EVALUATION OF BENEFITS AND OPPORTUNITIES FOR INNOVATIVE NOISE BARRIER DESIGNS

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16. Abstract
The primary goal of this project was to identify innovative noise barrier designs that had the potential to be implemented in Arizona. The study initially focused on gathering existing literature on noise barrier materials and designs that were non-conventional. Literature was collected on dozens of noise barrier research projects in 12 countries around the world. Many of the barrier designs consisted of treatments to the top edge of the barrier to change or disrupt the diffraction pathway from the noise source to the receiver.

The results of the previous research studies were compiled into a matrix to assist in evaluating the various barrier designs and materials. The evaluation matrix was used to score the barrier designs based on their acoustic performance, as well as economic, constructability, maintenance, and aesthetic considerations. Also, an attempt was made to identify the processes by which ADOT selects and approves various barrier designs for implementation on a project.

Based on the research and evaluation conducted for this study, it was recommended that two innovative barrier designs be implemented in Arizona – the T-top design with absorptive material placed on the top of the horizontal portion of the barrier and a vertical barrier with absorptive material applied to the face of the barrier. These two barrier designs have been shown in the available literature to reduce noise levels by up to 3 decibels, which could reduce overall barrier heights by as much as 5 feet compared with a conventional noise barrier of concrete or masonry block construction.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE AND PRESSURE OR STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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EXECUTIVE SUMMARY

Innovative noise barrier designs and treatments have been successfully implemented in other states and in other countries for a number of years. These innovative designs have allowed the initial construction of a noise wall to be lower in height than a conventional wall. These techniques have also been used to retrofit an existing noise barrier to achieve a higher level of noise reduction without substantially increasing the barrier height and at a much lower cost than replacing the barrier with a taller structure.

This research project was funded by the Federal Highway Administration through the Arizona Transportation Research Center. The project initially focused on gathering existing literature on noise barrier materials and designs that were non-conventional. The intent was to identify innovative barrier designs that may be considered for implementation by the Arizona Department of Transportation (ADOT). Literature was collected on dozens of noise barrier research projects in 12 countries around the world. Many of the barrier designs consisted of treatments to the top edge of the barrier to change or disrupt the diffraction pathway from the noise source to the receiver. A few innovative barrier materials were also included in the literature review.

The results of the previous research studies were compiled into a matrix to assist in evaluating the various barrier designs and materials. The evaluation matrix was used to score the barrier designs based on their acoustic performance, as well as economic, constructability, maintenance, and aesthetic considerations. The scores were weighted based on the potential reduction in barrier height. The evaluation matrix revealed that the designs with the most potential were a T-top barrier design with absorptive material on the top and a barrier with absorptive material applied to the roadway side or face of the barrier.

The T-top barrier design consists of a vertical barrier with a horizontal cap along the top edge of the barrier, creating a shape that resembles a “T.” The horizontal portion of the barrier is approximately 2 to 3 feet wide and creates a double-diffraction pathway over the top of the barrier, thereby reducing noise levels compared to a vertical barrier of similar height. To increase the noise reduction potential of this barrier design, an absorptive material is applied to the top of the horizontal portion of the barrier. Research has shown that this barrier design reduces noise levels by about 2 to 3 decibels, which could reduce barrier heights by approximately 4 to 6 feet, or about 5 feet on average.

The barrier with absorptive material consists of a vertical noise barrier with an absorptive material applied to the side of the barrier facing the highway traffic. This barrier reduces noise by absorbing noise and eliminating reflected noise off the face of the barrier. In addition, since the absorptive material is applied up to the top edge of the barrier, the diffracted noise over the top of the barrier is also reduced. Research results were less consistent with this barrier design, but typically showed noise level reductions by about 1 to 3 decibels. This barrier design has the potential to reduce barrier heights by about 2 to 5 feet, or about 3.5 feet on average. The application of this barrier design may be most

appropriate in locations with a parallel barrier situation, or when the noise barrier is located in close proximity to highway traffic.

Following the evaluation of barrier designs, an attempt was made to identify the procedures by which ADOT selects and approves various barrier designs for a project. This information serves to provide insight on whether mechanisms are currently in place to offer appropriate consideration to unconventional or innovative noise barrier design alternatives. The review focused on those individuals within ADOT who make noise barrier selections and on the criteria that those choices are based. This task revealed that ADOT does not have a standard process for noise barrier selection and approval. The individual project managers select the design of the barriers and the materials that will be used to construct the barriers.

Based on the research and evaluation conducted for this study, it is recommended that two innovative barrier designs be considered by ADOT – 1) a T-top design with absorptive material placed on the top of the horizontal portion of the barrier and 2) a vertical barrier with absorptive material applied to the face of the barrier. These two barrier designs have been shown in the available literature to reduce noise levels by up to 3 decibels, which could reduce overall barrier heights by as much as 3 to 5 feet compared with a conventional noise barrier of concrete or masonry block construction.

1. INTRODUCTION

Noise barriers have been used by the Federal Highway Administration (FHWA) and the Arizona Department of Transportation (ADOT) for over 30 years to reduce traffic noise levels for highway-adjacent residential areas and other noise-sensitive land uses. As traffic volumes and speeds have increased on highways, noise levels have risen for nearby homes, prompting transportation agencies to look for ways to provide more effective noise attenuation at a reasonable cost.

Noise barriers are typically constructed of cast-in-place concrete or masonry block. In some areas, where space allows and soil material is available, earth berms are constructed as noise barriers. The barriers effectively reduce noise levels, but often cause undesirable secondary impacts, such as blocked views of mountains and other scenic features, decreased visibility from the roadway, or large shadows cast across a resident's backyard for extended periods of the day. Raising noise barriers to achieve further noise reduction often exacerbates these secondary impacts.

Innovative noise barrier designs and treatments have been successfully implemented in other states and in other countries for a number of years. These innovative designs have allowed the initial construction of a noise wall to be lower in height than a traditional wall. These techniques have also been used to retrofit an existing noise barrier to achieve a higher level of noise reduction without substantially increasing the barrier height and at a much lower cost than replacing the barrier with a taller structure.

Some of the innovative materials and designs that have been researched and used in other jurisdictions include transparent panels, semi-translucent concrete materials, acoustical treatments, and specially designed top treatments, such as curved or angled tops, irregular top edges, or T-top treatments. Many of these designs have been shown to either diffuse the sound waves or change the angle of diffraction as they pass over the top of the barrier. The result is a lower noise level for adjacent properties without the secondary impacts of a substantially higher noise barrier.

A vital aspect of evaluating innovative noise barrier designs is the identification and evaluation of the processes and mechanisms for successfully implementing a unique barrier design. ADOT has a long-established process for internal design review, as well as established design standards and construction procedures. These procedures may need to be adjusted to allow the implementation of an unconventional barrier design. In addition to achieving ADOT's internal acceptance of the innovative noise barrier designs, the public would also need to "buy into" the use of a design that is unfamiliar.

The first objective of the research project was to identify and evaluate noise barrier designs that may offer improved attenuation with reduced secondary impacts. A thorough literature search was conducted to collect published research and documentation from other jurisdictions that have successfully used innovative designs for noise barriers. The intent of the literature search was not to focus on proprietary materials or barrier systems, but rather to identify innovative barrier designs. The literature review is presented in Chapter 2 of this report. The results of the literature search were then synthesized to identify barrier designs with potential for use in Arizona. Potential designs were evaluated using a matrix to weigh the advantages and disadvantages of each design. The evaluation is presented in Chapter 3 of this report. Following the evaluation, a short list of alternative noise barrier designs was identified that could be implemented in Arizona.

The second objective of the research project was to detail the procedures and processes within ADOT for the design, specification, and construction of noise barriers. The emphasis of this stage was to identify the process that would be needed to deviate from the standard barrier design and gain internal acceptance of the alternative designs. Details of this investigation are presented in Chapter 4 of this report. A related objective was to involve identifying other processes, such as public involvement and education strategies, to gain the public's acceptance of the unfamiliar barrier designs.

The third objective of the research project was to combine the results of the first two stages of the project and make recommendations of specific noise barrier designs for potential use by ADOT. The recommendations, presented in Chapter 5, specify the scenarios and typical locations where the barrier design may be used most effectively. As part of the recommendations, an implementation guide is presented in the Appendix to assist ADOT decision-makers, FHWA reviewers, and others in the process.

2. LITERATURE REVIEW

This chapter presents the results of the comprehensive literature review conducted for this project. The literature review collected over 50 research reports, technical papers, journal articles, conference proceedings, websites, and brochures documenting theoretical calculations, scale model and full-size testing, experimental field applications, and real-world practical use of innovative designs and materials for noise barriers in a dozen countries on five continents around the world.

T-PROFILE BARRIER DESIGN

Much of the available research focuses on various treatments for the top edge of the barrier. The intent is to alter the hard linear edge that causes diffraction of sound toward receivers behind the barrier. Some of the earliest research identified that a T-profile top edge reduced noise levels in a residential area behind the barrier by 1.0 to 1.5 decibels (dBA), compared with a conventional vertical barrier of the same height (May & Osman, 1980b). Later studies confirmed the benefits of a T-profile top edge in reducing noise levels, even when compared to variations such as Y-profile and arrow-profile barriers (Hothersall, Crombie & Chandler-Wilde, 1991; and Hasebe, 1994).

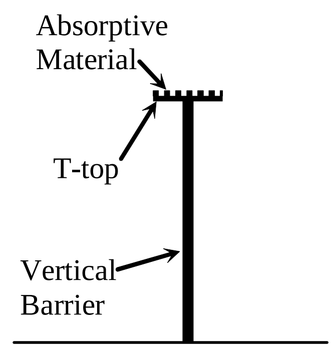

Figure 1. T-top barrier design with absorptive material on top

More recent research into T-profile barriers in the Netherlands has shown that adding an absorptive material to the top horizontal section of the T-profile barrier, as shown in Figure 1, further increases the noise reduction properties of the barrier (Salomons, Vedy & de Beer, 2005; and Noise Innovation Program, 2005). The research showed noise reductions of 2 to 3 dBA at a cost similar to raising the barrier by 3 feet, but did not have the implications for the wall foundation as raising the height of the wall (Noise Innovation Program, 2005).

JAGGED TOP EDGE BARRIER DESIGN

In the late 1990s and early 2000s, several researchers examined the potential noise reduction created by replacing the linear top edge of a noise barrier with a jagged or irregular top edge. The results were mixed, with some researchers demonstrating as much as 6 dBA reduction in noise levels (Busch-Vishniac & Blackstock, 1998; and Menounou & Busch-Vishniac, 2000). However, two research teams identified that at lower frequencies, the jagged edge barrier design provided minimal benefit (Ho, Busch-Vishniac, & Blackstock, 1997; and Sarigul-Klijn & Karnopp, 2000). The poor low-frequency performance was unexplained and led one research team to conclude that there was no benefit in using the jagged top edge design for highway noise barriers (Sarigul-Klijn & Karnopp, 2000).

VARIOUS TOP TREATMENTS

In addition to the T-top and jagged top edge barrier designs, a number of other top treatment designs have been studied by researchers in a number of countries. The designs range from modifications of the T-top concept, such as a fork-like profile and a branched barrier top, to a cylindrical top, a mushroom-shaped top edge, and an active noise control along the barrier's top edge.

The earliest research in this sub-area of innovative noise barrier designs occurred in Japan. Here, researchers examined acoustically hard and absorptive cylinders along the top edge of an existing noise barrier (Fujiwara & Furuta, 1991). Field tests of the two cylinder attachments showed that the absorptive cylinder provided 2 to 3 dBA excess attenuation compared with a conventional noise barrier, which translated into about 6.5 feet of comparable barrier height (Fujiwara & Furuta, 1991). Subsequent research compared the absorptive cylinder with an absorptive mushroom-type attachment (Fujiwara, Ohkubo & Omoto, 1995). Later, the same researchers modified the cylinder into a waterwheel-shaped cylinder that was more effective in laboratory tests (Okubo & Fujiwara, 1999).

The mushroom-shaped top treatment was examined by several researchers in 1995. Throughout the research, the mushroom-type design was constructed with absorptive materials and was applied as a retrofit application to the top edge of existing noise barriers. Gharabegian (1995) applied the mushroom-type design along a barrier near Los Angeles and showed the application, with an effective height of 1.5 feet, provided the same noise reduction as 2.0 to 3.5 feet of additional barrier height. Yamamoto, et al. conducted similar field applications along two expressways in Japan, resulting in negligible reductions along a depressed roadway, but approximately 1.8 to 2.3 dBA reductions along an elevated roadway.

Multiple-edge attachments on the top of barriers have been examined by several researchers, although the individual designs vary somewhat. Crombie and Hothersall (1994) designed a fork-like attachment that could be applied to an existing noise barrier to provide additional noise reduction. Watts and Morgan (1996) conducted full-scale tests on a sound-interference-type barrier profile, consisting of a multiple-edge design with absorptive material applied. Tests resulted in about 1.9 dBA of additional noise reduction. Shima, Watanabe, and Yokoi (1998) conducted tests of various branched top design, two of which showed reductions of 3 to 4 dBA. Fujiwara and Ishiduka (1999) combined multiple edge designs with absorptive material to create a barrier top treatment that would provide about 2.5 to 2.7 dBA of noise reduction, compared to a single absorptive barrier or a reflective multiple edge barrier.

Active noise control involves a device attached to the top of a noise barrier that continually samples the ambient noise spectrum and produces an opposite sound wave to cancel the sampled noise. This is an emerging area of noise barrier research in recent years. Among the first practical research in the area of active noise control consisted of a theoretical concept by researchers in Japan that showed, in simulations, attenuation of 3 to 5 dBA more than an absorptive top edge treatment (Ohnishi, et al., 1998). Researchers in Australia conducted a comparison of various barrier designs, identifying active control as one of three warranting further consideration (Samuels & Ancich, 2002).

ANGLED BARRIER DESIGN

Little research was available in the area of angled barrier designs. Although the design has been used in several areas around the United States, only one published study was found. The researchers, from Egypt, examined angled barriers on bridges in parallel barrier situations, and showed benefits compared to vertical barriers, specifically in reducing reflected noise (Ibrahim, et al., 2004). The only other published study addressing angled barriers was one of the first published on noise barrier designs; however, the study actually referred to *horizontal* angle and varying degrees of incidence (Foss, 1976).

ABSORPTIVE BARRIER MATERIAL

A few researchers have evaluated the potential additional noise abatement provided by the addition of an absorptive material to noise barriers. The research has primarily focused on applications with parallel barriers on both sides of a highway, since the noise reflected between the barriers is believed to increase noise levels (Hendriks, 1996). Available research generally shows that the addition of absorptive material on the roadway side of a barrier (see Figure 2) in a parallel barrier situation achieves up to 4 dBA of additional noise reduction versus conventional reflective noise walls (Watts, 1994; Watts, 1996; Watts & Godfrey, 1999).

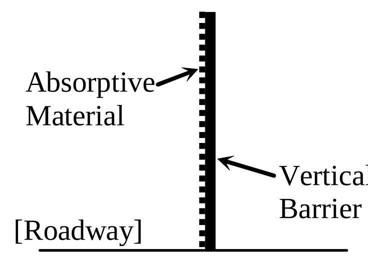

Figure 2. Vertical barrier with absorptive material

Rather than covering an entire noise wall with absorptive material, some research has examined adding absorptive material to only part of the noise barrier, such as the bottom 2 feet or the top 6 inches. This research showed marginal benefit in most cases, generally in the range of 1 to 2 dBA versus conventional reflective barriers (Anderson, Ross, Menge & Arnold, 2003).

Another researcher has studied the application of absorptive material on the underside of multi-level roadways, such as double deck freeways. That research showed that in dense urban areas, the application of the absorptive material on the underside of the upper decks, in conjunction with roadside noise barriers, provided substantial noise reduction (Chalupnik, 1992).

TRANSPARENT BARRIER MATERIALS

Research into transparent noise barrier materials is not intended to show increased noise reduction with reduced wall height, as with other innovative barrier designs. Rather, it is intended to examine various materials that minimize the aesthetic impacts caused by taller noise walls, such as reduced visibility and extended solar shadow zones. Available information on transparent barrier materials was primarily obtained from corporate and government websites.

The Virginia Department of Transportation issued a press release in 2003 announcing the installation of one of the first transparent sound walls in the United States. The barrier, along the new Woodrow Wilson Bridge, was intended to protect historic neighborhoods in Alexandria from noise impacts, while minimizing the aesthetic impacts (Neale, 2003). Other press releases detailed an anti-graffiti coating on a transparent noise barrier in Germany (Röhm GmbH & Co. KG, 2005). Transparent barriers were also considered along a highway expansion project in Australia to reduce noise impacts while protecting views (Queensland Government, Department of Main Roads, 2004).

A new material in the area of transparent barriers, invented by a Hungarian architect, adds glass fiber into a conventional concrete mixture to produce a translucent concrete product that is not see-through, but allows light to be transmitted through the wall (Hartman, 2004). Such a material, after further development, could be used to reduce the effects of solar shadow areas behind walls while shielding residents from viewing the freeway and preventing highway users from viewing into residents' back yards.

OTHER BARRIER MATERIALS

A unique barrier material has been developed in Germany that incorporates a woven metal cloth surfacing over an absorptive barrier core material. The barrier has an interesting aesthetic appearance and has been used in several applications throughout Germany, including as a free-standing noise barrier, on tunnel approaches, and along rail lines (Schallschutz und Raumakustik GmbH, 2005). However, this barrier material may not provide any additional benefits other than a unique appearance.

COMPARISON STUDIES

Rather than focusing on one design, several research teams have conducted comparison studies between various design techniques or noise barrier materials. Some of the studies examined and compiled earlier research, while other studies conducted new research into comparisons of numerous design techniques.

One comprehensive summary study that compiled results from other studies was conducted in the United Kingdom. The study provided a catalog of noise barrier profiles, described the effects of ground and atmospheric conditions, identified the types of barriers commonly used in practice, and highlighted those designs warranting further research (Ekici & Bougdah, 2003). About 10 years earlier, Cohn and Harris (1993) conducted a similar compilation study of various noise barrier designs for the Washington Department of Transportation. That study was followed by two additional phases of research into a short-list of barrier designs (Cohn & Harris, 1995) and scale modeling of the most promising designs (Cohn & Harris, 1996). A survey of noise barrier implementation by state highway agencies was conducted in 1992. The survey identified a number of non-conventional barrier designs that had been utilized up to that point in several states, including Arizona (Bowlby, 1992).

Among the studies that included new testing, one of the earliest studies involved a relatively comprehensive list of barrier designs, some with absorptive materials. This early study consisted of scale-model testing to calculate the theoretical noise reduction provided by the barrier design. The study, by researchers in Canada, identified some specific potential application scenarios for some of the barrier designs (May & Osman, 1980a). Researchers in the United Kingdom conducted full-scale controlled tests of T-shaped barriers, multiple-edge barriers, and double barriers, showing additional attenuation of 1.4 to 3.6 dBA compared to a single vertical reflective barrier (Watts, Crombie & Hothersall, 1994). Finally, researchers in Japan examined various configurations of barriers with both reflective and absorptive materials. They found that having an absorbing or acoustically soft edge significantly improved the barrier's performance, but the various top configurations provided only slight changes in performance. They also found that a soft T-shaped barrier provided the best performance (Ishizuka & Fujiwara, 2004).

A number of other studies have been conducted on barrier designs by researchers around the world, usually involving scale-model testing or mathematical calculations of noise reduction benefits. Such studies have been conducted in Japan (Matsumoto, et al., 1994), Australia (Alfredson & Du, 1995), France (Berengier & Anfosso-Ledee, 1998), and the United States (Suh, Mongeau & Bolton, 2001; Mongeau, Bolton & Suh, 2003; and Suh, Badagnani, et al., 2003).

Some information was obtained on noise barrier experimental research programs in several countries. In the Netherlands, research has primarily focused on developing a quieter pavement surface (Hofman, 2005), but substantial research has also concentrated on innovative barrier designs, specifically T-top profiles with absorptive materials (Nijland, Vos & Hooghwerff, 2003; and Ooststroom, 2005). Research by the Government of Hong Kong has centered on specific applications of noise abatement in highly urbanized areas, identifying several innovative and rather extreme techniques to reducing roadway noise, such as enclosure tunnels (Hong Kong Special Administrative Region, 2005). Most of these programs are still experimental and are not producing feasible noise solutions at this time.

3. MATRIX EVALUATION

Following the identification of available innovative noise barrier designs, a matrix was created to evaluate and rank the barrier designs. The matrix is shown as Figure 3 at the end of this chapter. Evaluation criteria consisted of 14 criteria, generally grouped into five main categories, including acoustic performance, material availability/economic considerations, constructability considerations, maintenance considerations, and aesthetic considerations. Each of the 14 criteria is described in greater detail below.

EVALUATION CRITERIA

Data input into the matrix for acoustic performance were obtained from the studies reviewed during the literature review portion of this study. Where conflicting results were presented in separate studies, a range of data was entered. The key criterion in the acoustic performance category was the average potential reduction in barrier height. This number, in feet, was later combined with the average score from the remaining four categories to produce a weighted average score and a ranking of the barrier designs.

For the four remaining categories, including material availability/economic considerations, constructability considerations, maintenance considerations, and aesthetic considerations, the criteria were evaluated based on a 5 point rating scale as follows:

1 Substantially better than conventional barrier.
2 Somewhat better than conventional barrier.
3 Similar to conventional barrier.
4 Somewhat worse than conventional barrier.
5 Substantially worse than conventional barrier.

Acoustic Performance

Three criteria were evaluated for acoustical performance, added insertion loss, potential reduced height (range), and potential reduced height (average). The added insertion loss, in decibels, was obtained directly from previously published research studies reviewed during the literature review. This was the additional noise reduction provided by the innovative noise barrier design compared with a conventional noise barrier of the same height. When multiple studies provided conflicting results on insertion loss, a range is presented in the matrix. Some of the studies indicated the potential reduction in barrier height that could be achieved because of the additional insertion loss. When available, this data was taken directly from the published studies. When a potential barrier height reduction was not indicated in the studies, a range was determined based on the general acoustic principle of approximately 0.5 decibel reduction per foot of barrier.

Material Availability/Economic Considerations

Evaluations for material availability and economic considerations focused on whether the barrier design or material was a proprietary material or whether there would be additional cost associated with implementation of the barrier design. Proprietary materials may result in increased cost because of the limited availability and distribution of the material. Also, some barrier designs could result in increased cost because of special techniques required in constructing the barrier.

Constructability Considerations

Constructability considerations consisted of three evaluations: foundation requirements, structural issues, and drainage issues. Foundation requirements evaluated whether the barrier design would require an increased footing size due to additional barrier weight, wind loads, or cantilevered design elements. Structural issues consisted of primarily whether there would be structural considerations in a retrofit installation. The evaluation for drainage issues considered both stormwater drainage around the base of the barrier and drainage of stormwater along top elements of the barrier, such as with the Y-top design.

Maintenance Considerations

Maintenance considerations consisted of three evaluations: added maintenance, debris collection, and durability. Added maintenance evaluated whether the barrier design would require additional maintenance compared with a conventional barrier design. Debris collection considered whether some specific design element of the barrier would result in the collection of debris, such as in the top channel of a Y-top barrier design. Such debris would require periodic removal that would increase maintenance costs. Durability evaluated how long the material would last before requiring substantial maintenance or replacement. Absorptive material was assumed to require somewhat more maintenance and require replacement more frequently than concrete or masonry.

Aesthetic Considerations

Aesthetic considerations consisted of three evaluations: general appearance, elimination of shadows, and increased visibility and views. General appearance included the overall attractiveness or unattractiveness of the barrier as well as whether the barrier would generate attention and interest because of a unique design. Elimination of shadows evaluated whether the barrier could result in a lower overall height, which would decrease seasonal shadows for properties along the north side of the barrier. Increased visibility and views also evaluated whether the barrier could result in lower overall height to maintain views and visibility over the top of the barrier, but added the element of transparency that could also preserve views and visibility.

AVERAGE SCORES AND WEIGHTED SCORES

Following the scoring for each of the evaluation criteria, an average score was calculated based on all of the evaluations except acoustic performance. Average scores ranged from 2.8 to 3.6, with the top three barrier designs (lowest average scores) being a transparent barrier material, the T-top barrier design, and the T-top barrier design with absorptive material.

The average scores were then weighted based on the acoustic performance results. The weighting formula emphasized the potential reduction in height of a noise barrier based on the innovative barrier design. Specifically, the formula multiplied the average score by 2, and then divided by the square root of the average potential reduced height. The weighted scores, which ranged from 2.6 to 10.3, were ranked from best performing (lowest weighted score) to worst performing (highest weighted score).

RESULTS

Based on the scoring for each evaluation criterion and the weighting for acoustical performance, a ranking was developed to identify the barrier designs with the highest potential for implementation. The best ranked barrier design was the T-top design with absorptive material along the top of the barrier. This design ranked very well, primarily for its potential for an average barrier height reduction of 5 feet, which reduced secondary impacts such as shadows and visibility issues.

The second ranked barrier design was the active noise control top treatment. This design also ranked well because of its potential for substantial height reductions. However, the additional cost of this barrier design may not have been adequately assessed in the scoring system. At the present time, the active noise control barrier design is mostly theoretical and has only seen limited field test installations. There have not been any practical real-world installations of the active noise control barrier design. As a result, even though this design ranked second, it is not being recommended at this time. The research on this barrier design should be periodically reviewed to determine if it would be feasible to implement the design at a later date.

The third ranked barrier design was the vertical barrier with absorptive material applied to the roadway side of the barrier. Potential average height reductions with this barrier design were 3.5 feet, which contributed to the relatively high ranking of the design.

Based on the matrix evaluation, the T-top barrier design with absorptive material along the top of the barrier and the vertical barrier with absorptive material are being recommended for consideration by ADOT. As discussed, although it ranked well in the evaluation, the active noise control barrier design cannot be recommended at this time. Chapter 5 details the project summary and recommendations.

Barrier Type	Acoustic Performance: Added IL * (dBA)	Acoustic Performance: Potential reduced height (Range)	Acoustic Performance: Potential reduced height (Average)	Availability / Economic Considerations: Special or proprietary material?	Availability / Economic Considerations: Additional cost	Constructability Considerations: Foundation requirements	Constructability Considerations: Structural issues	Constructability Considerations: Drainage issues
T-top barrier design	1 - 1.5	2 - 3	2.5	no	3	3	3	3
T-top design with absorptive material	2 - 3	4 - 6	5	no / yes	4	3	3	3
Y-top barrier design	0.5 - 1	1 - 2	1.5	no	4	3	3	4
Jagged-top barrier design	0 - 6	0 - 3	1.5	no	3	3	3	3
Cylindrical top treatment	2 - 3	3 - 4	3.5	yes	5	3	4	3
Mushroom-shaped top treatment	0.5 - 1	1 - 2	1.5	yes	4	3	4	3
Multiple-edge top treatments	1.9 - 4	3 - 5	4	no / yes	4	3	4	4
Active noise control top treatment	2 - 4	4 - 6	5	yes	5	3	3	3
Angled barrier design	0	0	0	no	4	5	5	4
Absorptive barrier material	1 - 3	2 - 5	3.5	yes	4	3	3	3
Transparent barrier material	0	0	0	no / yes	3	3	3	3
Woven metal barrier material	0	0	0	yes	5	4	3	3

IL = Insertion Loss

Rating Scale

1 Substantially better than conventional barrier
2 Somewhat better than conventional barrier
3 Similar to conventional barrier
4 Somewhat worse than conventional barrier
5 Substantially worse than conventional barrier

Figure 3. Evaluation Matrix

	Maintenance Consideration			Aesthetic Considerations					
Barrier Type	Added maintenance	Debris collection	Durability	General appearance	Elimination of shadows	Increased visibility / views	**Average Score ****	**Average Score Weighted for Potential Reduced Height ****	**Rank ****
T-top barrier design	3	4	3	2	2	2	**2.8**	3.5	5
T-top design with absorptive material	4	4	4	2	1	1	**2.9**	**2.6**	**1**
Y-top barrier design	4	5	3	3	2	2	3.3	5.4	8 (tie)
Jagged-top barrier design	3	3	3	4	3	3	3.1	5.1	7
Cylindrical top treatment	4	3	4	4	2	2	3.4	3.6	6
Mushroom-shaped top treatment	4	3	4	4	2	2	3.3	5.4	8 (tie)
Multiple-edge top treatments	4	5	3	3	2	2	3.4	3.4	4
Active noise control top treatment	5	4	5	3	1	1	3.3	**3.0**	**2**
Angled barrier design	3	4	3	2	2	2	3.4	9.7	11
Absorptive barrier material	4	3	4	3	2	2	3.1	**3.3**	**3**
Transparent barrier material	5	3	4	2	1	1	**2.8**	8.0	10
Woven metal barrier material	5	4	4	2	3	3	3.6	10.3	12

** Shading indicates top three

4. NOISE BARRIER SELECTION AND APPROVAL STRUCTURE

This chapter discusses the individuals involved and the existing procedures used by ADOT in barrier design decisions. The review of these procedures was necessary to determine how various barrier designs are selected for implementation on a project. This information serves to provide insight on whether mechanisms are currently in place to offer appropriate consideration to unconventional or innovative noise barrier design alternatives. The review focused on those individuals within ADOT who make noise barrier selections and on the criteria that those choices are based.

A KEY ROLE FOR THE PROJECT MANAGER

To understand the approval structure, numerous informal interviews were conducted with several ADOT employees in the Environmental Planning Group (EPG), as well as in the Valley Project Management (VPM) and Statewide Project Management (SPM) groups. These interviews revealed that ADOT does not have a standard process for noise barrier selection and approval. Once the environmental process is completed and the project progresses toward final design, EPG is no longer involved in decisions and oversight of the recommended noise barriers. The individual project managers within VPM and SPM have the authority to select how to implement the noise barrier recommendations. The project managers select the design of the barriers and the materials that will be used to construct the barriers.

PUBLIC INPUT AND FEEDBACK

While technical performance is a key aspect of noise barrier design selection, other considerations are also important. One such consideration is whether or not a particular barrier design and appearance receives public acceptance. It is in this light that part of the initial objectives was to evaluate the extent to which the public would accept designs such as the ones just presented. However, following several unsuccessful attempts to implement such a public survey, it was decided it could not be completed in a timely manner as part of this effort. Nonetheless, it is worth emphasizing that efforts toward public “buy-in” of unconventional approaches ought to be considered during a project. In so doing, chances are much better that any concerns communities may have are eventually overcome.

5. PROJECT SUMMARY AND RECOMMENDATIONS

PROJECT SUMMARY

This research project initially focused on gathering existing literature on noise barrier materials and designs that were non-conventional. The intent was to identify innovative barrier designs that would have the potential to be implemented in Arizona. Literature was collected on dozens of noise barrier research projects in 12 countries around the world. Many of the barrier designs consisted of treatments to the top edge of the barrier to change or disrupt the diffraction pathway from the noise source to the receiver. A few innovative barrier materials were also included in the literature review.

The results of the previous research studies were compiled into a matrix to assist in evaluating the various barrier designs and materials. The evaluation matrix was used to score the barrier designs based on their acoustic performance, as well as economic, constructability, maintenance, and aesthetic considerations. The scores were weighted based on the potential reduction in barrier height. The evaluation matrix revealed that the design with the most potential was a T-top barrier design with absorptive material on the top, followed by a design with an active noise control top treatment, and then by a barrier with absorptive material applied to the roadway side of the barrier.

Although the barrier with active noise control was rated as substantially higher cost than a conventional barrier, the design ranked second because of its potential for a substantial reduction in barrier height. The evaluation may not have completely factored in the additional cost of this type of barrier, as well as the fact that the design is still in the prototype stage and may not be feasible to implement on a large-scale at the present time. As a result, the active noise control barrier design is not being recommended at this time, but should be evaluated at a later date as technology in this area progresses and the design becomes more feasible. The remaining two high ranking designs are being recommended for consideration.

The T-top barrier design consists of a vertical barrier with a horizontal cap along the top edge of the barrier, creating a shape that resembles a “T.” The horizontal portion of the barrier is approximately 2 to 3 feet wide and creates a double-diffraction pathway over the top of the barrier, thereby reducing noise levels compared to a vertical barrier of similar height. To increase the noise reduction potential of this barrier design, an absorptive material is applied to the top of the horizontal portion of the barrier. Research has shown that this barrier design reduces noise levels by about 2 to 3 decibels, which could reduce barrier heights by approximately 4 to 6 feet, or about 5 feet on average.

The barrier with absorptive material consists of a vertical noise barrier with an absorptive material applied to the side of the barrier facing the highway traffic. This barrier reduces noise by absorbing noise and eliminating reflected noise off the face of the barrier. In addition, since the absorptive material is applied up to the top edge of the barrier, the diffracted noise over the top of the barrier is also reduced. Research results were less consistent with this barrier design, but typically showed noise level reductions by about 1 to 3 decibels. This barrier design has the potential to reduce barrier heights by about 2 to 5 feet, or about 3.5 feet on average. The application of this barrier design may be most appropriate in locations with a parallel barrier situation, or when the noise barrier is located in close proximity to the highway traffic.

RECOMMENDATIONS

Based on the research and evaluation conducted for this study, it is recommended that two innovative barrier designs be considered by ADOT – 1) a T-top design with absorptive material placed on the top of the horizontal portion of the barrier and 2) a vertical barrier with absorptive material applied to the face of the barrier. These two barrier designs have been shown in the available literature to reduce noise levels by up to 3 decibels, which could reduce overall barrier heights by as much as 3 to 5 feet compared with a conventional noise barrier of concrete or masonry block construction. A noise barrier design that could provide comparable noise reduction at a substantially reduced barrier height will minimize some of the negative aspects of conventional noise barriers, such as blocked views and large areas in shadow for extended periods of the year.

Because ADOT does not employ a standard process for noise barrier selection and approval, it is also recommended that these results periodically be presented to and discussed with project managers. The Implementation Guide will provide a basis for this discussion.

The Implementation Guide establishes a set of criteria for those situations where the innovative barrier designs are most appropriate and should be considered. It was developed by the researchers to provide summary characteristics for the two specific innovative barrier designs being recommended.

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APPENDIX

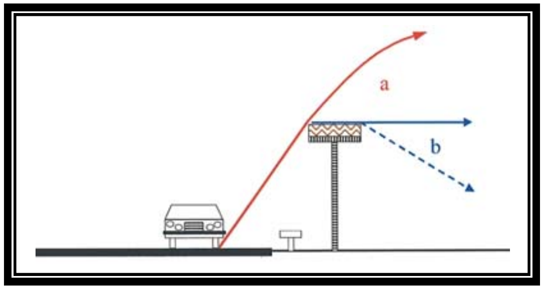
Implementation Guide

A product of:

SPR 572 – Evaluation of Benefits and Opportunities for Innovative Noise Barrier Designs

Prepared by:

Dustin Watson, HDR Engineering, Inc.



Innovative Noise Barriers

Implementation Guide

November 2006

Prepared for:

Arizona Department of Transportation
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in cooperation with

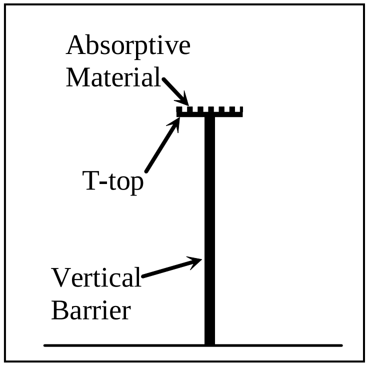
U.S. Department of Transportation
Federal Highway Administration

Introduction

As a result of a research project conducted through the Arizona Transportation Research Center, a division of the Arizona Department of Transportation (ADOT), two styles of innovative noise barrier designs have been recommended for consideration by ADOT. The two barrier designs, a T-top design with absorptive material along the top edge and a vertical barrier with absorptive material, have been evaluated and shown to have benefits for special applications.

T-Top Barrier with Absorptive Material

This barrier design consists of a vertical barrier capped with a horizontal bar, resembling a T. The horizontal bar is typically 2' to 3' wide and 6" to 8" thick. To improve the noise reduction properties of the barrier, an absorptive material is applied to the top portion of the horizontal bar.



Benefits and Potential Applications

The T-top Barrier with Absorptive Material design has several benefits:

- Increased noise reduction compared to vertical barrier of the same height, which translates to shorter barrier heights
- Reduced negative impacts from shadows on adjacent properties
- Increased views for adjacent property owners since the barrier can be shorter

This barrier design has a potential application in areas where a shorter height barrier is preferred, while maintaining substantial noise reductions.

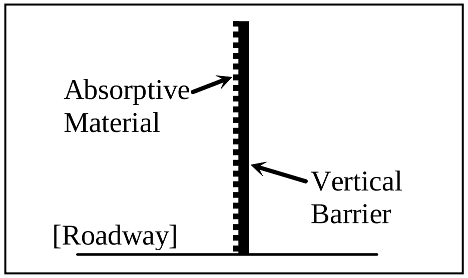
Possible Constraints and Considerations

Some possible constraints that should be considered when implementing this barrier design include:

- Higher construction cost
- Debris may collect along top of horizontal bar
- Absorptive material may require periodic maintenance and cleaning
- Wind loads are higher than a standard vertical barrier

Vertical Barrier with Absorptive Material

This barrier design consists of a standard vertical barrier that has an absorptive material applied to the roadway side of the barrier.



Benefits and Potential Applications

The Vertical Barrier with Absorptive Material design has several benefits:

- Increased noise reduction compared to standard reflective vertical barrier
- May result in shorter barrier heights
- Substantially reduces reflected noise
- Reduces noise transmission through the barrier

This barrier design has a potential application in areas where parallel barriers are located on opposite sides of the roadway and reflected noise between the barriers is a concern. Another potential application is in areas where receivers are located very close to the barrier.

Potential Constraints and Considerations

Some possible constraints that should be considered when implementing this barrier design include:

- Higher cost with absorptive material
- Absorptive material may require periodic maintenance and cleaning