Multi-Level Roadway Noise Abatement

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16. ABSTRACT

Noise from multi-level roadways poses a serious problem in the congested urban settings where such roadways are used to conserve precious urban real estate. This report addresses this problem and proposes a workable solution, which calls for adding acoustical absorption to the underside of the upper deck(s). Additional benefits can be had if roadside noise barriers are used in conjunction with the absorptive treatment. The approach is cost effective for crowded urban areas where large numbers of people are exposed to the noise pollution created by this type of design.

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Final Report

Research Project GC 8286, Task 39
Traffic Noise — Two-Level Structures

MULTI-LEVEL ROADWAY NOISE ABATEMENT

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DISCLAIMER

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CONCLUSIONS AND RECOMMENDATIONS

Noise reflection from the underside of multi-level roadways can cause serious noise pollution problems, but these are treatable with present state-of-the-art materials in commercially available systems. In sensitive areas, the cost-to-benefit ratio is relatively low, and the solution described here provides a tenable approach to solving the problem created by these structures.

PRIMARY RECOMMENDATIONS

Improvement can be made in the noise environment in the Seattle waterfront district by controlling the noise from the SR-99 Alaskan Way Viaduct. This project demonstrated that the largest portion of the noise coming from that multi-level roadway structure is caused by lower deck traffic noise reflected from the underside of the upper deck. Next in importance is the direct noise from these traffic lanes. (Techniques for dealing with both of these sources of noise are discussed in detail in the report.) A realistic approach to solving the problem follows.

We recommend that a unified program be applied to control the noise from the SR-99 Alaskan Way Viaduct.

First, to control the reflected noise from lower deck traffic, the underside of the upper deck should be treated with fiberglass (bare) backed, perforated metal panels mounted in the suspended ceiling fashion.

Second, roadside noise barriers should be erected on both sides of the lower and upper deck of the viaduct. These noise barriers would consist of a solid, 3-foot-high barrier of the same fiberglass backed, perforated metal construction.

Third, an additional 3-foot transparent section of 3/4-inch PLEXIGLAS type material should be installed above the roadside barriers on the upper and lower decks.

The anticipated noise reductions from the measures are listed in Table 1. Although these treatments are listed separately, they are interdependent. The anticipated

Table 1. Anticipated Noise Level Reductions for the Three Elements of the Unified Noise Reduction Program

Treatment	Anticipated Reduction dB
Underside absorptive treatment	5 - 7
Absorbent noise barriers	1 - 3
Plexiglass extension	1

noise level reductions listed presume that the item above them has been implemented previously.

ADDITIONAL RECOMMENDATIONS

The recommendations above are passive, in that they do not require any changes in patterns by users of the viaduct or other streets in the area of investigation. Additional benefit could be obtained by restricting vehicle operators.

Trucks and Heavy Vehicles

Trucks are much more noisy than automobiles, and the location of the noise sources on the vehicle are different, also. Noise exposure in the waterfront area could be reduced by restricting traffic on the SR-99 Alaskan Way Viaduct to passenger vehicles. Banning trucks could yield 4 to 5 decibels additional reduction.

Vehicle Speed

Noise from freely flowing traffic, such as that on the viaduct, is heavily dependent on the speed of the vehicles. A drop in mean speed from 50 MPH to 40 MPH could be expected to reduce the noise level by 2 decibels. If both heavy and medium trucks could be banned, then reducing the speed from 50 to 40 would result in a reduction of about 4 decibels. Because speed is generally set at the 85th driven percentile, merely posting a new speed limit might not be adequate to ensure compliance.

Surface Traffic

When the noise from the elevated roadways is controlled, the noise from vehicles on the surface streets will take on new proportions. This was amply demonstrated during the measurement session. When the traffic noises were recorded, two particularly noisy trucks, a garbage truck and a fire truck, drove by on Alaskan Way while the traffic on the lower deck of the viaduct was halted, thereby causing the reading at the waterfront location to be abnormally high.

We recommend that through-truck traffic be prohibited on the Alaskan Way surface street during peak visitor times, say from 9:30 am to 8:00 pm. Some benefit will occur when the routing to the ferry terminal is reversed so that its approach is from the south.

Roadway Surface Treatment

A particularly important source of traffic noise is noise created at the tire/road interface. Recent studies have shown that noise can be reduced by as much as 5 decibels by the choice of the roadway surface. Open-graded asphalt concrete has been found to be especially effective at reducing noise caused by this interaction. For this reason, we recommend that the roadways of the SR-99 Viaduct be resurfaced with this material. One of the additional benefits that accrue from the use of open-graded asphalt is that spray from heavy vehicles is greatly reduced during wet weather.

Lower Deck Underside Treatment

Noise from traffic on the surface streets also contributes to the noise at the surface level. Such noise could be reduced by applying the same absorptive treatment to the underside of the lower deck that is recommended for the upper deck. The noise reduction would not be as profound, but additional improvement would be noticed.

INTRODUCTION

THE PROBLEM

Multi-level roadways are popular in congested urban settings because they occupy less of the scarce land area. On the other hand, because they are used in congested areas, they are likely to be near large numbers of people. This proximity creates substantial environmental impacts that range from view obstruction to noise pollution. Despite the obvious noise problem that is associated with this design, little in the literature indicates that a remedial approach can solve the problem. A library search of the subject revealed only one study conducted in this country [1], and one recent study performed in Hong Kong [2].

The purposes of this study were to investigate the unique noise problems created by multi-level roadway structures and to propose remedial actions that can be taken to reduce the noise impacts of these roadways on communities.

The approach taken included looking at a particular multi-level roadway structure that was the subject of recent concern, analyzing the problem, and proposing a solution to the problem.

The structure studied was the SR-99 Alaskan Way Viaduct in Seattle, Washington. A sectional view that looks south of the structure and includes adjacent surface features is shown in Figure 1.

THE ALASKAN WAY VIADUCT

The City of Seattle has formulated a plan to beautify the Elliott Bay waterfront and to develop it into a pedestrian oriented center of attraction. Noise from the nearby SR-99 Alaskan Way Viaduct is a prominent environmental pollutant in the area. The city desires to mitigate the noise to enhance the appeal of the area to tourists and visitors. The

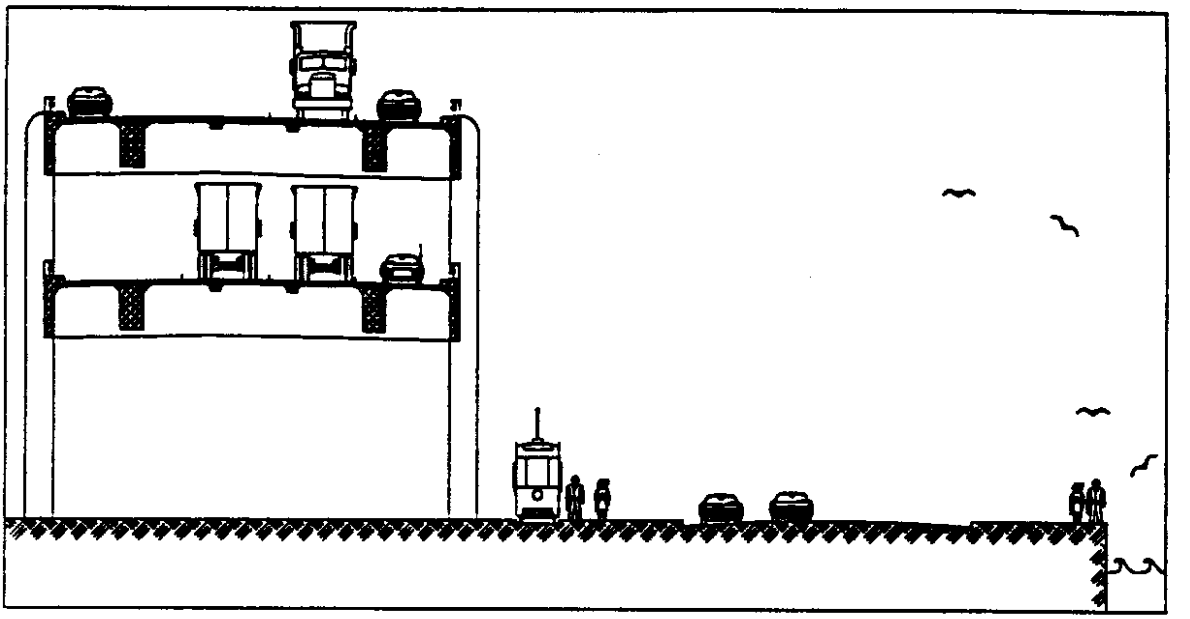

Figure 1. Section View of the SR-99 Alaskan Way Viaduct Looking South

area to be developed lies between the water's edge and the viaduct, which is a stacked express roadway connection between Aurora Avenue and East Marginal Way South.

The viaduct is a section of SR 99 and is owned by the Washington State Department of Transportation (WSDOT). Maintenance of the bridge structure is the responsibility of the city through an agreement with WSDOT. The structure carries traffic on two elevated decks. The upper level has three through-lanes of northbound traffic and the lower level has three lanes of southbound traffic. On each deck are also on- and off-ramp lanes, so that the total number of lanes may be three to four at any given location. In most locations there are only three lanes. At the site investigated in this study, the upper deck exits to Seneca Street with a sharp turn to the east. An additional exit lane is provided for this purpose, and a similar extra lane is on the lower level, although the lower deck lane was not in use. Average traffic volume is 89,500 vehicles per day, with a posted speed limit of 50 MPH.

The district to be developed is typical of a city center location where numerous noise sources abound. The waterfront is a few blocks west of the commercial center of

the city. The viaduct was built over an existing service road, Alaskan Way, and railroad tracks in 1951. Alaskan Way is a four lane surface street that services the waterfront businesses and the WSDOT ferry terminal. The tracks were moved from under the viaduct, but they run parallel and adjacent to the viaduct. The city has an agreement with the owner of the tracks stating that the railroad company will eventually cease to use the tracks; however, a tourist oriented trolley runs on surface rails next to Alaskan Way and the viaduct. A considerable amount of surface level traffic on side streets in the area also contributes to the overall noise.

While the other noise sources create a typical urban noise environment, the high volume of traffic and the high speed limit on the viaduct produce additional noise impacts near the development. The noise is inconsistent with the desired tranquil, park-like development. The purpose of this investigation was to determine the feasibility of applying noise control techniques to abate the noise impact from this multi-level roadway.

EXISTING CONDITIONS AND STUDY PROCEDURES

To assess the severity of the problem and the potential for mitigating the problem, the site was visited on numerous occasions, and measurements of the existing conditions were made. The location was near the heart of downtown Seattle, so numerous sources contributed to the noise in the neighborhood. The viaduct traffic was only one of them. For convenience, we will refer to the two levels of traffic as individual noise sources.

Traffic on the viaduct was a major contributor to the noise in this district, but a couple questions had to be answered before the study proceeded. These were the following: could the noise burden caused by this traffic be reduced at the street level, and could it be done economically?

To better understand the problem, a two-pronged approach was taken; in one, the actual noise levels were measured, and in the other, noise levels were calculated with the STAMINA 2.0 [4] computer program.

NOISE MEASUREMENTS

After visiting the site several times, we thought we had identified the cause of the noise problem by using our most sensitive instruments — our ears. The largest contributor to the noise at street level was obviously the traffic on the lower deck of the viaduct (the southbound traffic), but we needed to know how this contribution compared to the northbound traffic and the overall background noise. It is important to have quantitative information on the relative levels of different noise sources because if several major sources are at about the same level, the noise from all of them must be reduced to accomplish substantial noise reduction. On the other hand, if one source dominates, then reduction of the noise from that source can improve the noise environment.

The standard practice for quantifying and ranking of noise sources in the noise control profession is to measure the noise level with all the contributing sources, then to turn off individual suspected sources and measure the noise level, one after another. This

process is often easy to do when the sources are distinct. For instance, one can simply turn off a machine in a factory. However, we feared that we could not so easily turn off a stream of traffic on the second busiest north-south thoroughfare in Seattle.

Fortunately, we had excellent cooperation from the Seattle Police Department. It agreed to undertake a "rolling slowdown" for us on each level of the viaduct at any time except rush hour. In a rolling slowdown, several patrol cars (one for each lane) enter the traffic stream, line up abreast, and simply slow to a stop. Traffic would be held up for a minimum of five minutes in each direction, and we had to make our measurements during that period. We would also make a similar recording a few minutes before the other recordings with freely flowing traffic in both directions. Unfortunately, it was not possible to stop traffic in both directions simultaneously. We later learned that the Alaskan Way surface street was also a major noise contributor, and it, too, should have been stopped for some of the measurements. During the measurements, its counted volume was as high as 798 vehicles per hour, with 13 percent trucks. The effect this additional noise had on the analysis will be shown later. (See the discussion of the data in Table 3.)

We would have one shot at this measurement, so we had to muster a relatively large "army" to ensure we got all of the data.

Two tape recorders were used to make the recordings. Noise was recorded at three locations, one on the waterfront, or west, side and two on the city, or east, side of the viaduct between Seneca and Spring Streets. The city side locations were in a parking lot on the opposite side of the viaduct and were designated Space 99 and Space 92, the parking space numbers. Space 99 was the same distance from the edge of the viaduct as the waterfront location. Space 92 was chosen because it was the same distance from the viaduct as the boarding platform for the waterfront trolley. The city side was chosen to protect the microphone cables from traffic on the surface streets and tracks. Although the

distances from the edge of the structure were the same, the eastern sites were further from the Alaskan Way surface street, which was the major surface arterial in the area.

Three observers were stationed atop a parking garage that was level with the upper deck of the viaduct. Two counted and classified traffic in both directions, and the third timed a number of the vehicles over a measured distance to determine the average speed. Others recorded similar data for traffic on surface streets and staffed the three microphones to ward off inquisitive pedestrians.

Subjectively, the measurement session was highly enlightening. Traffic was stopped on the upper deck first, and the observers noted a slight reduction in the noise level. The amount of reduction was not enough to be substantial, so we waited with anticipation for the traffic to be stopped on the lower deck. The results were impressive. Observers exchanged gazes of astonishment, too surprised to speak and afraid that any comments would be picked up by the microphones and ruin the results. Clearly, most of the noise came from the lower deck.

To obtain the quantitative comparison, the noise levels were averaged over the respective five-minute periods with the energy average method. The results are shown in Figure 2. A small improvement was achieved by stopping the northbound (upper deck) flow, and a greater improvement was achieved by stopping the southbound (lower deck) flow. These results were consistent with our earlier subjective observations; that is, these measurements verified that the predominant noise source heard at the street level was traffic on the lower deck of the viaduct. In fact, these measurements indicated that, although traffic counts and speeds on the upper and lower decks were comparable, traffic from the lower level of the viaduct accounted for approximately 71 percent of the street level noise, while traffic on the upper level accounted for only about 17 percent of the noise. These data are also presented in tabular form in Table 2, below.

We had suspected for many years that reflection was the cause for the difference in the measured noise levels, and these tests confirmed our suspicion.

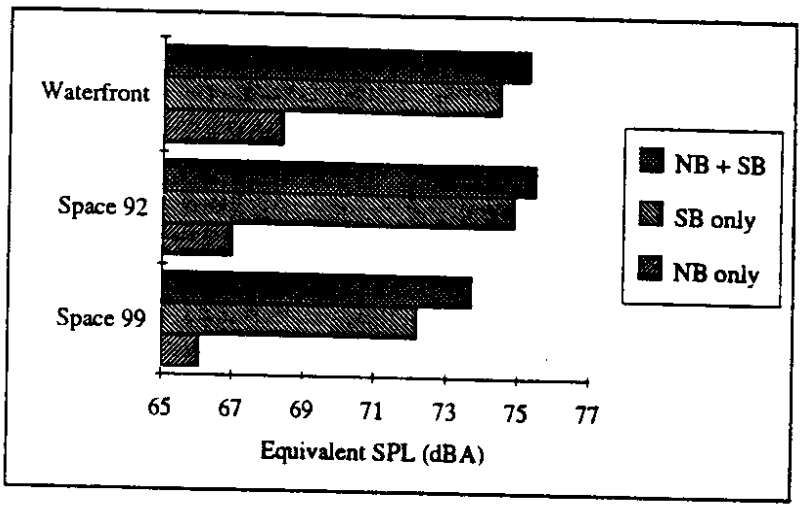

Figure 2. Bar Graph Showing the Changes in the A-weighted SPL at Three Measurement Locations

Table 2. Measured Noise Data for the SR-99 Alaskan Way Viaduct

Measurement Location	Lanes Running	Measured S.P.L. dBA	Reduction dB
Space 99	NB+SB	73.7	
	NB	66.1	7.6
	SB	72.2	1.5
Space 92	NB+SB	75.5	
	NB	67.0	8.5
	SB	74.9	0.6
Waterfront	NB+SB	75.3	
	NB	68.4*	6.9
	SB	74.5	0.8

* Adjusted value to exclude rare events from five minute sample.

TRAFFIC NOISE MODEL

STAMINA 2.0 is a computer program that predicts noise levels near highways and other roadways due to traffic. It is the most accurate and readily available program for this purpose in the U.S. Our experience in WSDOT District 1 has been that STAMINA produces results that agree with measured noise levels to within ± 2 decibels.

STAMINA is able to model a number of roadways, barriers, and receptor locations. Input data include roadway traffic volumes, mixes, and average speeds; roadway locations (including elevation and incline); barrier locations; and receptor

locations. Curving roadways must be made up of several linear sections, and in some cases, individual lanes are represented as separate roadways in this program. STAMINA does not calculate noise levels from stationary or other background noise sources, of course.

In this study, measured noise levels were calculated with the STAMINA 2.0 traffic noise model. As-built plans of the SR-99 viaduct were used, together with field survey distance measurements, to obtain accurate locations of traffic lane edges on the bridge, microphones, buildings, and other objects. The program was run several times to simulate the geometry and conditions at the three test locations. The individual lanes were treated independently, and the line of traffic was extended approximately one block beyond Spring Street to the south and Seneca Street to the north. The edges of the viaduct decks were modeled as barriers to the noise from the traffic on the respective levels. The Seneca off-ramp was modeled as a series of linear sections to represent the curve of that roadway. The Alaskan Way surface street was modeled as a single line source.

The first few computer runs were modeled exactly as the field conditions suggested but without coding for the reflections. The results that were obtained from these runs differed from the measurements by 0.7 to 11.0 dBA.

We expected differences to indicate reflection amounting to about 7.5 dBA. This had been first observed in 1985 while a noise report was prepared for an I-90 EIS. It, too, was to have been constructed with a two-level section, and a method was needed to calculate noise levels for that future roadway. A section of the SR-99 Alaskan Way Viaduct was used to develop the method. In that study, STAMINA results were compared to data from actual measurements. The section chosen for the measurements was away from surrounding buildings and surface traffic. The method developed for that project involved coding STAMINA to include a modified image roadway reflection. This STAMINA coding method would be used in this study's analysis, also.

The calculated data with the modified SB image reflections are compared with the measured data in Table 3.

As has been indicated earlier, the chosen study site was influenced by traffic on the Alaskan Way surface street. For example, the STAMINA computer output showed that most of the noise at parking space 92 when the northbound lanes were closed came from the surface street. The measurement at this location would have included noise reflected from the underside of the bottom deck. Bottom deck reflection of surface level traffic noise was not coded in the STAMINA model.

Table 3. Comparison of Measured and Calculated Noise Levels Measurement

Measurement Location	Lanes Running	Measured dBA	STAMINA dBA	Difference dB
Space 99	NB+SB	73.7	<70.0	3.7
	NB	66.1	64.3	1.8
	SB	72.2	69.3	2.9
Space 92	NB+SB	75.5	71.6	3.9
	NB	67.0*	63.5	3.5
	SB	74.9	71.3	3.6
Waterfront	NB+SB	75.3	72.7	2.6
	NB	68.4**	69.1	0.7
	SB	74.5	72.4	2.1

* The measured value includes reflected noise of heavy trucks and other traffic from the Alaskan Way surface street that bounced off the underside of the lower deck. This condition was not expected to be a problem and was most obvious when the southbound traffic volume was low or stopped.

** Adjusted value excludes several heavy trucks and other rare events from the five-minute sample. The one-minute L_{eq}'s in this time period ranged between 67 and 71 dBA.

DISCUSSION

The measured noise levels indicated that the noise from the lower deck was much higher than that from the upper deck. The lower deck was closer to the street, of course, but the difference attributable to this effect should have been relatively small.

The explanation for this difference is that the noise from vehicles on the lower deck was reflected downward from the underside of the upper deck, and the effect was more pronounced for locations that were closer to the viaduct. The noise level decreased directly under the viaduct because the lower deck shielded the roadway from traffic noise.

The results of our tests in which we stopped the traffic gave a good idea of the greatest improvement that could be expected from any noise abatement plan for the viaduct. Our objective, then, was to investigate how closely we could approach this limit.

In the following sections, we will discuss ways of accomplishing this goal.

TYPICAL NOISE PROBLEM

Let us look at this problem as a typical noise problem and investigate where we can apply our skills to reduce the problem.

Typically, a noise problem consists of a source and a receptor, which are connected by a transmission path for the noise. The relation between these elements is shown in Figure 3. The figure shows that characteristics of the source influence the way the receptor reacts to the noise, which is specified by the criteria by which the noise is evaluated. The path can modify the source characteristics to make the noise more acceptable to the receptor, usually by reducing the noise level perceived by the receptor.

Receptor — Criterion

The criterion that we use to evaluate the severity of our noise problem is the A-weighted Equivalent Noise Level L_{eq}, which has been adopted fairly universally

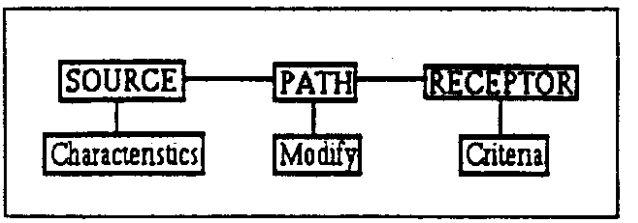

Figure 3. The Elements of a Noise Problem

throughout the world for rating traffic noise. This will be accepted as a given for the problem we are investigating.

Source — Characteristics

The noise characteristics of traffic noise sources have been investigated and have been documented. The computer program STAMINA is one source of this documentation. In this data bank are stored data on an average automobile, an average medium truck, and an average heavy truck. These were obtained from measurements on a large population of vehicles on average American highways. Taken as a whole, little can be done at the local level to reduce the noise generated by Fords, Toyotas, or Kenworths.

However, a number of parameters affect the noise output from a stream of traffic, and some of these can be used to control noise. These are speed, vehicle mix (percentage of trucks and other heavy vehicles), and roadway incline.

Path — Modifications

The most promising way to control noise is to modify the path between the source and receptor in such a way that the noise is not as objectionable to the receptor. Usually, this can be accomplished by inserting barriers of some sort in the path, moving either source or receptor so that the path length is longer, or absorbing some of the noise energy with materials that do this efficiently.

NOISE PROBLEM SOLUTIONS

People have suggested on more than one occasion that the Alaskan Way Viaduct should be torn down. This would solve the noise problem from this multi-level roadway, but it is not a practical solution.

Another solution is to enclose the roadways. However, this is an expensive proposition and would lead to other problems, such as view blockage. One of the principal difficulties with this approach is that the roadways would then have to be ventilated, and the cost of that type of treatment would be prohibitive. The additional load on the columns would pose a support problem, as well.

The two of the most important paths of noise transmission, direct and reflected, are shown in Figure 4. Note that the direct paths for the upper and lower decks were quite similar. The main difference in the way that noise from the two decks was transmitted to the surface level was that noise from traffic on the lower deck could be reflected or bounced from the underside of the upper deck.

Comparison of the difference in the noise levels measured for these two conditions showed that the noise from the lower deck was much louder than that from the upper deck. From this result we concluded that the major portion of the noise from the lower deck came from noise reflected from the underside of the upper deck. The STAMINA calculations led to the same conclusions. The differences between the measurements and normal coding indicated that the southbound lanes were producing an abnormal amount of noise.

The amount of attenuation depends on the location of the receiver. Those closer to the stacked roadway will receive more relief by implementation of these measures. On the other hand, those further from the roadway are less seriously affected by the noise from the roadway.

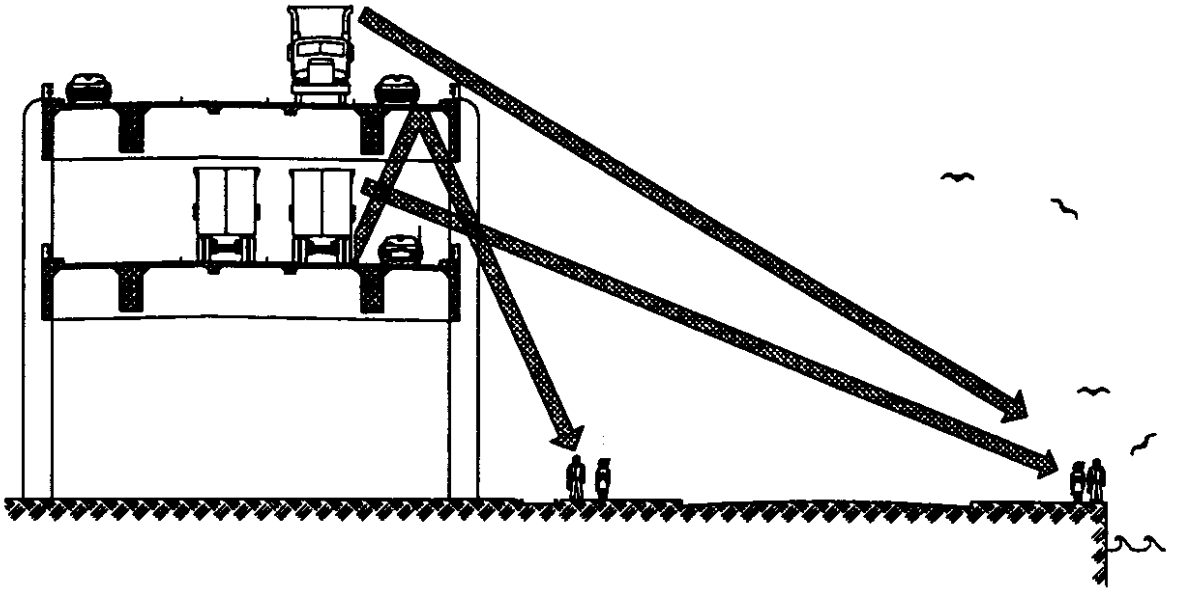

Figure 4. Schematic View Showing Noise Transmission Paths of Traffic Noise

The most effective way to control noise from this structure would be to eliminate the unwanted reflections. These reflections could be reduced by a couple of methods.

Unpainted concrete, like the underside of the decks of the viaduct, reflects between 98 and 99 percent of the sound that strikes it. Traffic noise from the lower deck striking the under-side of the upper deck reflects down to the roadway, which is also concrete, which in turn reflects the sound. Thus, the noise ricochets up and down, building until it reaches the side openings, where it spills out. Some of the sound goes up into the atmosphere and causes no more problem, but much of it is directed down to the street level, where it creates a serious pollution problem. If one of these surfaces were to be treated with a material that absorbed the sound incident on it, the reflected noise would be reduced. Sound absorbing materials are usually soft and porous, so they can not be used on the roadway surface, and while these materials pose some problems in terms of their weather resistance, this type of treatment can be reasonably expected to help reduce the reflected noise in this type of application. Because this approach is so promising, it will be discussed in detail later in this report.

The opening on the waterfront side of the viaduct could be closed in. This alternative would have the additional benefit of blocking the direct noise path, as well as the reflected noise path. To preserve the aesthetic quality of the waterfront drive, the wall could be made of a transparent material so that occupants of vehicles on the viaduct could see the scenery. Transparent plastics are made in suitable sizes and thicknesses to be used for this application, and, in fact, similar barriers are used frequently in Europe. Only one side could be closed in without requiring the expense of providing an enormously costly ventilation system.

The transparent panels are also good reflectors of sound. With the opening closed off with a good sound reflector, the noise would be reflected back onto the roadway, where it would build up even more, and eventually it would spill out the opposite side of the viaduct.

Along some portions of the Alaskan Way right-of-way, offices on the city side of the viaduct face the viaduct. In these areas, closing off the waterfront side of the lower deck would direct more noise toward these properties. Clearly, this would be an unacceptable solution to the noise problem on the street level, so the absorptive ceiling remains the preferred option.

When the dominant reflections are under control we can look at reducing noise from the other sources.

The open railings that now line the roadways offer no obstruction to noise, and they should be replaced with solid, noise control barriers. These could be partial-height walls that function in the same way as highway noise barriers. An appealing idea would be to use partial walls in conjunction with the sound absorption treatment on overhead surfaces mentioned above. Barriers could be used on the upper deck to reduce the noise from traffic on that level, as well. The use of sound absorptive treatment on these barriers would enhance their performance, particularly in reducing noise from tire/road interaction and engine and machinery noise from low slung passenger vehicles.

NOISE ABSORPTIVE MATERIALS AND SYSTEMS

Examination of the results of the field measurements proved that noise reflected from the underside of the deck structures was the major contributor to noise along the waterfront. One of the most effective ways to attack the problem of reflected noise is to provide an absorptive treatment to this surface. With this approach, a reduction of about 7 to 8 dB might be expected on the basis of the measurements taken in this study and shown in Table 2.

For the most part, sound is not attenuated until it strikes a surface. That is, little energy is lost during the propagation of sound in the air over normal distances. The most common way to absorb sound is to convert the sound energy to heat. This is caused by friction when air particles rub against the sides of a porous material. For better absorption, the material should be fairly open and the pores should be small. Open cell plastic foams and fiberglass mat are some of the best sound absorbing materials available, although other products composed of bonded cellulose (wood) or mineral fibers have advantages in certain applications. At least one product on the market consists of a foamed concrete that can be sprayed on the surface to be treated.

As a consequence of these requirements, sound absorbing materials are rather fragile, subject to contamination by airborne aerosols (diesel exhaust), and difficult to clean. Special precautions must be taken to protect these materials from damage and disfigurement.

The absorptive characteristics of a material are described by the absorption coefficient, α, which is the mathematical ratio of the acoustical energy absorbed to the incident energy, expressed as a number between 0 and 1. A perfect reflector has an α value of 0.0, and a perfect absorber has an α value of 1.0.* Absorption is dependent on

* Because of a quirk in the way the absorption coefficient is evaluated, values in excess of 1.0 are sometimes reported.

the frequency of the sound striking the material. In critical applications, this frequency dependency is used to obtain more accurate results. For simplicity, we might want a single number to compare the performance of two or more materials. In such a case, we might use the Noise Reduction Coefficient (NRC), which is an average of the α values in the range of frequencies that are most critical to human conversation, namely the 250, 500, 1,000, and 2,000 Hz octave bands.

To find which options are commercially available and to get an estimate of the cost of applying treatment, letters soliciting information on materials and systems suitable for this type of application were sent to approximately 80 vendors of these materials. The firms were selected from a list of suppliers published in the materials selection issue of Sound and Vibrations, a trade magazine for the noise control professional. Responses were received from about 25 suppliers. From this group, four systems were judged to be viable contenders for use in this demanding environment. These systems are discussed individually and collectively in the sections that follow. The order of presentation is somewhat arbitrary.

PYROK

PYROK is the trade name of a foamed cement product that is sprayed in place to provide the desired acoustical absorption.

Advantages of this treatment are that it can be sprayed directly on the underside of the existing structure, and that it will conform to the existing shape without intricate fitting and fastening of special panels.

Disadvantages are that the absorption coefficients are low in comparison to others in the group, and the application process requires extensive masking of the work area. Application has to be performed in two steps. In step one, the existing surface is cleaned and prepared for application; and in step two, the spraying occurs.

PYROK has the appearance of acoustical ceilings commonly used in residences. It would be very difficult to clean this material.

Figure 5 shows the sound absorption characteristics of PYROK as a function of frequency. The NRC of PYROK is 0.60.

Quilted Fiberglass Blanket

Two vendors proposed the use of quilted fiberglass blankets for this application. The basic product is a layer of approximately 1 inch of fiberglass quilting between layers of a plastic treated fiberglass fabric.

An advantage of this configuration is that installation is very quick. The quilted sections are fabricated at the factory and shipped ready for installation. The sections are then hung in place from studs that are attached to the concrete structure. The quilts are fairly easy to clean.

Disadvantages are relatively low absorption coefficients at higher frequencies, unattractive appearance, and a potential problem with birds nesting in the space between the quilt and the structure.

Figure 6 shows the sound absorption characteristics of the quilted fiberglass as a function of frequency. The NRC of this material is 0.80.

Fiberglass Backed, Perforated Metal

Fiberglass (or other mineral wools) is one of the best absorptive materials available. The fibers are made of spun glass (or slag) and are inert, providing a long life, as long as the material is protected from mechanical tampering. In this application, 2-inch-thick rigid bats of the material would be encased in galvanized and painted steel shells to form panels of convenient size. The face of the panels are made of perforated sheet steel. These panels have nearly the same absorption coefficients as the bare fiberglass bats. Performance degrades slightly at the very high frequencies, but that problem is not considered to be critical in this application. The performance of this type of absorptive element is described in detail in a document entitled, "Acoustical Uses of Perforated Metals" by Theodore J. Schultz [3].

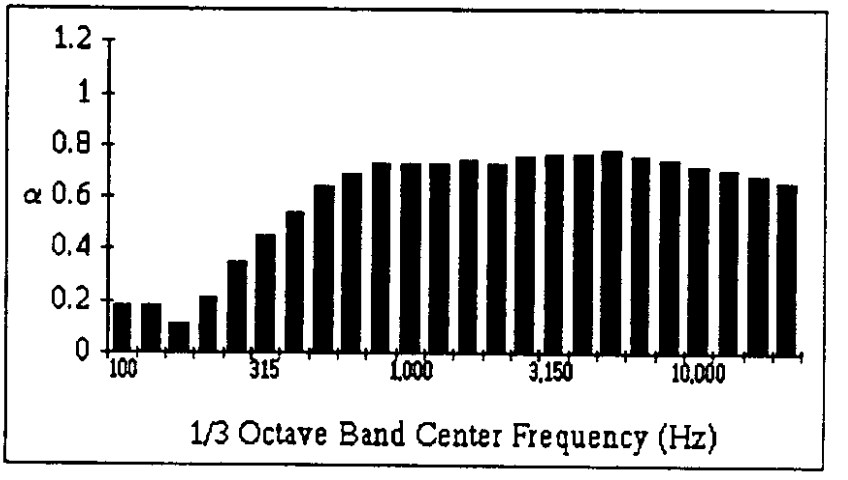

Figure 5. Sound Absorption Characteristics of PYROK Sprayed-on Acoustical Treatment

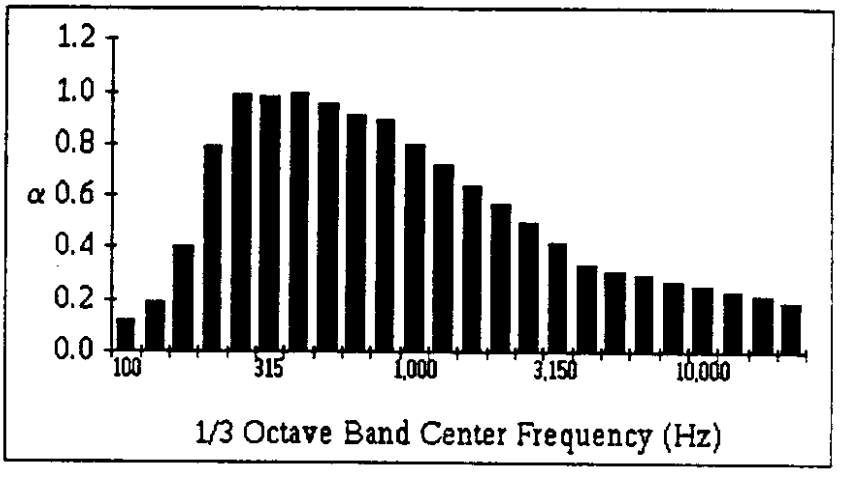

Figure 6. Sound Absorption Characteristics of Quilted Fiberglass Acoustical Treatment

The perforated metal panels could be installed in the viaduct structure in a couple of ways. In the first, panels would be placed directly against and fastened directly into the existing structure (see Figure 7a). Fitting the panels around beams, pipes, filets, and conduit in this option would raise the cost in relation to the second alternative. In this option, the panels would be supported below the existing structure, level with the bottom of the bents (see Figure 7b). The panels are strong enough to support a man, so this

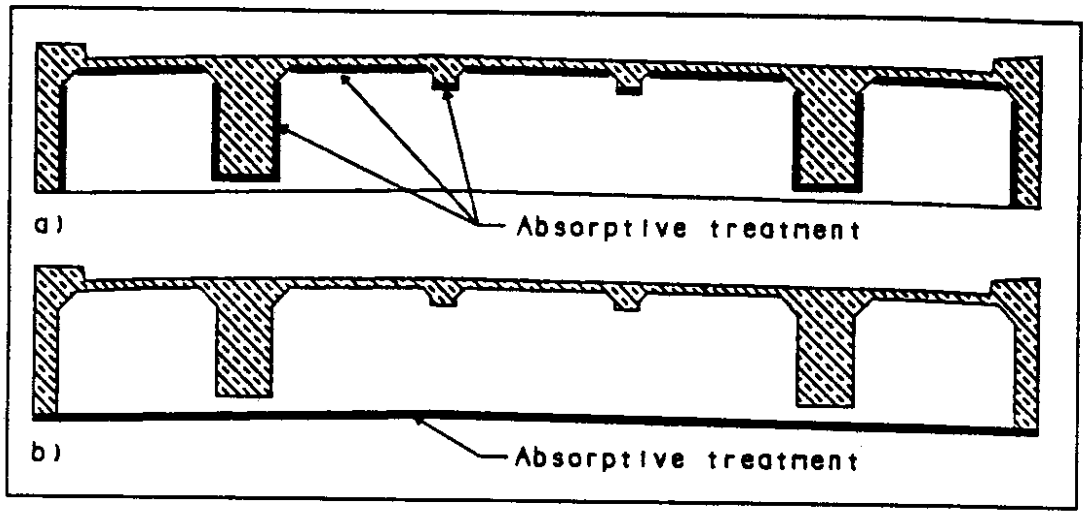

Figure 7a. Shows the Fitted Absorber Treatment; Figure 7b. Shows the Suspended Ceiling Absorber Treatment

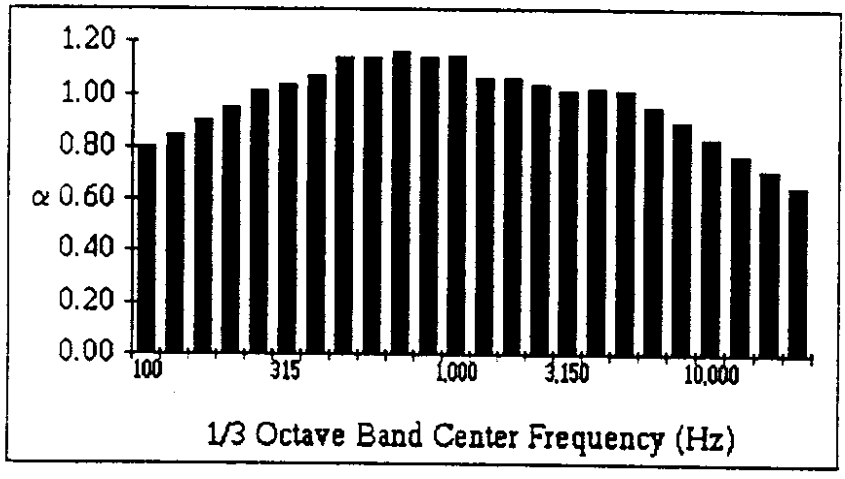

Figure 8. Sound Absorption Characteristics of Fiberglass Backed Perforated Metal Panels

option would provide a crawl space for access to electrical service and for inspection through access holes in the ceiling.

Advantages to this treatment are the highest acoustical performance and attractive appearance. Furthermore, the same treatment can be used on roadside barriers.

The main disadvantage is a slightly higher cost.

Figure 8 shows the sound absorption characteristics of the fiberglass backed, perforated metal panels as a function of frequency. The NRC for this system is 1.05.

Encapsulated, Fiberglass Backed, Perforated Metal

In the previous section, a system in which perforated metal sheets are backed by bats of fiberglass was described. One problem with that system is that particulate material can plug the pores in the metal if they are too small, or saturate the fiberglass in highly contaminated environments. To eliminate the latter of these problems, the fiberglass can be encapsulated in a plastic film, such as TEDLAR. TEDLAR is an essentially inert plastic with high strength characteristics that can be easily formed into film. The plastic film is said to be so thin and light that it moves with the acoustic wave and, therefore, is almost transparent to the wave. A slight degradation of the absorption characteristics occurs across the frequency range, particularly at the higher frequencies.

The main advantage to this system is that it is potentially easier to clean than the bare fiberglass backed, perforated metal. All other comments about that system apply to this system.

Figure 9 shows the sound absorption characteristics of the encapsulated, fiberglass backed, perforated metal panels as a function of frequency. The NRC of this system is 1.00.

COMPARISON OF ABSORPTIVE SYSTEMS

These systems are compared in matrix form in Table 4, below.

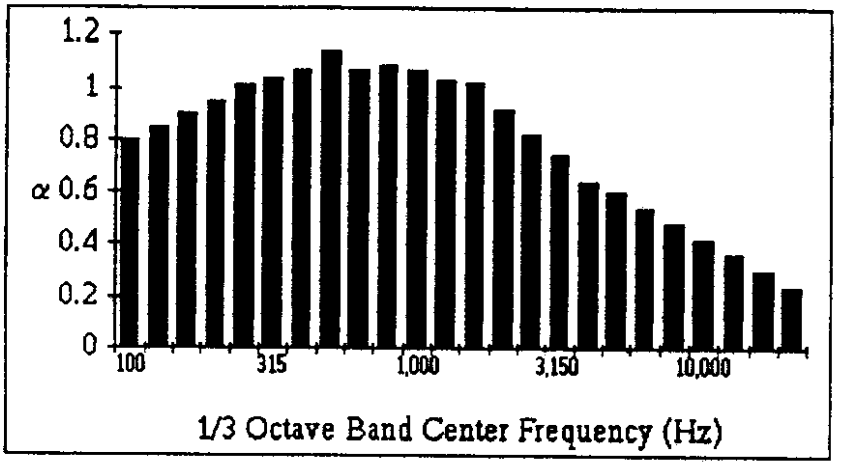

Figure 9. Sound Absorption Characteristics of Encapsulated Fiberglass Backed Perforated Metal Panels

Table 4. Comparison of Performance Characteristics of Four Noise Absorptive Systems

	PYROK	Quilted Fiberglass	Fiberglass Perf Metal	Encapsulated Fiberglass Perf Metal
Appearance	Good new	Poor	Excellent	Excellent
Acoustical Performance	Poor	OK	Excellent	Good
Cost ($/sq.ft. installed)	$3-4	$4-5	$7-10	$8-11
Longevity	?	OK	Good/Excellent	Excellent

NOISE CONTROL BARRIERS

Most traffic noise originates fairly close to or at the roadway surface. Notable exceptions are truck and bus exhausts and truck fans. Noise from these low lying sources is relatively easy to control by means of roadside barriers. However, barriers are only effective when used in conjunction with an absorptive treatment, as discussed above.

Ideally, the barriers should be as high as possible, but aesthetic and economic considerations create practical limits. In view of the proposed treatment of the underside

barriers were installed on the lower deck without treating the upper deck for reflection first. However, we are proposing absorptive roadside barriers.

It is important that waterfront activities remain visible to occupants of the vehicles on the viaduct, so the height of the acoustical treatment is limited to about 3 feet. However, additional improvement could be obtained if the barriers were made higher. The two requirements could be met by designing a 3-foot-high solid barrier topped with a 3-foot-high transparent extension. Disregarding noise from the Alaskan Way surface street and assuming that reflections were controlled, the viaduct roadside barrier effectiveness at the waterfront site would be about a decibel per foot up to 6 feet high. Locations closer to the viaduct would show less benefit because the direct sound path is already partially blocked by the edge of the structure.

APPLICABILITY

While this plan was postulated for the SR-99 Alaskan Way Viaduct in Seattle, Washington, the plan is general in nature and is indicative of solutions that can be implemented in other applications.

A case in point is the I-5 Ship Canal Bridge, also in Seattle. In this structure, the I-5 express lanes are routed under the main lanes, and properties under this structure receive an unusually large dosage of traffic noise. In the Wallingford and North Capital Hill districts, where the bridge terminates, the main lanes form Y's as the express lanes bisect and pass under the arms of the Y. The undersides of the main lanes form massive, flat slabs that are almost perfect reflectors. These reflect the noise from the express lanes into the neighboring communities. It is instructive to visit this site, walk from below the center of the bridge to the edge of the right-of-way, and notice how rapidly the noise level changes as one reaches the edge of the lower roadway.

These areas are prime candidates for absorptive treatment similar to that recommended for the SR-99 Alaskan Way Viaduct.

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