vertical, opaque, sound-reflecting barriers owned by the state highway agency and located on its ROW are by far the most common traffic noise abatement measure used by state highway agencies (*5*), there are many other techniques of proven and potential value. This chapter discusses state highway agency experiences in these other areas.

PATTERNS OF USAGE

As part of the WSDOT survey (*1*), the state highway agencies were presented with a list of twenty noise abatement measures. They were asked to indicate those they have used, would consider using, or would not use. Table 9 lists these abatement measures with the numbers of states in each category. Not included in the list were conventional sound-reflecting barriers. Data from FHWA indicate that 37 states have installed sound-reflecting barriers (*7*).

The most commonly used alternative abatement strategies were to depress the highway, shift the highway alignment, insulate public facilities, use sound-absorbing barriers, and prohibit heavy trucks from the facility. The number of respondents having used the last three measures was surprisingly high. It was also interesting to see that 16 respondents had used noise barriers on non-limited access facilities, which are traditionally viewed as difficult to abate with barriers because of the need to provide local access.

Another way of looking at the data is to examine patterns of usage by individual states. Thirteen states and one Canadian province indicated that they have tried five or more of the listed alternative strategies. Those that have tried the most strategies are (in alphabetical order) Alaska, Arizona, California, Minnesota, New Jersey, Oregon, Pennsylvania, Virginia, Washington, and the province of Ontario. In a second tier in terms of number of strategies tried are: Illinois, Michigan, New York, and Utah.

On the other end of the spectrum, four states—Montana, North Dakota, South Dakota, and Wyoming—specifically noted that they have implemented no traffic noise abatement measures. Six states indicated that they have used none of the listed measures (which does not preclude use of sound-reflecting barriers): Idaho, Mississippi, Missouri, South Carolina, and West Virginia. (Idaho did note that, historically, its primary abatement measure has been displacement of impacted residences and commercial establishments through right-of-way acquisition. It has recommended local land use control measures and traffic management techniques to abate projected noise impacts, but generally the low population and traffic levels preclude significant noise impacts.)

Respondents indicating use of only one of the listed strategies (again, excluding use of sound-reflecting barriers) includes: Alabama (depressed highway), Arkansas (shift alignment), Hawaii (facility insulation), Indiana (facility insulation), Kentucky (public facility insulation), Louisiana (sound-absorbing barriers), Nevada (tilted barriers), New Hampshire (earth berms), Puerto Rico (depressed highway), and Vermont (shifted alignment).

It was also interesting to examine what measures states would or would not consider using. At least sixty percent of the respondents indicated they would consider:

- Sound-absorbing barriers, tilted barriers, or other innovative materials or designs;
- Shifting the highway alignment;
- Providing buffer zones;
- Choosing alternative corridors or modes;
- Using pavement surface treatments; and
- Allowing privately funded barriers to be constructed on state ROW.

Additionally, 40 to 60 percent of the respondents would consider using translucent/transparent barriers, barriers on non-limited access roads, depressing the highway, insulating public facilities, or traffic management techniques to reduce speed limits or truck use.

These responses show a willingness to try new and different measures to control the noise problem. Of interest is the high percentage that would consider allowing privately funded barriers to be installed on the state ROW. In contrast to that, however, is a general unwillingness to install barriers off the ROW, which, given the physics of noise attenuation, can severely limit an agency's options in successfully reducing traffic noise in the communities.

A very interesting finding is that a large number of states would consider pavement surface treatment, given that only three have indicated that they have already done so. Many states may be taking a wait-and-see attitude until more results from U.S. and European efforts are known, with the hope that these efforts will be successful.

Many states indicate a willingness to try traffic management strategies, although few have actually done so (except for prohibiting heavy trucks). An openness to consider these strategies seems to be restrained by the primary goals of most highway projects (i.e., to improve flow and reduce congestion).

Of those measures that the states would not consider using, the most commonly cited were decking over the highway, canceling the highway project, noise-insulating private facilities, installing barriers off the state ROW, and prohibiting all (not just heavy) trucks from a facility. Cost, other project objectives, and concern over legal issues may be reasons for these strategies being cited so often.

In summary, the data show a willingness by highway agencies to try new and different ideas that is often not substantiated by prior action. This willingness is tempered by a lack of information of the actual benefits and costs of these strategies. A general sense was that hard data on the effectiveness of these strategies are not typically collected nor readily available.

TABLE 9
USE OF NOISE ABATEMENT MEASURES BY STATE HIGHWAY AGENCIES* (*1*)

Abatement Measure	Have Used	Would Consider Using	Will Not Use
Sound-absorbing barriers	15	32	4
Tilted barriers	5	33	11
Translucent/transparent barriers	4	23	21
Other innovative or low cost materials or designs	7	31	0
Barriers off state ROW	6	18	24
Privately funded barrier on state ROW	6	32	9
Barrier on non-limited access facility	16	22	12
Deck (lid) over highway	6	9	30
Depressed highway	24	24	4
Shifted highway alignment	17	32	0
Provided buffer zones	4	30	10
Chose alternative corridor/mode	6	30	8
Pavement surface treatment	4	30	13
Noise insulation:			
1. Public facility	18	22	9
2. Private facility	7	13	27
Traffic management:			
1. Prohibit heavy trucks	10	24	14
2. Prohibit all trucks	2	21	24
3. Reduce truck hours	1	29	17
4. Reduce speed limit	2	27	18

* Including Puerto Rico and Province of Ontario, Canada
Note: Two agencies indicated that they have cancelled projects due to noise issues, 11 said that they would consider doing so, while 27 said they would not do so.

EXAMPLES OF UNCONVENTIONAL NOISE BARRIERS

FHWA has compiled a fairly complete list of projects featuring "unusual" noise barriers and other non-barrier abatement measures implemented through the end of 1988 (*45*). In addition, a great deal of information was gathered during the WSDOT study (*1*). Interesting examples are presented in the next several subsections of this chapter.

Sound-Absorbing Barriers

The majority of noise barriers built in the United States have hard, sound-reflecting surfaces. Barriers that absorb sound are less frequent and are thus described here. Fourteen states report using sound-absorbing barriers (although, in at least two instances, the respondents were referring to a sound-reflecting barrier or an earth berm). The typical application of sound-absorbing walls would be in a situation where reflections off other single or parallel noise barriers were of concern.

Several of the reported uses are of interest. For example, California retrofitted one noise barrier in a parallel barrier situation with sound-absorbing panels because of complaints about increased noise levels from citizens living well over a thousand feet away (*25*). A study of measurements and predictions before and after the installation showed that increases in noise levels due to the reflections was not a problem to begin with, and as a result, the absorbing barriers did little to provide additional noise reduction.

Connecticut used perforated plastic panels with rock mineral wool filler in a parallel barrier situation on an overpass in East Hartford. Inadequate bracing at the bottom center of the panels led to some sagging that had to be corrected after installation was completed. The state paid an extremely high price ($37/ft^2) for these barriers compared to a typical value of $8/ft^2 for reflective walls, partially because this was the only product that it deemed suitable when the solution was needed. Louisiana has used the same product on its Natchez-Vidalia bridge project. Connecticut used sound absorbing blankets as part of temporary construction noise barriers in the New Haven area.

Steel panels with a perforated face and four inches of rockwool filler were used by Illinois DOT on I–255 in Collinsville and Centerville. Some incidence of peeling of the coating on the steel has been reported after two years in place.

New Jersey has used a foamed concrete finish on a precast concrete noise barrier on its I–78 project in Watchung. Some early questions had been raised about the durability of this finish, and performance is being monitored. Maryland has also used this product on an eight-lane section of I–695, where the walls are separated by a distance of 150 ft. The cost was approximately $200,000 for a section 480 ft by 20 ft high. Some noise level measurements have been made recently, but the data have not yet been analyzed. Maryland reports that the surface seems to "gouge easily," with the project beginning to weather already since its installation in 1987.

Pennsylvania has used a sound-absorbing product in several areas of the I–78 project in Allentown and in the I–476 project in Philadelphia. The product is a mineralized wood shavings board with a concrete backing that has been used extensively for noise barriers in Europe and Ontario for nearly 20 years. The I–78 project included use of this product on parallel barriers on a bridge high over a scenic public park and in a bench-cut section with a noise barrier opposite a retaining wall. Colorado has designed but not yet constructed a series of three parallel barriers on I–70 at the interchange with I–25. The middle of the three barriers will be sound-absorbing. Reported estimates of costs are $85/l.f. and $120/l.f. for 7.5-ft high walls.

A slotted concrete block was used on I-440 in Nashville by the Tennessee DOT. (*46*) This product was chosen to give a similar appearance to the sound-reflecting barriers elsewhere on the project. A field evaluation of the I–440 barriers has been conducted (*34*). Data at the parallel sound-absorbing site showed levels to be 2 to 3 dB lower than at an adjacent parallel reflective barrier site. The microphones were 25 ft behind the wall at elevations equal to those of the roadway surface (the road was on fill). The barriers were 8 to 9 ft high and separated by a distance of 140 ft. The sound-absorbing blocks had a noise reduction coefficient (NRC) of 0.65. TDOT is using sound-absorbing barriers on the Nonconnah Parkway in Memphis.

Three other states that have used sound-absorbing barriers include Utah (70th Street South), Virginia (Route 164, Portsmouth), and Pennsylvania (Vine Street, Philadelphia). In contrast, Michigan designers believe the distance between barriers in their state make sound-absorbing systems unnecessary. In one case, however, a 2 dB degradation was predicted. This effect was accounted for by increasing the heights of the parallel walls.

In 1984, FHWA commissioned a detailed study of sound-absorbing barriers (*47*). The study examined the literature and available proprietary systems and products. It also presented 29 examples of sound-absorbing projects in North America, Europe, and Japan, and included a case study of the Tennessee DOT I–440 project.

Tilted Barriers

Use of tilted noise barriers (as an alternative to sound-absorbing barriers to prevent reflections back across a roadway by deflecting the sound upward) has been reported by five states. For example, Nevada used 22-gauge formed metal panels on a concrete safety shape barrier on U.S. 95 in Las Vegas. The 11-ft high panels are tilted outward 10° for the 4,000-ft length of the project. Installed cost was approximately $6/ft^2.

Also, New Jersey DOT has used tilted barriers, in addition to sound-absorbing barriers, on several sections of its I–78 project, as well as on Route 24 in Morris County. The designs are concrete post and panel, with the posts installed at an angle of 10° off the vertical. The Route 24 section is 1,000 feet long and the I–78 section extends for 2,600 feet. In both cases, tilted walls are on both sides of the highway. New Jersey also installed 4,100 ft of walls tilted at 6° on Route 17 in Bergen County.

Washington has used walls tilted at about 6° on its I–90 project in Seattle (both retaining walls and noise barrier extensions above them), as shown in Figure 12, and on SR-14 in Kennewick. Arizona also reports use of tilted walls on the Pima Freeway. On the Vine Street project in Philadelphia, Pennsylvania used sloped sides to retaining walls (5° angle) in a depressed section, but reports no freestanding tilted barriers yet.

Translucent/Transparent Barriers

Arizona, California, Massachusetts, and Maryland reported use of translucent or transparent noise barriers. The Arizona project,

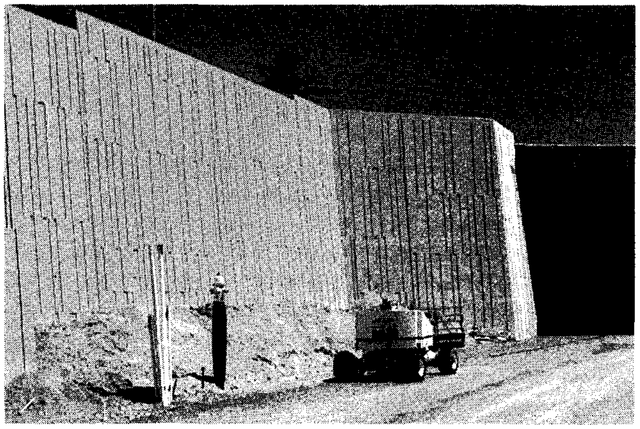

FIGURE 12 Tilted walls on I–90 in Washington.

constructed in the early 1970s, consisted of a series of vertical tubes of triangular cross-section with slots cut in them to act as resonating chambers for certain sound frequencies, while allowing drivers to see through the spaces between them. This "kinematic sound screen" was reported by the state as only marginally effective and has not been used in any other applications.

Caltrans installed a transparent barrier made of polycarbonate panels in the Huntington Beach area of southern California. This barrier was requested by the State Coastal Commission so that the beach parking area could be seen from the road and that viewsheds from across the road would be maintained. The barrier is located along a road with few trucks and, as a result, is only 7 ft high, consisting of 4- x 8-ft polycarbonate panels turned sideways atop a 3-ft high block wall. Redwood pilasters are used to support the polycarbonate panels along the 2,500 ft length of the wall. A sidewalk is located between the edge of the pavement and the wall, which is built in a trapezoidal fashion to provide an interesting design. To accommodate the wind loads, ½-in. thick panels were used. The project is off of the state ROW and a temporary construction easement was obtained, with the project ultimately being turned over to the city or private owners.

At a border patrol station in San Diego, Caltrans has installed a tempered glass wall where noise from accelerating trucks disturbed office workers, but where an unimpeded view was necessary. The wall is set back from the road in this instance so that cleaning is not viewed as a major requirement.

Maryland also used polycarbonate panels as an experiment on I–95 at Caton Avenue along the edge of a ramp protecting a school from traffic noise. The ¼-in. panels were installed between steel H-beams with clips. The posts were set on 7-ft, 6-in. centers with 10-ft high panels. Total project length was 435 ft. The state reports many maintenance concerns. No provisions were made for cleaning and some graffiti have appeared. There has apparently also been some damage from bullets. The panels, which were initially smoke-gray in tint, have now become clouded through ultraviolet yellowing so that they are no longer transparent.

Massachusetts used transparent barriers on the I–93 project in Somerville, but reports that it will not use such a treatment again because of durability problems with the polycarbonate panels (cracks in panel corners in less than two years).

Ontario is conducting an experiment on the weathering and visibility degradation of 12 one-foot square samples of polycarbonate, laminated tempered glass and laminated annealed glass on a test section of barrier in Toronto. An excellent paper on the experiment and topics such as safety, design, flammability, and cost was recently published (*48*).

Overseas, both the French and the Japanese have used transparent and translucent walls. The French have used both glass and polycarbonate panels in several installations in Paris and Lyon. Barriers close to the road edge get very dirty and require periodic cleaning (several times per year). However, in situations where the barriers are closer to the homes and away from the roads, a mixture of transparent and opaque materials has led to visually interesting solutions. Relevant sections of a French report on the subject have been translated into English (*49*). The Japanese have used a number of transparent and translucent solutions for many of their barriers. Generally these barriers are at the edge of pavement and are used to provide some visual relief for the driver who is in an environment of nearly continuous walls in the urban areas. The barriers, however, are subject to the same road grime problems as elsewhere. Another transparent material that has been used in Europe is acrylic sheet, a thermoplastic product. One manufacturer notes in its literature that its product is stabilized against ultraviolet radiation and is weather resistant, chemical resistant, and lightweight. However, acrylics, like other plastics, are combustible and could break if dropped onto a hard base during installation or if struck by a vehicle.

Innovative or Low-Cost Materials or Designs

Eleven agencies reported using innovative or low-cost materials or designs for noise barriers.

Pennsylvania installed a lightweight composite material noise barrier system on I–78 in Allentown in 1989 on several bridges, because it lightens structural load compared to concrete. The product cost approximately $\$20/ft^2$ delivered and approximately $\$40/ft^2$ installed. Pennsylvania reports that the product would be used on non-bridge barriers if it can compete in cost with other methods. Connecticut has also used the product as a construction noise control measure on a bridge on Route 104 in Stamford.

Pennsylvania has used a system of decreasing-width, stacked concrete cribbing filled with dirt and planted to give the appearance of an earth berm with very steep sides. An 800-ft long, 16-ft high experimental section has been installed on I–476. The cost was reported at $\$50/ft^2$, and the state notes that the establishment of the desired vegetation has been slow. The product was invented in Switzerland, and is used there extensively for noise barriers and retaining walls. It is expensive and has raised questions with some state highway agencies regarding safety and maintenance of the landscaping.

Iowa has been concerned with minimizing winter shadows cast onto the roadway by a barrier. One idea, as yet untried, was to use some sort of "movable" wall whereby the top portion of the wall could be removed during the winter months to allow the sun to shine on the roadway. The resultant seasonal loss of noise reduction would conceivably be acceptable in the winter when outdoor yards are not being used as much. Suggested ways for removing the barriers included hinged sections (for wood and/or possibly steel walls) or actually completely removing panels between the supports. Maintenance and the need for twice-a-year servicing should be considered before such a strategy would be deemed practical.

As a potential solution in parallel barrier situations, structural engineers in Utah have considered a design of a solid wall with a louvered or clapboard surface (angled at 10°) to reflect sound upward instead of back across the highway. Such a concept has been used on at least one major project in Germany, with sound-absorbing material behind the louvered panels (*50*).

California has studied the use of compost (derived from sewer sludge) and co-compost (derived from sewer sludge and refuse) as potential products for noise barriers (*51*). They recommended against such use "due to uncertainty in the concentration of biological and chemical contaminants."

Illinois has been approached by several manufacturers interested in recycled plastic walls. Iowa has expressed interest in any low-cost material, especially recycled plastic panels.

Ontario has had contact from several companies regarding use of recycled tires as a base material for noise barriers. The tires are chopped up into $\frac{1}{16}$-in. to $\frac{1}{4}$-in. particles and formed into panels with a binder. Another configuration uses $\frac{1}{64}$-in. to $\frac{1}{16}$-in. crumb, which may prove to give a more consistent product. Ontario has been conducting tests on the panels for a variety of properties. Key concerns include flammability and smoke. Flammability does not appear critical based on initial tests, being about the same as pine wood. Smoke output during burning is high, but one company is developing a smoke retardant. The potential toxicity of the product when burning is also a concern, but has not yet been tested. The durability of the product appears to be excellent, and no leachate problems were found using standard tests. Reliable sound absorption tests have not yet been made, so no conclusions can yet be drawn on the sound absorption effectiveness. The expected cost would be greater than the currently used sound-absorbing product, which Ontario routinely installs at a cost of $12/ft^2 (Canadian). Structural details have yet to be seriously addressed until all of the other test results are in. There are concerns about the lack of stiffness or rigidity of the panels, which would be inserted between H-beams.

New Jersey, in conjunction with FHWA, is considering alternative designs to reduce structural costs, especially regarding wind loadings. In contrast, Texas designs its coastal-area barriers to withstand hurricane force winds, at a high cost. Texas also builds noise barriers out of concrete in an effort to minimize maintenance. Washington has used a plain plywood wall in one location, sacrificing appearance to reduce costs. Ohio reports that a product consisting of interlocking ribbed plastic sheets, which can be driven into the ground like sheet piling, has been approved for bidding but has not yet been used on any projects.

Delaware, Massachusetts, New Hampshire, and Maine specifically noted the use of earth berms as a low-cost material solution. Earth berms have been used by many other states quite successfully and are often an excellent solution when the needed right-of-way and specific materials are available.

Barriers Off State ROW

In some cases, the best location for a noise barrier, from an acoustical effectiveness point of view, is off the state's property. This is especially true in a case where the houses are located above the roadway on a hill or cut slope. Arizona had such a situation on its I–17 project, where the property owners became involved. As a result, a temporary easement was obtained for construction and the property owners are responsible for maintenance. Wisconsin has also worked with private subdivisions in the Madison area on barriers off the right-of-way.

Along Route 52 in San Diego, where houses were built on a bluff, the California state ROW extended only halfway up the slope. In consultation with the homeowners, a point-of-entry permit was obtained to construct the sound wall. During construction, the liability was the responsibility of the contractor; subsequently, the landowners were in charge of maintenance.

In Georgia, a demonstration project on I–285 in Avondale Estates was partially funded by a barrier manufacturer. The cost to protect an impacted property exceeded the Georgia DOT guideline of $12,000 per residence. The property owner approached the manufacturer who agreed to provide the barrier at the $12,000 cost as a demonstration. Georgia agreed to installation but assumed no responsibility for maintenance, necessitating location of the barrier off the ROW.

Utah has worked with a homeowners' association along I–215 to split the $35,000 cost of a 614-ft long, 8-ft high barrier. The project is located atop a 30-ft cut where the state had not originally planned to construct a barrier. After a reevaluation of the predicted noise levels using the then-new STAMINA 2.0 model, the state agreed to protect some of the homes. The state paid for the length of the wall needed to protect the residences that it determined to be impacted, while the homeowners paid for the rest of the cost to protect other homes in the neighborhood. The homeowners are now in charge of maintenance for the masonry block wall.

Oregon has had two cases where homeowners came to the state requesting an installation off the ROW. In the first case, the request was accommodated with no problems. In the second case, ten percent of the homeowners did not want the wall and the state had problems getting easements. In addition, overhead power lines impeded installation. An agreement was finally reached with an abutting railroad to put the wall on railroad property between the highway and the residences.

Barriers on Non-Limited Access Facility

Typically, noise barriers are used on limited access facilities where gaps for driveway access or cross roads are not needed. However, 16 states have used barriers in situations where access is not limited. Such use is common in Arizona in many cities where a standard 6-ft high masonry wall has been used. There were no studies on their effectiveness, and no legal or safety concerns were reported. At the corners of the barriers, the walls typically step down in size.

In 1989, a barrier was constructed in the Denver area by Colorado to protect apartments along an arterial. The apartment building was oriented so that there was no need for multiple access points through the wall.

In Florida, a project on an arterial involved widening of the existing roadway from two lanes to four or six lanes, plus ROW acquisition. Even though the barriers were constructed on the ROW line, legal agreements were drawn up to provide free construction easements and permanent maintenance easements. On both this and a second project, the subdivisions had internal circulation roadways that exited to other streets. For the first project (Palm Beach County), the barrier ends were extended far enough to minimize flanking around the barrier. On the second project (Pinellas County), a property owner found it to be in his interest to donate a portion of his property to provide a 45° wrap on the barrier end to provide adequate sight distance in accordance with local specifications. On both projects, sight distance considerations were minimized due to the presence of signalized intersections at the barrier ends. In addition, signs were installed to prevent right-turn-on-red, which further reduced the sight distance problem.

Pennsylvania had a similar case on Route 512 in Allentown, where the road was expanded from two to five lanes. There was no direct driveway access, and no safety problems were encountered. The project was funded with 85 percent federal money.

In Jacksonville, North Carolina, a state highway widening project on Western Boulevard was under way at the same time that a major residential development was being constructed. A noise barrier was designed by the state and landscaped by the developer to look like a simple property line fence. Also, part of the barrier was built off of the ROW, which had to be worked out with the developer in advance.

Privately Funded Barriers on State ROW

In some situations, homeowners or developers may wish to install a barrier at their own cost to protect their properties. Often, however, the best location is on the state ROW.

In Fairfield, California, a developer along I–80 obtained an encroachment permit for construction of a wall for his development, and had the wall designed to meet state standards. The state now maintains the wall.

In Ohio, a community in Moraine along I–75 desired a noise barrier and hired a consultant to produce the design. ODOT reviewed and approved the design and a contract was written to hold the state harmless and to make maintenance the responsibility of the community. From the state's perspective, the process was quite fast because it only had to approve the plans while the community did everything else. Other instances include: Illinois, where local agencies have funded some extensions of barriers on IDOT right-of-way; in Michigan, on I–696 near Farmington Road; and in Washington, on SR 520, SR 14, I–90 (Northbend).

Colorado had some concern regarding liability issues and design standards when a homeowners association had asked a district office about constructing a barrier on the ROW. On the attorney general's recommendation, the CDOT district office denied the request, setting a precedent for the state.

Pennsylvania is developing a policy on this issue. Any design would have to meet state standards, but the legal or maintenance issues have not yet been addressed. While such a policy would be useful in a Type II program, there is some concern that the policy could be viewed as exclusionary.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The following are drawn from the surveys and information developed for this synthesis.

CONCLUSIONS

Three key factors emerge for a state to be able to successfully mitigate transportation noise problems. There must be:

• Public support for traffic noise mitigation;
• Legislative response, including laws conducive to noise mitigation; and
• Administrative commitment to implementing the laws.

Even given the above, two other factors must be kept in mind:

• Noise abatement must compete with other areas of environmental protection that the public, the legislature and administration also consider to be important (and in some cases, more important); and
• Demands, laws, choices, and policies are useless without the resources to bring about action.

A number of conclusions can be drawn:

• There is a significant need in the United States for Type I noise barriers for planned new highways and reconstruction of existing highways. There is also an extremely large demand in some states for noise barriers on existing highways (both federal-aid and non-federal systems) that will probably only increase in the future.
• There is a need for legislation to provide funding sources for Type II programs. More flexibility in the use of federal funds would help. Policies regarding matching funds from local governments or affected homeowners warrant consideration. The Wisconsin idea of a local match for barrier costs exceeding its criteria and the local pay-back provision in the California Type II program may serve as useful models. Having a good prioritization system for Type II projects is essential.
• For Type II projects, it is a good idea for state highway agencies to call for some type of action from local government, such as a municipal resolution supporting the project and development of a land use compatibility program for other existing highway situations.
• Nationwide, there is variability in the interpretation of the FHWA noise standards in terms of "substantial" increases in noise levels, noise barrier design goals and interpretation of the noise abatement criteria.
• There is a willingness on the part of state highway agencies to consider new noise abatement measures, but there has not been a great deal of actual use of these measures. The state highway agencies need more information on the costs and benefits of all noise abatement measures. There appears to be inadequate information on the consequences and legal aspects of several abatement measures, such as locating state barriers off the right-of-way or private barriers on the right-of-way.
• In terms of specific strategies, not all sound-absorbing barrier systems currently being used seem suitable for the highway environment. More study of the actual degradation in noise barrier insertion loss between parallel barriers is needed to better define those situations where special treatment is needed. Tilted noise barriers appear to be a feasible alternative to adding sound-absorbing material in some cases; however, there are limited field data on the effectiveness of this strategy other than at controlled test sites, and data for in-situ traffic situations are needed.
• The use of transparent noise barriers at the roadside edge has resulted in problems due to accumulation of dirt. However, a transparent barrier in this location could help with winter shadows in states where snow is a problem. Transparent barriers seem to be a more viable alternative when the barrier location is near the right-of-way line. More knowledge of maintenance, durability, and prevention of ultraviolet yellowing is needed. In many states, problems have occurred with the durability of in-place wooden barriers.
• There is potential for using recycled materials such as plastic and tire crumb rubber for noise barriers, although more research, development and testing are needed. The use of the "planted" noise barrier system has potential for good aesthetic treatment but costs are much higher than conventional barriers. Some maintenance and landscaping questions also remain.
• The use of barriers on unlimited access facilities is feasible where local access and safety are not issues, and where barriers can extend down side streets for proper end protection.
• The use of private funding for noise barriers on the state right-of-way can be a very workable strategy. However, it is important that these barriers be designed to state standards, both in terms of physical and acoustical properties. Those states unwilling to consider placing their noise barriers off of a state right-of-way may be missing a good opportunity for cost-effective noise abatement.
• State highway agency noise specialists have identified many research needs for traffic noise analysis and abatement. The pooled-fund concept works well to allow states to make more efficient use of limited resources. State highway agencies plan to play an active role in helping FHWA shape an expanded environmental research agenda. Among the needs are better ways to define when multiple reflection effects between parallel noise barriers degrade barrier performance, and improved prediction modeling algorithms and tools. More evaluation of noise barrier field performance is also needed using the American National Standard as a guide (*28*).

RECOMMENDATIONS

The following recommendations with respect to noise barriers are offered:

• Develop specifications for sound-absorbing barriers to avoid previous problems with certain materials and systems; further study of tilted noise barriers as an alternative to sound-absorbing barriers is warranted;

• Carefully examine wooden noise barrier specifications with respect to durability;

• Consider the use of transparent barriers in situations where the view is important, but be cognizant of maintenance problems when locating these barriers along the roadway shoulder;

• Study the costs and benefits of the various noise barrier alternatives on a life-cycle cost basis; initial capital costs alone are insufficient to fully evaluate a potential measure;

• Investigate relocatable barrier systems to avoid problems when existing roads with barriers are widened;

• Develop minimum noise barrier materials and systems standards for developer-installed barriers along transportation facilities. This includes a process for review and approval of noise barrier materials and systems and noise barrier plans to influence or provide for consistency (or sense of appropriateness) of developer-installed noise mitigation measures, especially on the highway side of the measures;

• Consider placing privately funded noise barriers on the state right-of-way with provision for the requestor to pay the state all costs to review and approve the acoustical, structural, and aesthetic design, and to inspect the construction;

• Develop an agreement for a local government to sign that either endorses or precludes the installation of retrofit noise barriers in its jurisdiction; consider agreements for the affected homeowners to sign, using the Connecticut DOT model as an example;

• Develop policies and investigate legal aspects for installing state noise barriers off the right-of-way and for private funding contributions to Type II barriers where such a contribution would move the project up on the state's priority list;

• Take a lead role as a technical resource to cities, counties, and their developers regarding noise mitigation; help with the preparation of instructional materials and courses to assist in noise compatibility plans;

• Develop aesthetic guidelines for the design of noise barriers and effectively address visual impacts of the resident and motorist, architectural details and landscaping so that barriers fit into the community environment and establish continuity throughout the highway corridor.

Duties and responsibilities of the state highway agencies regarding noise mitigation are already quite extensive, and will certainly continue to grow in the future. Adequate funding is required for state highway agencies to follow through on their commitments toward noise abatement. A separate source of funding is needed. Further, some of the most effective noise mitigation measures, such as source control and land use planning, are out of the direct control of an agency, but require its guidance and assistance to be successful.

CLOSING REMARKS

This synthesis began by defining the problem of traffic noise in the words of a legislator from the state of Washington. It is appropriate to close by looking at how WSDOT is responding to the problem because its responses are indicative of the challenges faced by many state highway agencies. WSDOT has embarked on a process called *Choices in Transportation for Washington's Environment.* A briefing document sums up the problem and espouses a philosophy for the future:

> As Washington's population continues to grow, greater demands would be placed on schools, housing, jobs, open spaces, air, water, and transportation. The number of vehicles registered in this state continues to grow at almost twice the rate of the population.
>
> As more is learned about transportation's effects on the environment, additional policies and procedures will be needed to protect and enhance our state's valuable resources. Washington citizens concerned about the environment will continue to have significant influence on transportation decisions. Partnerships among federal, state and local agencies will also help to make the right choices in transportation for Washington's environment. (*52*)

The document reports that WSDOT will encourage local agencies to adopt noise compatible land use plans for undeveloped areas near highways, and will continue to install noise barriers to protect noise sensitive land uses along existing highways.

The Choices process is an outgrowth from the *1991 Transportation Policy Plan* for Washington state (*53*), which defines Environmental Protection and Energy Conservation as a major emphasis area and notes,

> Transportation will protect the natural environment and improve the built environment by conserving scarce resources; reducing pollutants, and other waste by-products from transportation systems; avoiding the disruption and degradation of historically and environmentally significant locations; and by including effective urban design in transportation facilities.

The Policy Plan recommends that WSDOT should "minimize noise impacts from transportation systems and facilities" and delineates four action strategies:

• Require that all new transportation system facilities and structures be evaluated for adverse noise impacts; minimize adverse noise impacts if reasonable and feasible;

• Require that local land use plans identify excessive noise impacts from noise generators including transportation facilities; identify locations of needed noise mitigation measures; and avoid future excessive noise impacts by establishing a pattern of land uses and building codes that minimize the exposure of community residents to excessive noise levels;

• Develop a state transportation program to mitigate excessive noise impacts from transportation facilities as identified in local land use plans; this program will be available to local governments which have adopted land use controls that will avoid future excessive noise impacts; and

• Support research into development of alternative transportation modes that create minimal operational noise impacts within and adjacent to transportation corridors.

Successful implementation of noise abatement measures, including vehicle noise control and land use noise compatibility programs for cities and counties, will require proper staffing, funding, and upper management support within all states to get the job done. Clearly, the task is not small. But just as clearly, the national problem of transportation noise impacts will not disappear on its own.

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APPENDIX A

SURVEY QUESTIONNAIRE

NCHRP SYNTHESIS ON TRAFFIC NOISE BARRIER DESIGN CONSTRUCTION AND MAINTENANCE
TELEPHONE INTERVIEW FORM FOR STATE HIGHWAY AGENCIES

DESIGN

1. *What design specifications do you use?*
2. *Have you evaluated AASHTO Noise Barrier Specs? What do you think of them?*
3. *Do you use the AASHTO Noise Barrier Specs? If not, why not?*
4. *Have you changed any design specs based on experience? Describe.*
5. *How do you decide what systems/materials to put in plans, specifications and estimates (PS&E)?*
6. *Do you use different systems for different situations (e.g., edge of shoulder, top of cut, ROW line, bridges)?*
7. *Do you use a standard material/system for all projects? Describe.*
8. *Do you ever include alternatives in the bid package? Describe.*
9. *Do you allow contractors to bid unspecified alternatives? Describe.*
10. *What proprietary products have you specified? How? Under what circumstances?*
11. *What is your process for reviewing/approving proposed materials/systems?*
12. *What is the most commonly used material? Why? Most commonly used system? Why?*
13. *Do you take special consideration on bridges? Describe (special material/system/design criteria, etc.)*
14. *What materials will you not use? Why?*
15. *What systems will you not use? (generic, such as "wood post and panel" or proprietary)?*
16. *Describe special details for:*

    a. *Fire hose access*
    b. *Maintenance access (doors, gates, overlaps)*
    c. *Attachment to bridges*
    d. *Provision of crash attenuation (end and side)*
    e. *Light poles, sign poles*
    f. *Drainage, flood control*
    g. *Foundations*

CONSTRUCTION

1. *What is your maximum, minimum, and average cost/square foot for barrier design, materials and installation? Break out % of cost for Type I and Type II projects.*

a. Engineering	*e. Drainage*
b. Materials	*f. Landscaping*
c. Foundation	*g. Traffic control*
d. Labor	*h. Crash protection*

2. *Describe any construction problems and related solutions (materials, installation, drainage, foundations, safety, contractor experience, etc.)*

3. *Describe any special training for state barrier construction inspectors.*

4. *Do you provide barrier construction guidelines or have standard practices?*

5. *Describe unsolved construction problems or research needs.*

6. *Have you changed any construction practices based on past experiences? Describe.*

7. *Describe largest complaint from (1) DOT construction personnel and (2) contractors.*

MAINTENANCE

1. *Describe typical maintenance practices or actions for barriers and related landscaping.*

2. *Is there a maintenance "program"? Please send any written guidelines.*

3. *Describe typical, special and unique maintenance problems and solutions (barrier surface, material integrity, posts, drainage, landscaping, roadside, community side, snow removal/storage, fire, vehicle hits)*

4. *What is the annual maintenance cost per unit of barrier (linear foot, mile, square foot, etc.)?*

5. *What is the biggest complaint from maintenance people?*

6. *Have you changed any maintenance practices based on past experiences?*

7. *Describe any maintenance research needs or unsolved problems.*

8. *How do you accommodate potential future need for replacement materials or components (panels, posts, connectors, etc). Do you stockpile? Any problems (and solutions) related to past stockpiles?*

MATERIALS/SYSTEMS

1. *Any structural (including foundations) failures? Describe.*

2. *Any material failures? Describe.*

3. *What sound-absorbing systems have you used? How long have they been installed? Your experience with them?*

4. *What is the expected life of the systems/materials you have used?*

5. *How old is the oldest of your "typical" or "standard" barriers? Describe its condition and its maintenance history.*

SUMMARY

1. *Summarize what your agency has learned over the life of its barrier program regarding*

   (1) barrier design
   (2) barrier construction
   (3) barrier maintenance
   (4) barrier materials/systems

APPENDIX B

GUIDELINES AND SAMPLE BROCHURE FOR TRAFFIC NOISE ABATEMENT IN CALIFORNIA

CHAPTER 1100
HIGHWAY TRAFFIC NOISE ABATEMENT

Topic 1101 - General Requirements

Index 1101.1 - Introduction

The abatement of highway traffic noise is a design consideration that is required by State and Federal Statutes and regulations and by Caltrans' policy. This chapter provides the basic guidelines that are to be followed to determine when noise abatement is required and to design abatement features in major projects. Specific structural, architectural, and noise design procedures are covered in other manuals, guides, and in Standard Plans as mentioned below.

Because of the sensitivity of the public to the highway noise issue and the relatively high cost of abatement, it is imperative that the Districts carefully follow the guidelines, reference procedures, and standards.

The three basic types of projects include:

(a) The construction of new highways or the reconstruction or widening of existing highways.

(b) The retrofitting of noise abatement features on existing freeways through residential areas.

(c) The retrofitting of noise abatement features to reduce the level of freeway traffic noise that intrude public and privately-owned primary and secondary schools.

1101.2 Objective

The objective is to limit the intrusion of highway traffic noise into adjacent areas to specified levels or standards on new construction or reconstruction of highways, to achievable levels within practical and financial limits on existing freeways, and to specified levels by statute on freeways adjacent to qualifying schools. To achieve these objectives the Department supports the following three approaches to alleviate traffic noise impacts:

(1) Reduction at the Source. Reduction of traffic noise at the source is the most effective control. Therefore, Caltrans encourages and supports legislation to require reduction in motor vehicle noise as advances in the state-of-the-art of motor vehicle engineering permit.

(2) Encouraging Compatible Adjacent Land Use. Caltrans encourages those who plan and develop land and local governments controlling development or planning land use near known highway locations to exercise their powers and responsibility to minimize the effect of highway vehicle noise through appropriate land use control. For example, cities and counties have the power to control development by the adoption of land use plans and zoning, subdivision, building and housing regulations.

(3) Noise Abatement. Caltrans will attempt to locate, design, construct, and operate highways to minimize the intrusion of traffic noise into adjacent areas. When this is not possible, noise impacts may be attenuated by the construction of noise barriers.

1101.3 Procedures for Assessing Noise Impacts

Highway traffic noise impacts are identified in the project noise study report and are listed in the environmental document. The procedures for assessing noise impacts for new highway construction or reconstruction projects, retrofit projects (Community Noise Abatement Program - HB311) along existing freeways, and School Noise Abatement Projects (HB312), are included in FHPM 7-7-3, the Caltrans Noise Manual developed by the TM&R and Sections 215.5 and 216 of the Streets and Highways Code relating to the California Department of Transportation.

Topic 1102 - Design Criteria

1102.1 General

This section covers the noise level criteria for the various types of noise abatement projects, and gives guidelines on noise reduction, noise barrier location, and various design aspects such as height and length of noise barriers. Alternate designs, maintenance consider-

ations, and aesthetic aspects are also discussed. Various types of Caltrans' standard noise barrier designs are referenced. Noise barrier design procedures, from the acoustical standpoint, are included in the Caltrans' Noise Manual.

1102.2 Noise Abatement Criteria Levels

(1) General. The noise abatement criteria levels in Table 1102.2 represents a balancing of that which may be desirable for the various land use activities and that which may be achievable. In many cases the achievement of lower noise levels would result in even greater benefits to the community and should be considered. The additional cost should, of course, be compared to the added benefits.

(2) New Highway Construction or Reconstruction. For new highway construction or reconstruction which meets the definition of a Type I Project as defined in Index 1106.7, noise abatement measures which are reasonable and feasible should be incorporated into the plans and specifications to reduce or eliminate the traffic noise impacts on existing or design year activities. Traffic noise impacts occur when the predicted traffic noise levels approach or exceed the noise abatement criteria shown in Table 1102.2 or when the predicted traffic noise levels substantially exceed the existing noise levels.

(3) Existing Freeways. On existing freeways, the construction of noise barriers is limited to residential areas meeting the criteria outlined in Index 1104.2 when the existing noise levels exceed the noise abatement criteria level for land use activity Category B shown on Table 1102.2.

(4) School Noise Abatement. Section 216 of the Streets and Highway Code requires the Department to reduce the freeway noise levels to 55 dBA, L_{10}, or 52 dBA L_{eq}, within the interior of public and private elementary and secondary schools if the school was constructed within the time frame specified in the Code.

Table 1102.2

Noise Abatement Criteria

Hourly A-Weighted Sound Level(1) (dBA)		
Activity Category	L_{eq} (h)	L_{10} (h)
A	57 (Exterior)	60 (Exterior)
B	67 (Exterior)	70 (Exterior)
C	72 (Exterior)	75 (Exterior)
D	--	--
E	52 (Interior)	55 (Interior)

(1) Either L_{10} (h) or L_{eq} (h) (but not both) may be used on a project.

Description of Activity Categories

A Lands of which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.

B Picnic areas, recreation areas, playgrounds, active sport areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.

C Developed lands, properties, or activities not included in Categories A or B above.

D Undeveloped lands.

E Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

1102.3 Noise Reduction

(1) Minimum Attenuation. The noise abatement criteria levels of Table 1102.2 should not automatically be considered the lower limit of attenuation if it is reasonable and feasible to achieve a lower noise level. Whenever a noise barrier is proposed it should achieve a minimum attenuation of 5 decibels, except under certain conditions such as where a gap between two noise barriers is closed to provide continuity.

(2) Substantial Increase. On new construction and reconstruction projects, noise abatement facilities should be provided if the predicted traffic noise levels substantially exceed the existing traffic noise levels even though the predicted levels are below the noise abatement criteria shown on Table 1102.2. In order to provide a uniform approach for substantial increases, noise abatement must be considered on all construction or reconstruction projects where the predicted design year noise level increases by 12 decibels over the ambient and the design year level equals or exceeds 65 dBA L_{eq}. However, attenuation for lesser increases in noise levels above the ambient and lesser design year levels should be considered when a lower noise level is a clear and special need.

1102.4 Noise Barrier Location

(1) Lateral Clearances. **Minimum lateral clearance to noise barriers shall be as provided in Topic 309.1, Horizontal Clearances, of this manual.** Lateral clearances greater than the minimums should be used whenever feasible. Where terrain permits, the most desirable location for a noise barrier is just inside the right of way or, alternatively, 30 feet or more from the traveled way.

When clearance is 15 feet or less, the noise barrier shall be placed on a safety shape concrete barrier. Guardrail or safety shape barrier protection should be considered when the noise barrier is located between 15 feet and 29 feet from the edge of the traveled way.

(2) Sight Distance Requirements. The stopping sight distance is of prime importance for noise barriers located on the edge of shoulder along the inside of a curve. Horizontal clearances which reduce the stopping sight distance should be avoided. Noise barriers in gore areas should begin or end at least 200 feet from the theoretical curb nose location.

1102.5 Noise Barrier Heights

(1) Minimum Height. Noise barriers should have a minimum height of 6 feet (measured from the top of the barrier to the top of the foundation).

(2) Maximum Height. Noise barriers should not exceed 14 feet in height (measured from the pavement surface at the face of the safety-shape barrier) when located within 15 feet of the traveled way, and should not exceed 16 feet in height above the ground line when located more than 15 feet from the traveled way.

(3) Truck Exhaust Intercept. Current FHWA noise barrier design procedures result in noise barrier heights which often do not intercept noise emitted from the exhaust stack of trucks. For design purposes, the noise barrier should intercept the line of sight from the exhaust stack of a truck to the receptor. The truck stack height is assumed to be 11.5 feet above the pavement. The receptor is assumed to be 5 feet above the ground and located 5 feet from the living unit nearest the roadway. If this location is not representative of potential outdoor activities, then another appropriate location should be justified in the noise study report.

(4) Two-story Development. The noise barrier should not be designed to shield the second story of two-story residences unless it provides attenuation for a substantial number of residences at a reasonable increase in cost. If the noise barrier is extended in height to provide second story attenuation, this attenuation is to be at least 5 decibels.

1102.6 Noise Barrier Length

(1) General. Careful attention should be given to the length of a noise barrier to assure that it provides adequate attenuation for the end dwelling. Where there is no residential area beyond the end dwelling, consideration should be given to terminating the noise barrier with a section of the barrier perpendicular to the freeway which could reduce the overall barrier length. This could require an easement from the property owner to permit construction of the noise barrier off the right of way.

(2) Gap Closures. In some cases, short gaps may exist between areas qualifying for a noise barrier. The closure of these gaps should be considered on a project by project basis and be justified in the Project Report.

(3) Local Street Connections. At on- and off-ramp connections to local streets, the Department's responsibility for noise abatement should be limited to areas where the traffic noise level from the State highway is the predominant noise source.

1102.7 Alternate Noise Barrier Design

(1) General. Every noise barrier that is constructed as a part of new highway construction or reconstruction, or along freeways as a part of the Community and School Noise Abatement Programs, should include at least two alternate designs. Standard sheets for noise barriers (sound walls) developed by the of Structure Design have been furnished to the Districts. These standard designs include the following materials:

- o Masonry block.
- o Precast concrete panel (with post or mounted on safety shaped barrier).
- o Wood (post and plank or framed plywood).
- o Metal (ribbed steel).
- o Composite beam (Styro-foam and wire mesh core with stucco exterior).
- o Other design alternates maybe considered provided they meet the structural and noise attenuation criteria.

(2) Design Procedures. The plans for alternate noise barriers are to be prepared using the standard sound wall sheets and the appropriate Standard Special Provisions. As a minimum, the sound wall plans are to show the horizontal alignment, the wall profile made up of a top elevation line and a bottom elevation line, the applicable standard sound wall detail sheets, and aesthetic features sheet. The top elevation line is defined as the profile line of the minimum wall height required for the design insertion loss, and the bottom elevation line is defined as the finished grade ground line. If a concrete safety-shape barrier is involved, the top of barrier is to be designated as the bottom elevation line of the sound wall. For alternate sound walls not on a barrier, the footing design does not have to be detailed on the plans. If a barrier is required, the pile layout should be detailed for only one of the alternate designs. Although this method does not require the detailing of one complete sound wall alternate, it does not remove the necessity to solve drainage, utility, foundation, or any other problems which are unique to each project.

(3) Pay Quantities. The pay item for alternate sound walls without a barrier is square foot of sound wall and is measured between the top elevation line and the bottom elevation line. The pay item will be in three groups: H = 6' to 8', H = 10' to 12', H = 14' to 16'. The square foot cost includes all types of supports (footings, piles and pile caps).

Since the elevation lines define the pay item they must be clearly noted on the typical sections and profile plans, and the limits of each wall height group must be designated for pay purposes. All reference to "pile length for payment" should be removed from the Standard Plan sheets if there is no safety shape barrier involved. If the sound wall is on a barrier the sound wall pay item is measured from top elevation line to top of barrier, and the supporting piles or footings and barrier will be separate pay items.

The aesthetic features affect the amount of footing for the masonry block design, and these features must be shown clearly on the plans. The "Typical Sections" sheet is the recommended location to show the aesthetic treatment.

(4) Shop Plans. The Special Provisions should require the successful bidder to submit two sets of shop plans of the alternate selected for approval. These shop drawings must show pile spacing, pile lengths, expansion joints location, and aesthetic treatment.

(5) Preliminary Site Data. In using the "Top Line/Bottom Line" concept, it is important that the preliminary site data be complete as possible. To eliminate or minimize construction change orders the following guidelines are suggested.

- o Provide accurate ground line profiles.

- o Select only standard design alternative sound wall types. Determine locations where these are acceptable and describe in the Special Provisions or show on the plans.
- o Provide adequate foundation investigation.
- o Locate overhead and underground utilities.
- o Review drainage and show any modifications on the plans.
- o Determine and specify architectural treatment.
- o Determine the need for special design, and coordinate with the Division of Structures during the early stages of design.

1102.8 Noise Barrier Aesthetics

(1) General. A landscaped earth berm or a combination wall and berm tend to minimize the apparent noise barrier height and are probably the most aesthetically acceptable alternative, but unfortunately these alternatives are not suitable for many sites due to limited space.

Some moderate additional cost to enhance the noise barrier's aesthetic quality is warranted. However, elaborate or costly individualized designs which significantly increase the cost of the noise barrier should be avoided. When landscaping is to be placed adjacent to the sound wall which will eventually screen a substantial portion of the wall, only a minimal aesthetic treatment is justified. Sound walls should not be designed with abrupt beginnings or ends. Generally, the ends of the sound wall should be tapered or stepped if the height of the sound wall exceeds 6 feet.

(2) Standard Aesthetic Treatment. Only the standard aesthetic treatments for the various alternative materials developed by the Division of Structures should be used. A description of the different types of aesthetics treatments developed are included in the "Instructions for Using the Standard Aesthetics Features Sheets" which are available from the Aesthetics and Models unit of the Division of Structures.

1102.9 Maintenance Consideration in Noise Barrier Design

(1) General. Noise barriers placed within the area between the shoulder and right of way line complicate the ongoing maintenance and landscaping operations and lead to substantially increased costs, especially if landscaping is placed on both sides of the noise barrier. The area behind noise barriers adjacent to the right of way line require special consideration. If the adjoining land is occupied with streets, roads, parks, or other large parcels, an effort should be made during the right of way negotiations to have the abutting property owners maintain the area. In this case, the chain link fence at the right of way line would not be required. Maintenance by others may not be practical if a number of small individual properties abut the noise barrier.

(2) Access Requirements. Access to the back side of the noise barrier must be provided if the area is to be maintained by Caltrans. In subdivided areas, access can be via local streets, when available. If access is not available via local streets, access gates or openings are essential at intervals along the noise barrier. Offset barriers concealing the access opening must be overlapped a minimum of 2.5 to 3 times the offset distance in order to maintain the integrity of the sound attenuation of the main barrier. Location of the access openings must be coordinated with the District maintenance office.

(3) Sound Wall Material. The alternate materials selected for the noise barrier should be appropriate for the environment in which it is placed. For walls that are located at or near the edge of shoulder, the portion of the noise barrier located above the safety-shape concrete barrier should be capable of withstanding the force of an occasional vehicle which may ride up above the top of the safety barrier. At this location, concrete block, cast-in-place concrete, or precast concrete panels are the recommended alternative sound wall materials. In locations which are susceptible to fires, use of the wood noise barrier option should be avoided.

Topic 1103 - Procedures for Designing Noise Barriers

1103.1 General

The procedures for predicting highway noise levels and calculating the insertion loss of a noise barrier are included in the Caltrans' Noise Manual and are based on the FHWA Highway Traffic Noise Prediction Model (Report No. FHWA-RD-77-108). As the result of a research project conducted by the TM&R, the national (FHWA) reference energy mean emission levels reported in the FHWA Report No. FHWA-RD-77-108 are to be replaced by the California Vehicle Noise (Calveno) reference energy mean emission level curves related to vehicle speeds and vehicle type (autos, medium and heavy trucks).

The Calveno curves have been programmed as an option in the following computer programs for predicting noise levels and calculating the noise insertion losses of a barrier:

LEQV2, SOUND3, and SOUND32

All traffic noise predictions and noise barrier insertion loss calculations for noise studies started on March 26, 1985, or later must use the Calveno curve option.

Topic 1104 - Community Noise Abatement Projects

1104.1 General

This topic covers the procedures to follow in order to identify and prioritize residential areas adjacent to existing freeways which qualify for noise abatement pursuant to Section 215.5 of the Streets and Highway Code.

1104.2 Section 215.5 Requirements

(1) General. Section 215.5 of the Streets and Highways Code requires Caltrans to develop and implement a system of priorities for ranking the need for installation of noise attenuation barriers along the California Freeway and Expressway System and, consistent with available funding, recommend in the STIP, a program for construction of noise attenuation barriers beginning with the highest priority.

(2) Qualifying Areas. In order for a residential area to qualify for this program it must meet one of the following conditions:

(a) Developed prior to the opening of the freeway, or

(b) Developed after opening of the freeway, but before the completion of an alteration to the freeway which caused at least a 3 dBA increase in noise levels.

In determining the time relationship between residential development and freeway opening, the date of residential development means the date of the issuance of a building permit and the opening date of the freeway means the date that the adjacent freeway was opened to traffic.

1104.3 Inventory of Qualifying Areas

The Districts must maintain an inventory of residential areas adjacent to freeways on the California Freeway and Expressway System that meet the criteria stipulated in Index 1104.2(2). This inventory should be segregated into logical construction project limits.

1104.4 District Priority List

From the inventory of qualifying projects, a priority index is to be calculated for each project where the measured or adjusted noise levels exceed the noise level criteria for Activity Category B, shown on Table 1102.2 (67 dBA, L_{eq}). This priority index is to be calculated using the following formula:

$$PI = \frac{AR \times (NL-67)^2 \times LU}{Cost\ (\$1000)}$$

Where:

PI = Priority Index

AR = Achievable Reduction

NL = Measured Noise Levels, L_{eq}

LU = Number of Living Units

In the above formula, the achievable reduction should be the average reduction in noise levels that the proposed noise barrier will achieve. The noise abatement criteria level (or lower) shown for activity category B on Table 1102.2 is a goal for achievement, but is not mandatory. However, any noise barrier considered under this program, in order to provide a significant benefit in noise reduction, must provide a minimum of 5 decibels reduction.

The noise level used in the formula should be the average of the actual field measured design hour levels for the project in L_{eq}. These measured levels should be adjusted as follows to account for future increases in noise levels, unless unique conditions dictate otherwise:

Present Design Hour Level of Service(1)	Adjustment
A	+ 2 dBA
B	+ 1 dBA
C	0
D,E,F	(2)

(1) As defined in 1985 Highway Capacity Manual.

(2) Noise measurements not recommended during this level of service.

The number of living units should be limited to the residences immediately adjacent to the freeway. Residences located above the first floor in multi-story units should be included in the residential count if the proposed barrier provides a 5 dBA reduction for these units.

1104.5 Priority Adjustments

Section 215.5 stipulates that one of the factors in determining the priority shall be whether a majority of the occupants in close proximity of the freeway resided there prior to the time the freeway routing was adopted by the CTC. The city or county in which the residential area is located is responsible for providing documentation to the department on the percentage of original occupants still residing along the freeway.

If a city or county submits documentation which shows that for a specific project the majority (over 50%) of the current occupants in close proximity of the freeway resided there prior to the adoption of the freeway, the Priority Index, as calculated by the above formula, is to be enhanced in an amount equal to the actual "current residing percentage". For example, if the priority index for a project is calculated to be 10.00 and the documentation furnished by the local agency indicates that the "current residing percentage" is 52.5%, then the priority index is adjusted to 62.5.

When verifying the documentation submitted by a city or county, the following definitions shall apply:

(a) Majority - Over 50% of total persons i dwelling units that are living in clos proximity or immediately adjacent to th freeway.

(b) Occupants - Person or persons who are cur rently occupying the dwelling units unde consideration.

(c) In Close Proximity - the area encompasse by residential units immediately adjacent t the freeway. (Same first line receptors use in above Priority Index formula).

If the current occupant or occupants are th owners, than the date of purchase should b submitted as documentation. Fo renter/occupants, a statement should be ob tained from the renter as to date occupanc commenced. For occupants other than the prin cipal occupants, a statement which shows th date these occupants first began to reside in th residence should be obtained from the princip occupants.

1104.6 Cost-effectiveness

Projects on the priority list must be "cost e fective projects". Projects costing no more tha $30,000 per residential unit protected by th barrier are considered to be cost-effective. I calculating the cost-effectiveness, include a living units (houses, apartments, cond miniums, etc.) that will benefit by a 5 decibel c more reduction in noise levels by reason of th noise barrier construction. This could incluc some of the second line receptors which are n included in the priority index calculations.

Topic 1105 - School Noise Abatement Projects

1105.1 General

Section 216 of the Streets and Highway Code requires the Department to measure and attenuate the noise from a freeway in specific areas within public and private elementary secondary schools when the noise levels fro the freeway within the school exceeds 55 dB L_{10}, or 52 dBA L_{eq}. In addition, the time school construction and the current use mu meet the requirements of the Code.

The options available for reducing the noise levels within the school include construction of a noise barrier, acoustical treatment of the school structure, or a combination of both. A preliminary investigation should be made to determine which method of attenuation is the most appropriate. If it is determined that the construction of a noise barrier is the appropriate solution, then a noise barrier would be designed and constructed similar to those constructed for the Community Noise Abatement Program. If it is determined that it would be more appropriate to perform acoustical treatment on the school,then a cooperative agreement should be entered into with the School District. This allows the School District to prepare the plans and specifications for the proposed acoustical work and to administer the construction contract using the Preapproved Agreements in Appendix 3, Volume 2A of the Cooperative Agreement Manual.

The school district generally engages an architect to do the design and prepare the PS&E. When Federal-aid funds are used for the project, the PS&E are to be submitted to the Office of Project Planning and Design to obtain FHWA approval before the District authorizes the school district to advertise the project.

Topic 1106 - Definitions

1106.1 Noise

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

(2) Insertion Loss. The net reduction in noise levels resulting from the installation of a noise barrier.

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

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

(5) L_{eq}. The equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same period.

(6) Traffic Noise Impacts. Impacts which occur when the predicted traffic noise levels approach or exceed the noise abatement criteria (see Table 1102.2), or when the predicted traffic noise levels substantially exceed the existing noise levels.

(7) Type I Projects. A proposed Federal or Federal-aid highway project for the construction of a highway on new location or the physical alteration of an existing highway which significantly changes either the horizontal or vertical alignment or increases the number of through-traffic lanes. This definition also applies to State only funded highway projects.

(8) Type II Projects. A proposed Federal or Federal-aid highway for noise abatement on an existing highway. This definition also applies to State only funded highway projects.

For a more complete list of definitions commonly found in environmental noise literature, refer to Appendix IA of the Caltrans' Noise Manual.

BACKGROUND

In 1973-74, State and Federal agencies adopted formal policy and criteria for construction of noise barriers.

California leads the nation in both completed and planned soundwalls. About 150 miles of walls have been completed (costing $120 million) compared to 210 miles for the other forty-nine states.

There are four basic programs under which CALTRANS may undertake soundwall construction:
1. As part of a new freeway project
2. As a part of a freeway widening project
3. Under the School Noise Abatement Program
4. Under the Community Noise Abatement Program

By far, the most requests fall under the Community Program.

Typically, the request is to build a soundwall on an existing freeway to shield adjacent residences from freeway noise.

The immediate key questions that need to be answered are:
1. Does the area qualify? If yes...
2. When will it be built? If not soon...
3. Where does it stand on the waiting list?

The answer to the first question is usually easy—Does the area qualify? Yes, if it meets all of the following:
1. Residential property, built prior to the freeway or prior to a major widening.
2. Has hourly noise levels that exceed the 67-decibel (Leq) threshold
3. Must be able to achieve at least a 5-decibel reduction
4. Cost does not exceed $30,000 per residential unit (1987 dollars)

Second question—When will it be built?

Normally, engineering and construction scheduling are not a problem. However, the availability of funds is usually the major stumbling block, which generally means waiting.

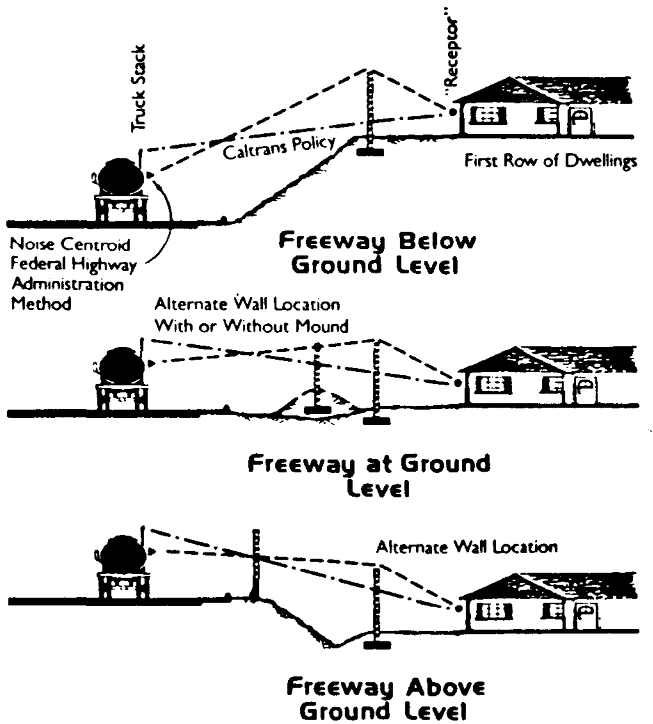
Third question—Where does it stand on the waiting list?

Because the demand for soundwalls has far exceeded the funding to build them, a priority waiting list has been developed.

This waiting list is based on a formula which combines noise levels, number of living units and cost effectiveness to produce a ranking.

There are currently over 200 projects totalling about 200 million dollars awaiting programming.

Current Funding levels provided under the Deddeh Transportation Improvement and Reform Act of 1988 are set at 15 million dollars per year.



COSTS AND DESIGN FEATURES

Total Cost:	Averages about $200 per lineal foot or $1 million per mile
Type of Wall:	Usually reinforced concrete, reinforced concrete block or combination earth mound wall
Footings:	Trench footings, spread footings or pile footings are used as appropriate
Typical Height:	8 to 14 feet, depending on specific design needs
Aesthetic Treatment:	Decorative concrete block, e.g., color, split face, slumpstone, scored or fluted, is used
Engineering of Plans:	Usually 12 months
Construction Project:	Typically 12 months

FUNDING METHODS

Traditional Financing

The California Transportation Commission is the approving body for program and project level funding.
Soundwalls which come under new or major reconstruction projects are automatically included as a part of the project design.
Soundwalls which are retrofitted to existing freeways fall under the Community Noise Abatement Program. Under Commission policy, this program is subject to available funding. Since funding is limited, a priority list has been developed to rank future projects. On an annual basis, the Commission selects the highest ranking projects to match available funding.

Payback Option

State law allows cities or counties to construct eligible soundwalls ahead of the time that they would be built under traditional funding. Then, when the funding priority is eventually reached, CALTRANS would reimburse the local agency for the actual cost. It's important to note that reimbursement does not include interest.

Benefit Assessment District

Some local agencies are considering a benefit assessment district whereby residents in effect tax themselves under some formula to generate funding. Under this method bonding could be used for early construction at the expense of a longer payback.

Special Legislation

Soundwalls have occasionally been funded and constructed by special State legislation. These have occurred outside of CALTRANS' and the California Transportation Commission's process.

TYPICAL QUESTIONS

1 Q How does my area qualify for a soundwall?
A The two key factors under the Community Noise Abatement Program are
a The residential area existed prior to the freeway opening date or major reconstruction completion
b Outside noise levels exceed 67 decibels (Leq)

2. Q Why is the 67 decibels (Leq) level so important?
A This is the noise level established by Federal and State agencies which must be exceeded before impacted neighborhoods are eligible for mitigation.

3. Q What does Leq mean?
A. It is the steady noise level equivalent to fluctuating traffic noise over a given period of time.

4. Q Do you measure noise for a 24-hour period?
A. No. Measurements are taken during time periods which register the noisiest traffic.

5. Q When are noise levels usually measured?
A. In the greater Los Angeles Area our studies have shown that the highest noise measurements usually occur between 9:00 a.m. and 3:00 p.m. and not at peak congestion times

6 Q Why aren't noise measurements taken during the peak congestion time?
A. Traffic noise is speed related, i.e., as vehicles move faster, they produce more noise. Likewise, when traffic is stop-n-go or at low speeds, noise levels are also lower

7 Q Why does it seem noisier late at night and early morning?
A Because the surrounding area is in fact quieter at these times, the masking effect of other noise does not screen the freeway noise. This usually makes the freeway noise more prominent but lower than the midday level

8 Q Why are noise measurements taken for only ten minutes?
A Our measurements on heavily traveled roads have shown that a ten-minute period is sufficient to reliably reflect an hourly noise level

9. Q Why is there a soundwall on the other side of the freeway or just down the road and not in my area?
A. There are many factors which affect noise levels even when traffic volumes are the same. These differences usually happen when . . . the terrain changes . . . the freeway curves in a different direction . . . the freeway elevation changes from above to below ground level. Also, soundwalls have sometimes been constructed by developers of the adjacent property.

10. Q Why can't you place a soundwall to protect our area from cars running off the freeway?
A. Soundwalls are not intended to be safety barriers. There are other reliable methods used such as installing guardrails to protect against vehicles running off the road. All improvements, whether to reduce noise or enhance safety, have to meet specific criteria and be justifiable on their own merits. Cost is always a factor.

11 Q Why are soundwalls built to protect commercial property in some locations?
A Commercial property in itself is not eligible for soundwall protection. However, when designing a wall in a particular location safety, aesthetics or continuity will sometimes dictate gap closures which can end up protecting non-eligible property. Also, in some instances, the walls were privately funded

For additional information, please write or call	Environmental Planning 120 South Spring St. Los Angeles, CA 90012-3606 (213) 620-5166

SOUNDWALLS

Caltrans

Prepared by
District 7
Caltrans
California Department
of Transportation

APPENDIX C

CALTRANS MEMO TO DESIGNERS 22-1, SOUND WALL DESIGN CRITERIA

SOUND WALL DESIGN CRITERIA

The following criteria shall be used when designing sound walls.

I. Loads

Wind Load

For wall heights less than 12';
10 psf for sound walls on ground;
20 psf for sound walls on bridges or retaining walls.

For wall heights 12' and greater;
15 psf for sound walls on ground;
30 psf for sound walls on bridges or retaining walls.

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 $(h/30)^{2/7}$ where h is the distance in feet measured from the top of wall to the average level of the adjoining ground.

Seismic Dead Load

0.30 dead load, except on bridges.
1.00 dead load, on bridges.

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 seismic loads.

Seismic Earth Load

For those sound walls that are also used as earth retaining structures, add the seismic load of the fill being retained. The most frequently used method for the calculation of the seismic soil forces is the static approach developed by Mononobe and Okabe. The Mononobe–Okabe analysis is an extension of the sliding wedge theory which takes into account the horizontal and vertical inertia forces acting on the soil. The analysis is described in detail in the publication *Design of Earth Retaining Structures for Dynamic Loads*, Seed, H. B. and Whitman, R.V. (1970), ASCE Specialty Conference – Lateral Stresses in the Ground and Earth Retaining Structures.

Supersedes Memo to Designers 22-1 dated August 1981

MEMO TO DESIGNERS JULY 1989 22-1

Traffic Impact Load

It will not be necessary to apply traffic impact loads to sound walls unless they are combined with concrete safety shaped barriers. The foundation systems for those sound wall and barrier combinations that are located adjacent to roadway side slopes shall not be less than what is required for the traffic impact load alone. The minimum foundation requirements for traffic impact loading are shown in Section IV: Foundation Design.

When the sound wall and barrier combination is supported on a bridge superstructure, the design of the barrier attachment details shall be based on the group loads that apply or on a traffic impact load, whichever controls. The application of traffic impact loading shall be as specified in Article 2.7 – Railings of the *Bridge Design Specifications.*

The walls and foundation of Standard Retaining Wall Types 1, 1A, 2, 3, 4 and 5 can be considered to withstand the traffic impact load that is transmitted to the wall from the barrier. The walls and foundations will, however, have to be investigated for sound wall loading using the appropriate sound wall group loads.

Bridge Loads

When a sound wall is supported by a bridge superstructure, the wind or seismic load to be applied to the superstructure and substructure of the bridge shall be as specified in Articles 3.15 – Wind Loads and 3.21 – Seismic Forces of the *Bridge Design Specifications.* Note that additional reinforcement may be required in the barrier and overhang to resist the loads carried by the sound wall.

II. Load Combinations

The following groups represent various combination 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 1, 2 or 3; or Groups A, B, C, D or E — as they apply.

Working Stress Design (WSD)		Percentage of Unit Stress
Group 1:	D + E + SC	100%
Group 2:	D + W + SC + E	133⅓%
Group 3:	D + EQD + E	133⅓%

Where: D = Dead Load
E = Lateral Earth Pressure
SC = Live Load Surcharge
W = Wind Load
EQD = Seismic Dead Load

Load Factor Design (LFD)

Groups with Load Factors
Group A: (β x D) + 1.7 E + 1.7 SC
Group B: (β x D) + 1.7 E + 1.3 W
Group C: (β x D) + 1.3 E + 1.3 EQE
Group D: (β x D) + 1.3 E + 1.3 EQD
Group E: (β x D) + 1.1 E + 1.1 (EQE + EQD)

Where : β = 1.0 or 1.3, whichever controls in Design
D = Dead Load
E = Lateral Earth Pressure
SC = Live Load Surcharge
W = Wind Load
EQE = Seismic Earth Load
EQD = Seismic Dead Load

Strength Reduction Factors, ϕ

Reinforced Concrete:
For Flexure ....ϕ = 0.90
For Shear ....ϕ = 0.85
For Axial Compression ....ϕ = 0.70

Foundations:
For Soil Resistance ....ϕ = 0.90
For Soil Active Resistance ....ϕ = 1.00
For Soil Bearing Pressure, Except Under EQ .....ϕ = 0.50
For Soil Bearing Pressure, Under EQ ....ϕ = 1.00
For Pile Bearing Load, Except Under EQ ....ϕ = 0.75
For Pile Bearing Load, Under EQ ....ϕ = 1.00

III. Wall Design

Specifications

The structural members of the sound wall and the foundations shall be proportioned according to allowable stresses given in the codes listed below.

Applicable Codes

Concrete *Bridge Design Specifications*, Section 8 - Reinforced Concrete Design.

Masonry *Uniform Building Code (UBC)*, 1979 Edition, Chapter 24 – Masonry.

Stucco[1] *Uniform Building Code (UBC)*, 1979 Edition, Chapter 47 – Wall and Ceiling Coverings.

Timber *National Design Specification for Wood Construction*, National Forest Product Association, latest edition.

Plywood *Plywood Design Specifications*, American Plywood Association, latest edition.

Steel[2] *Specification for the Design, Fabrication and Erection of Structural Steel for buildings*, American Institute of Steel Construction, latest edition.

Steel[3] *Specification for the Design of Cold-Formed Steel Structural Members*, American Iron and Steel Institute, latest edition.

Welding *Uniform Building Code (UBC)*, 1979 Edition, Chapter 27 – Steel, Table 27.

Design Methods

The following materials shall be designed by the Load Factor Design (LFD) Method: Cast-in-place Concrete, Precast Concrete, Rolled Steel shapes and Rolled Steel Plates.

The following materials shall be designed by the Working Stress Design (WSD) Method: Masonry, Stucco, Timber, Plywood, Cold-Formed Steel Ribbed Sections and Sheet Metal.

Safety shaped barriers and foundations supporting such barriers, including piles, must be designed for an ultimate strength of f'_c = 3250 psi. All other concrete components of sound walls may be designed for an ultimate strength for which each part is designed. 2700 psi is the assumed ultimate strength for concrete containing five sacks of portland cement per cubic yard.

When designing steel sound walls, note that both AISC and AISI require that the sections be checked for compressive buckling.

Masonry Design

Masonry walls shall be designed as reinforced hollow unit masonry using the Working Stress Design (WSD) Method.

Walls are to be reinforced as required by design or to meet the minimum area requirements of UBC. To comply with UBC, the sum of the areas of horizontal and vertical reinforcement shall be at least 0.002 times the gross cross-sectional area of the wall and the minimum area of reinforce-

[1]Exterior portland cement plaster.
[2]Hot rolled shaped and plates.
[3]Cold-formed ribbed sections and sheet metal.

ment in either direction shall be not less than 0.0007 times the gross cross-sectional area of the wall. The maximum spacing of this reinforcement shall be 4'-0" on center. Bond beams will be required at locations where horizontal reinforcement is placed. (See Figure 1.)

When masonry units are laid in stacked bond, ladder type longitudinal joint reinforcement will be required. The joint reinforcement will be not less than two continuous 9 gage wires. This reinforcement is to be embedded in the mortar bed joints at 24 inches maximum between bond beams.

Sound Walls on Structures

For sound walls on structures and adjacent to the traveled way, the portion of the sound wall above the traffic barrier should be able to resist the impact of a vehicle climbing above the traffic barrier. The recommended materials for use on structures are masonry block and cast-in-place concrete. Cast-in-place concrete is preferred over masonry block due to its resistance to fragmenting upon impact. (See Figure 2.) For similar reasons, do not use wood or lightweight masonry blocks adjacent to traffic. Precast panels are not allowed on bridges or retaining walls. Each masonry block on bridges must be reinforced and the lower two feet of blocks should be fully grouted.

Expansion joints are required in walls at the centerline of bents, at the centerline of spans, at hinges and at any other existing expansion joints in the structure. Place additional joints in the wall as required to minimize stresses on the wall due to live load deflection of the bridge. A dowel is required at the top of masonry block walls at each joint to maintain proper alignment. (See Figure 3.) The bridge barrier should be continuous except at expansion joints in the deck.

Retrofitting barriers with sound walls may require replacing the entire barrier due to either its inadequate flexural capacity to carry the wall loads, or because of inadequate anchorage of the barrier to the deck. See Memo to Designers 14-6 for barrier anchorage recommendations.

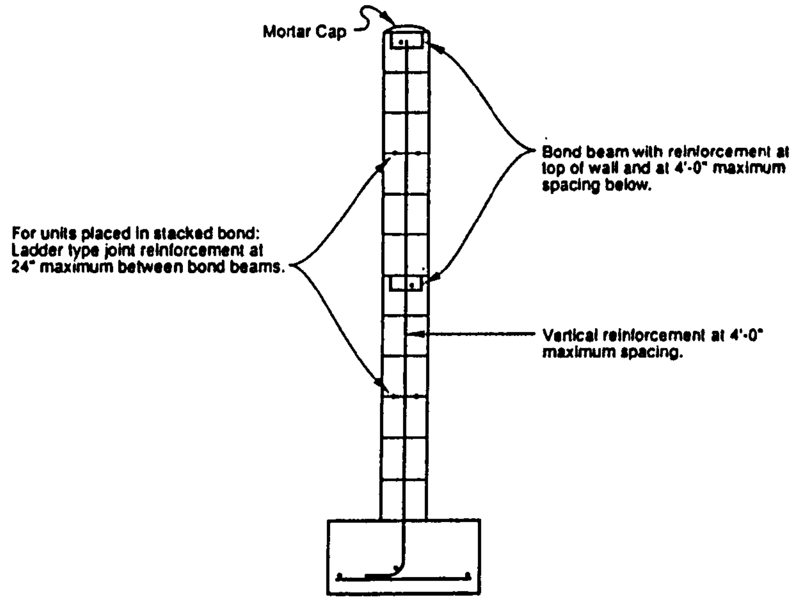
Bridge overhangs and retaining walls must be checked for structural adequacy. Check as-built plans or Memo to Designers 9-4 for material capacities of the existing structure. Steel girder bridges may require strengthening.

The addition of sound walls to existing bridges may cause changes in the structure deflections that could result in drainage problems along the deck surface. Since this may be a particular problem when concrete or masonry sound walls are placed on structures with flat grades, it is suggested that existing profiles, cross slopes, and deflections be reviewed to assure that adequate drainage is available. To correct water ponding problems that developed on several recent projects, the Office of Structures Construction used a detail similar to the standard Deck Bleeder Drain, Detail 7-6, shown on Standard Plan Sheet B7-5. In the detail used, a 1" diameter PVC pipe was glued into a 1¼" diameter hole that had been cored through the deck overhang. The pipe was located 1" clear from the face of barrier, set flush with the deck surface and was extended 1" below the overhang soffit.

MEMO TO DESIGNERS JULY 1989 22-1

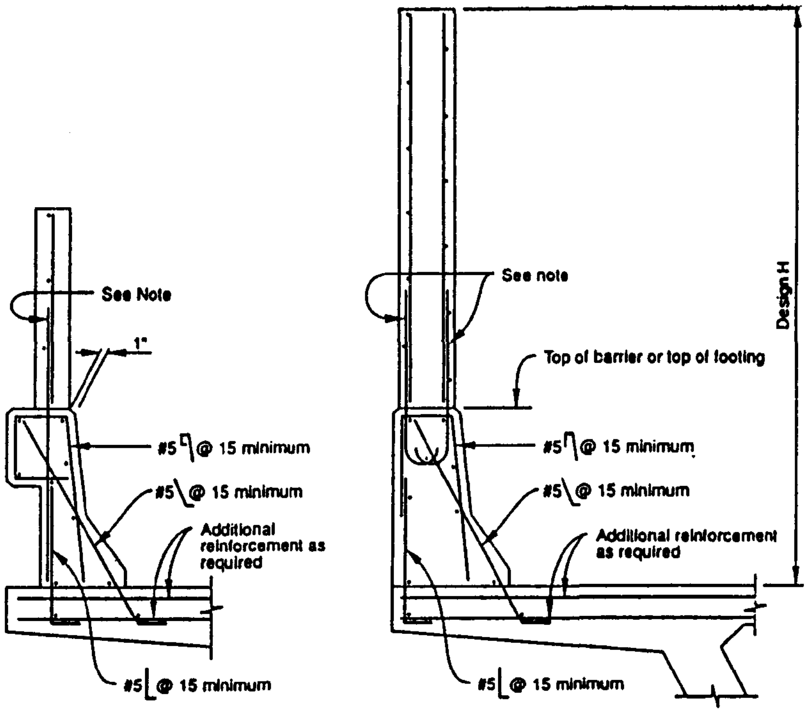
Do not place masonry block walls on existing steel girder bridges when traffic is carried on the structure during masonry construction. Traffic vibration will settle blocks into the mortar bed.

Sound walls on approach slabs require special consideration. Approach slabs are not designed to accommodate the wall dead load and loads transferred from it. Also, approach slab settlement and deflection may cause structural and alignment problems. See the Approach Slab Committee for recommendations.



Minimum Reinforcement for Masonry Block Walls

Figure 1



Cast-In-Place Sound Wall

Note: Designer to determine reinforcement.

Figure 2

IV. Foundation Design

The allowable vertical soil bearing capacity, the soil properties to be used in calculating the lateral soil bearing values and other pertinent foundation data will be shown in the foundation report that is provided by the Engineering Geology and Technical Services Branch of the Transportation Laboratory.

The passive soil pressures *shall be* increased by a factor of 1.5 for the design of laterally loaded piles located in cohesionless soils and in level ground. The increased pressure is defined as the 'EFFECTIVE' passive pressure and the increase factor of 1.5 is defined as the 'ISOLATION' factor. The 'ISOLATION' factor is a means to account for the assumption that a laterally loaded pile is resisted by a section of earth that is wider than that of the pile. A level ground condition is defined as one in which the ground surface is approximately level or, when sloping down and away from the pile, is not steeper than 10:1 for $\phi = 35°$ or 14:1 for $\phi = 25°$. A level ground condition may also be assumed when the hinge point of any adjacent down or negative slope that is steeper than 10:1 for $\phi = 35°$ or 14:1 for $\phi = 25°$ is not located closer than 2 times the pile embedment. The 10:1 and 14:1 negative slopes are approximately equal to a β/ϕ ratio of - 0.15, where β is the angle of the slope in degrees and ϕ is the angle of shearing resistance in degrees. There shall be no increase in the 'EFFECTIVE' passive pressure for piles located in cohesive soils or in sloping ground. Figure 5 illustrates the parameter for the level ground condition.

With the exception of the factors of safety for the stability of spread footings, the foundation requirements for embedment, width, depth and strength shall be determined by the Load Factor Design (LFD) Method using the loading combinations, the load factors and the strength reduction factors shown in Section II: Load Combinations.

Piles located on slopes *are* to be protected by a berm. The berm should have 1'-0" minimum width and provide 6" minimum depth of cover above the top of pile or pile cap.

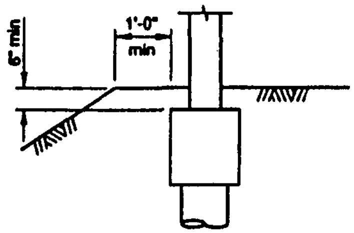
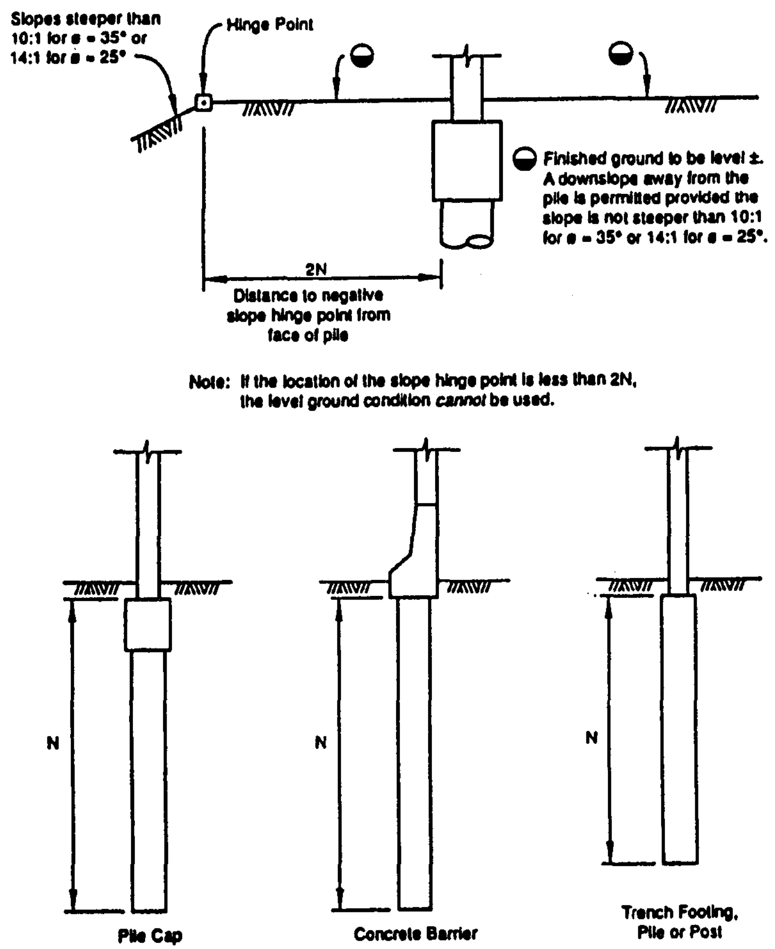


Figure 4



Criteria for Level Ground

Figure 5

Spread Footing

Use Service Level Loads for determining the factors of safety for stability.

Minimum Factors of Safety for Overturning.

Group 1 = 2.0
Group 2 = 1.5
Group 3 = 1.5

Minimum Factors of Safety for Sliding.

Group 1 = 1.5
Group 2 = 1.2
Group 3 = 1.2

Pile Embedment

Pile embedments are to be determined by structural analysis.

The procedure shown on page 19 of the U.S.S. Steel Sheet Piling Design Manual, printed July 1975 *may be* used. The analysis is based on the assumption that the pile is relatively stiff. Therefore, the depth of pile embedment should be limited to 12 times the pile diameter. Since the analysis is also based on passive soil pressures which are ultimate values, the required factors of safety for stability will be provided through the use of the load factors and the soil strength reduction factors shown in Section II: Load Combinations.

Several computer programs are available for determining sound wall pile embedment. Passive soil pressures for use in hand calculations or as computer input data are also available by program. See the sound wall technical specialist for information on these programs.

Pile Design

Although a study of the interaction diagrams for laterally loaded sound wall piles indicated that they behaved more as flexural members than as compression members, it is strongly recommended that those portions of the UBC, ACI and AASHTO codes dealing with compression members subjected to lateral loads be used for pile design. The three codes have similar requirements for design in seismic areas where the probability of major damage during an earthquake is high.

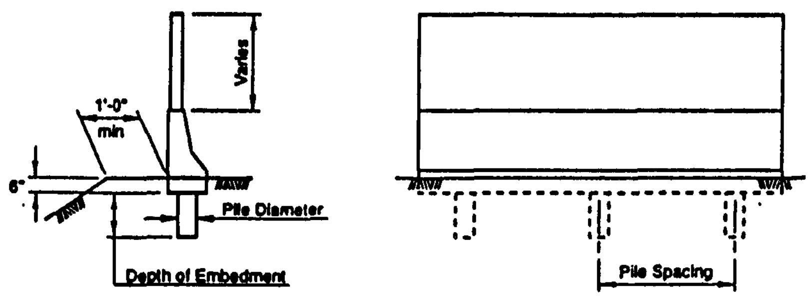
Piles must have the capacity to take the applied shear that is generated by the lateral loads. It can be assumed that the spiral reinforcement will serve as the transverse or lateral reinforcement required by the codes. The total shear capacity of the pile can be based on the combination of the resisting values of the concrete and the spiral shear reinforcement. The recommended minimum spiral for shear is W3.5 at six inch pitch. It is further recommended that the spiral be adequately supported by a minimum of six longitudinal bars and that the minimum bar size be #4. The size of the longitudinal bars should be as required to provide the needed flexural capacity.

The interaction diagrams in *Bridge Design Aids*, page 16-9, may be used for determining the longitudinal pile reinforcement. Note that there are two sets of diagrams. Each set is based on a different ultimate concrete strength. The capacity of most piles should be based on $f'_c = 2700$ psi, which is the ultimate value for concrete containing five sacks of cement per cubic yard. Piles that support the concrete safety shaped barrier must, however, be based on $f'_c = 3250$ psi. The production computer program YIELD may be used for the design of sound wall piles.

When P_e, the maximum factored axial load, is less than $0.4\ \phi\ P_b$, the requirement for volumetric ratio for concrete confinement may be waived. P_b is the nominal axial load strength at balanced strain conditions. It is also suggested that the d/2 spacing requirement for shear reinforcement be waived when the recommended spiral reinforcement provides sufficient shear capacity.

Minimum Foundation Requirement for Traffic Impact Loading

When the sound wall is combined with a concrete safety shaped traffic barrier the resulting foundation shall meet or exceed the following minimum foundation requirements which were developed from results of crash tests. The test results are contained in Research Report No. M & R 36412.



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

Figure 6A. Barriers with Pile Supports

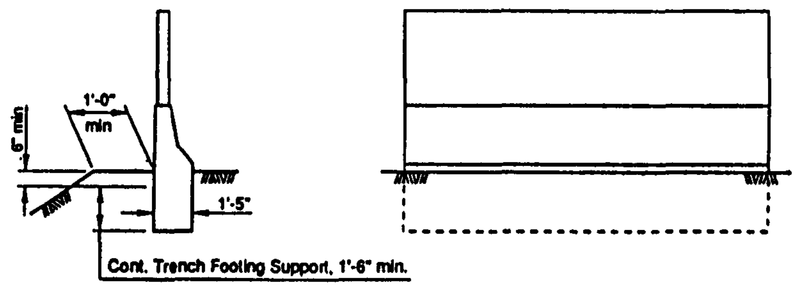


Figure 6B. Barriers with Continuous Trench Footing Support

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APPENDIX D

ONTARIO MINISTRY OF TRANSPORTATION MATERIAL SPECIFICATION FOR NOISE BARRIERS, FINAL DRAFT

FINAL DRAFT

MATERIAL SPECIFICATION FOR NOISE BARRIERS

90 06 08

INDEX

.01 SCOPE

This specification covers the design and material requirements for Noise Barriers.

.02 REFERENCES

This specification refers to the following standards, specifications or publications:

Ontario Provincial Standard Specifications (Material)

OPSS 1350 Concrete (Materials and Production)
OPSS 1352 Precast Concrete Barriers
OPSS 1440 Steel Reinforcement for Concrete
OPSS 1442 Epoxy Coated Steel Reinforcement for Concrete
OPSS 1506 Timber Posts and Block (Steel Beam Guide Rail)

Canadian Standards Association

CSA G164-M 1981	Hot Dip Galvanizing of Irregular Shaped Articles
CSA A23.2-M77	Methods of Testing for Concrete
CSA CAN3-A5-M83	Early Stiffening of Cement Paste
CSA W47.1-1983	Certification of Companies for Fusion Welding of Steel Structures
CSA W59.1-M1989	Welded Steel Construction (Metal Arc Welding)
CSA O112-M1979	CSA Standards for Wood Adhesives
CAN/CSA-O122-M89	Structural Glued-Laminated Timber

ANSI/ASTM Standards:

E795-83	Practices for Mounting Test Specimens During Sound Absorption Tests
E90-87	Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions
C423-89	Sound Absorption and Sound Absorption Coefficient by the Reverberation Room Method
Z26.1-1983	American National Standard for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways - Safety Code.

Ontario Highway Bridge Design Code:

OHBDC-1983 Ontario Highway Bridge Design Code
National Lumber Grades Authority:

NLGA Standard Grading Rules for Canadian Lumber (87)

National Standards of Canada:

CAN/ULC-S102.2-M88 Standard Method of Test for Surface Burning Characteristics of Flooring, Floor Covering and Miscellaneous Materials and Assemblies.

MTO Research & Development Reports

AE-81-01 Traffic Noise Barrier Design for Sound Transmission.

.03 DEFINITIONS

.04 SUBMISSION AND DESIGN REQUIREMENTS

.04.01 Design Drawings

Manufacturers wishing approval of noise barrier designs, shall submit 6 copies of the following items to the approving authority.

- All design calculations
- Detailed design drawings
- Specifications regarding installation requirements as well as sequence of construction
- Specifications for all materials
- Effective sound transmission loss report for the noise barrier system
- Noise reduction coefficient report for the noise barrier system if the noise barrier is to be considered as sound absorptive
- All test results as required

All drawings and calculations shall bear the seal and signature of a Professional Engineer who is licensed by the Association of Professional Engineers of Ontario.

The tests and subsequent reports shall be conducted and prepared by a recognized independent testing authority.

.04.02 Design Requirements

.04.02.01 Structural Design

Except where otherwise noted, the noise barrier shall be designed in accordance with the Ontario Highway Bridge Design Code (OHBDC) as a slender structure not unusually sensitive to wind action. Design wind loads and ice accretion loads on panels shall be as prescribed for sign panels. Reference wind pressure for a 25 year return period shall be used. The reference wind pressure shall be determined on a site specific basis as described in the OHBDC.

In the calculation of section properties and strength for cold formed steel members for which the provisions of the OHBDC are not applicable, the requirements of the CSA Standard for ultimate limit state design shall apply.

.04.02.01.01 Explanatory Notes

The following notes are not part of the criteria. They are not intended to obviate the need for familiarity with the OHBDC and with the analytical procedures required for the design of noise barriers. They are intended to assist in a cursory assessment of the criteria.

(i) The OHBDC (Section 4) prescribes an equivalent uniformly distributed wind load of $F_d = q\ (C_eC_dC_g)$, where q is the reference wind pressure, C_e is an exposure factor equal to 1.0 for wall heights up to 10 m, and C_d is a drag coefficient equal to 1.3 for surfaces having a length which is large in relation to the height. The gust coefficient C_g is 2.5 for light, slender structures not unusually sensitive to wind action.

(ii) For panels in the size range considered, ice accretion loads are prescribed assuming that one side of the panels becomes coated with ice. Longitudinal elements at the top of the panels would have to be assumed coated on all surfaces. For most areas in Southern Ontario a coating of 31 mm on vertical surfaces and 18 mm on horizontal surfaces is assumed in design.

(iii) The OHBDC gives no provisions for the calculation of section strengths for cold formed steel elements, but prescribes all necessary loads and covers all other types of materials likely to be used for noise barriers. It is assumed to be self evident that where section strength or performance provisions from a code are employed, the other provisions of that code necessary to ensure that the performance will be achieved, must also apply.

(iv) Load factors and combinations are given in Section 2 of the OHBDC. It is expected that three load cases will govern design:

at the ultimate state:
$1.10\ D + 1.30\ W$ loading case 8
and $1.10\ D + 0.9\ (1.30\ W - 1.30\ I_g)$ loading case 16

and at the serviceability limit state Type II:

$1.00\ D + 0.7\ W$ loading case 6

where D is the dead load of materials assumed to be factory produced, W is the wind load and I_g is the ice accretion load.

.04.02.02 Foundation Design

The depth of footings shall be determined in accordance with the OHBDC, Clause 5-7.2 based on the soil design parameters as provided on a site specific basis.

.04.02.03 Aesthetics

.04.02.03.01 Visual and Physical Relief

Visual and physical relief at uniform intervals is required on both sides of the barrier by the use of

.05.05 Sound Absorptive Insulation

Materials used to fill cavities in double walled noise barriers to increase sound absorption shall be manufactured to meet CGSB 51GP10M rigid type. The fibres shall be vermin proof and highly resistant to damage in handling and shall show no apparent damage from vibration.

The noise reduction coefficient (NRC) shall be not less than 0.70 using 25 mm of insulation thickness on an F400 mount in accordance with ASTM E795-83.

Insulation shall be void of any vertical joints.

.05.06 Reinforcing Steel

All reinforcing steel shall conform to the requirements of OPSS 1440.

All reinforcing steel must be epoxy coated in accordance with OPSS 1441. The concrete cover shall be a minimum of 35 mm.

.05.07 Pop-Rivets

Pop-rivets shall be either aluminum with an aluminum mandrel or aluminum with a stainless steel mandrel.

.05.08 Glazing Material

All glazing materials shall meet the requirements of ANSI Z26.1-1983 for flat safety glazing plastics and laminated glass used for windshields.

.07 PRODUCTION

.07.01 General

All components shall be consistent in appearance, dimensions and quality as specified in this specification and by the manufacture and preapproved by the Authority.

The individual components shall be capable of being assembled on site to conform to the finished structure as indicated on the drawings.

.07.02 Welding

All welding of steel shall conform to CSA W59.1-M1989 and CSA W47.1-1983.

.07.03 Delivery and Packaging

Unless otherwise specified by the Authority, all panel material shall be packaged so as to avoid damage during and after delivery.

.07.04 Concrete

All concrete products shall conform to the requirements of OPSS 1350 unless otherwise specified by the Authority.

.07.05 Marking

Each noise barrier panel shall be marked to assist in consistent orientation of the panel during installation.

Each panel and/or bundle of panels shall be marked in a position readily visible for inspection with the following information:

1) Name or trade mark of manufacturer.

2) Identification of plant if manufacturer has more than one plane.

3) The lot and/or date of manufacture.

.07.06 Dimensions and Tolerances

All dimensions and tolerances shall conform to the manufacturers specification as pre-approved by the Authority.

.08 QUALITY ASSURANCE

.08.01 Certificate of Compliance

Test certificates for each production lot supplied, showing compliance with all requirements of this specification, shall be obtained by the Contractor and submitted to the Engineer prior to installation.

.08.02 Sampling

One panel per 1000 (minimum 3) will be selected at random by the Authority as soon as the material arrives at the job site. The samples selected shall be cut to a length of 1 m and used for testing by a laboratory designated by the Authority for compliance with this specification.

.08.03 Testing

.08.03.01 Concrete

Concrete products shall be tested in accordance with sections 05.02 and 05.05 of this specification.

08.03.02 Steel Panels

Steel panels shall be tested for metal and coating thickness.

.08.04 Acceptance/Rejection

If any one of the samples fails to comply with any requirements of this specification an additional 3 samples shall be obtained for testing. Failure of any one of these samples shall be cause for rejection of the product.

.09 AUTHORITY PURCHASE OF MATERIAL BY PURCHASE ORDER

.09.01 Technical Information to be Provided in Quotations

Each bidder shall submit with his quotation four copies of the following information to the Authority's Purchasing Office, for preliminary approval:

(a) outline specification and preliminary layout drawing.

If the bidder has previously submitted this information and it has been previously approved by the Authority, only reference to the original submission is required.

posts or other approved means.

.04.02.03.02 **Changes in Alignment**

Changes in elevation greater than 2% shall be performed by stepping successive sections.

Changes in horizontal and vertical alignment shall occur at the posts by suitable means which will avoid acoustical leakage.

.04.02.03.03 **Panel Orientation**

Corrugated or ribbed panels must be mounted such that the features are oriented vertically. Any horizontal ledges or areas for perching, nesting of birds or collecting of dirt and debris must be avoided in the design of the noise barrier system.

.04.02.04 **Acoustics**

.04.02.04.01 **Effective Sound Transmission Loss**

The random incidence sound transmission losses of the panel material when tested in accordance with ASTM E90-87 shall have an effective sound transmission loss of $T \geq 20$, computed from test results in accordance with MTO, Research and Development Report AE-81-01, November, 1981.

Testing of materials in accordance with ASTM E90-87 is NOT REQUIRED IF the following conditions are met.

1) The density of the (non-corrugated, flattened-out) panel material shall not be less than 30 kg/m^2 if metal, brick, concrete or fibre reinforced plastic are used. The density shall not be less than 60 kg/m^2 if wood is used.

2) The Effective Sound Transmission Class (ESTC) of the panel material is demonstrated to be 32 or greater.

.04.02.04.02 **Noise Reduction Coefficient (NRC)**

The panels must be tested in accordance with ASTM Standard C423-89 and placed in accordance with ASTM Standard E795-83, mounting type 1 (free standing) to determine the NRC of the material.

Any panel design which has an NRC rating equal to or greater than 0.55 will be considered as sound absorptive. All others will be considered as sound reflective.

The NRC rating must appear on the design drawing in the following form:

For sound reflective barriers - NRC < 0.55
For sound absorptive barriers - NRC ≥ 0.55 one side
or
NRC ≥ 0.55 both sides

.05 **MATERIALS**

.05.01 **General**

Any material used in the construction of noise barriers must meet the specified requirements for sound transmission loss and structural design.

All materials shall be durable with a predicted maintenance free lifespan of 20 years.

All exposed steel components shall be hot dip galvanized after fabrication in accordance with the requirements of CSA Standard G164.

All materials must have a minimum Flame Spread, Smoke Developed and Energy Contributed classification less than or equal to red oak when tested in accordance with CAN/ULC-S102.2-M88.

All exposed material must be impervious to ultra violet light.

.05.02 **Steel Panels**

Any profile which is vertically mounted is acceptable. Panels must be constructed of minimum 0.91 mm (nominal) galvanized steel (20 ga.) and coated with a "Barrier Series" coating system 0.2 mm thickness on the traffic side of the panel and a 0.1 mm thickness on the reverse side.

.05.03 **Concrete Panels and Posts**

All concrete panels and posts shall have a nominal minimum 28 day compressive strength of 30 MPa.

Three panels will be selected at random by the Authority for the purpose of compressive strength testing. Nine tests will be conducted on each panel. Each test shall consist of a pair of 50 mm (±1 mm) cubes taken adjacent to each other. Capping and compressive strength testing will be carried out in accordance with the requirements of CAN3-A23.2-9C-M90 and CAN3-A5-M88 respectively. The cubes shall be tested in the saturated surface dried condition. The load shall be applied perpendicular to the axis of the panel (in the vertical direction). The average strength of a pair of adjacent cubes shall constitute a test result. The mean and standard deviation of all the test results will be calculated for each set of three panels.

Requirements:

1. The specified 28 day strength of the concrete shall be 30 MPa.

2. The mean strength shall be at least 1.4 standard deviations higher than the specified nominal minimum 28 day strength.

3. No individual test result shall be more than 3.5 MPa below the specified nominal minimum 28 day strength.

The panels and posts shall also be tested for durability (salt scaling resistance), with no failures after 50 freeze/thaw cycles, when tested in accordance with OPSS 1352.08. If the samples are not able to contain the salt solution, the specimen will be considered to have failed the test.

.05.04 **Wood Panels and Posts**

All wood products shall be pressure treated and shall be identified using certification marks authorized by the Canadian Wood Preservers Bureau (CWPB) and the National Lumber Grades Authority (NLGA). The panels must be laminated in accordance with CAN/CSA-O122-M89. All glues must be water resistant in accordance with CSA O112-M1977. Nails and other fastening devices must be either galvanized or made of non-ferrous metals.

.09.02 Shop Drawings

Within thirty calendar days of receipt of a purchase order to supply the material specified herein the supplier shall submit to the Authority's Purchasing Office, six copies of the following information;

(a) detailed dimensioned layout shop drawings, including plans, elevations, sections and foundation details;

(b) detailed bill of materials.

Drawings submitted for approval will be given final approval by the Authority if found to be acceptable, or will be marked with corrections if found to be non-acceptable. Non-acceptable drawings will be returned to the supplier for correction. The supplier shall resubmit six copies of corrected shop drawings within fourteen calendar days. When the resubmitted drawings are found to be acceptable by the Authority, they will be given final approval. One copy of the final approved drawings will be returned to the supplier along with written notification of acceptance.

Installation of the noise barrier shall not commence until the supplier has received final approved shop drawings and written notification of acceptance.

.09.03 Inspection

All work is subject to an inspection by the Authority's representative prior to shipment.

The supplier shall notify the Authority of the date that the fabrication of the noise barrier commence.

The Authority's representative shall have free access to the place of manufacture of the noise barrier components while work on the contract is being performed for the purpose of inspecting and examining plant records and certificates, materials used, process of manufacturing including welding, galvanizing, and precasting and to make any tests as may be considered necessary.

.09.04 Measurement of Payment

The unit of measurement for payment will be made on the basis of length of each differing height of barrier.

.09.05 Basis of Payment

Payment at the contract price for noise barriers shall be full compensation for all labour, equipment and materials required for the manufacture, testing, supply and delivery at the time and at the place specified.

.05.10 DESIGNATED SOURCES REQUIREMENTS

In order for a supplier to be considered for addition to the MTO Manual of Designated Sources for Materials, the supplier shall provide the following:

i) The trade name of the product.

ii) The manufacturer's name and address, manufacturing (plant) where the product is produced, and, if applicable, the supplier's name and address.

iii) All design calculations.

iv) Detailed drawings of the entire noise barrier system and all its components.

v) A general statement as to the composition of the material and method of its production.

vi) Results of the tests required by this specification.

vii) Specifications regarding installation requirements as well as sequence of construction.

viii) Noise reduction coefficient report for the noise barrier system if the noise barrier is to be considered as sound absorptive.

Approval of the noise barrier will be based not only on the test data submitted with the application but also on results of the MTO laboratory and field tests.

If the sample conforms to this specification and MTO is satisfied that the supplier has the equipment and ability to consistently produce acceptable material in bulk quantities, then the MTO will list the supplier in the Manual of Designated Sources for Materials.

When a noise barrier system is approved, its design formulation and method of production shall not be changed without the Authority's knowledge. If a change is made, this Authority's reapproval will be required for that manufacturer to remain on the designated sources list.

All drawings and calculations shall bear the seal and signature of a Professional Engineer who is licensed by the Association of Professional Engineers of Ontario.

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