CHAPTER 18
NOISE GUIDE

18.0 INTRODUCTION

The problem of noise generated by highway traffic involves physical, physiological, and psychological factors that cause varying reactions by the public. Highway traffic noise should be considered in the location and design of roadways.

This chapter is intended to help designers identify issues related to highway traffic noise, understand the applicable federal and state regulations and guidelines, analyze traffic noise for specific projects, and select and implement noise mitigation measures.

From a project's inception, noise mitigation measures may need to be considered as a part of the project. As early in the process as possible, consult the appropriate environmental documentation, if available, to determine if mitigation commitments were made. Contact the Region Environmental Staff for assistance with these determinations and with the appropriate regulatory requirements.

This chapter contains a summary of basic concepts and supplements existing published material. If more detail is needed concerning any of the following specific subjects, consult the references at the end of this chapter.

18.1 NOISE FUNDAMENTALS

Noise, in general, is defined as unwanted or excessive sound. Sound (or noise) levels are measured in units of decibels (dB), which are measured on a logarithmic scale that condenses the large range (several magnitudes) of possible sound pressure levels. For the purposes of highway traffic, an “A-scale” weighting is applied to noise levels as the human ear does not perceive all sound frequencies equally. These are referred to as A-weighted decibels (dBA).

Since the sound intensity of highway traffic is never constant, a descriptor is needed to describe the source in a steady-state condition. The most common descriptor (which is also used for CDOT projects) used is the hourly equivalent sound level, or L_{eq}(h). For highway traffic noise analyses, the noise levels are expressed in terms of hourly equivalent A-weighted decibels and expressed in this manner: 70 dBA L_{eq}(h).

Since noise levels in the decibel scale are logarithmic, they cannot be added arithmetically. For example, two 70-decibel sources added together do not yield a noise level of 140 decibels, but rather a noise level of 73 decibels. Thus, any doubling of a noise source, such as doubling the volume of traffic on a roadway or moving the existing traffic twice as close to a neighborhood, only increases the overall decibel level 3 decibels. Three decibels is an important value; studies have shown that a 3-decibel change in noise levels is only barely detectable by the human ear, even though the overall sound energy has doubled. It normally takes a 5-decibel change in noise levels to be perceptible to most people. A 10-decibel change in noise levels is normally perceived as either a doubling or a halving of the perceived "loudness" of noise levels. Frequency changes, however, may be detectable by people even if the overall decibel levels are unchanged.

For highway projects, the noise level of interest is the worst-hour noise equivalent level. This is the time of day where the noise levels are the highest, and is used for comparison with the impact criteria to determine noise impacts. It is also when the highest number of vehicles is traveling at the highest possible speed. This is not necessarily the peak travel hour or rush hour, because there may be periods of congestion when the traffic tends to slow, resulting in lower noise levels. For highways that tend to be congested at peak hour, the worst-noise hour is the period either just before or just after the peak hour.

18.2 NOISE REGULATIONS AND ANALYSIS REQUIREMENTS

The regulations that govern highway traffic noise for Federal-aid projects are contained in Part 772 of Title 23 of the Code of Federal Regulations (23 CFR 772) **(1)**. Regulation 23 CFR 772 describes the methods that must be followed in the evaluation and mitigation of highway traffic noise in Federal-aid highway projects. The FHWA will not approve the plans and specifications for any federally aided highway project unless the project includes noise abatement measures that are deemed to be feasible and reasonable to adequately reduce noise impacts. When warranted, noise mitigation is to be considered as an integral component of the total project development process and incorporated as such.

Projects that fall under 23 CFR 772 are classified as Type I, Type II or Type III.

Type I projects are defined as projects that consist of either construction of a new highway or an alteration of an existing highway that either significantly changes the roadway alignment, vertical profile or increases the number of general purpose, managed, or auxiliary traffic lanes. Only the addition of a turning lane is exempt from Type I status. Most recent revisions to the regulations include the addition of a new or substantial alteration of a weigh station, rest stop, ride-share lot, or toll plaza, and removal of exiting noise shielding from large structures or natural terrain to the Type I project list. It is mandatory that all states comply with the noise regulations for proposed Type I projects. Some examples of Type I projects include capacity widening (i.e., 4 to 6 lanes), addition of climbing lanes, acceleration or deceleration lanes, additions of new interchanges or alterations of existing interchanges, additions of HOV lanes, or major alterations of the vertical/horizontal profiles of a roadway.

Type II projects are defined as the construction of noise abatement on existing highways ("retrofit" projects) in absence of major highway construction. CDOT does not conduct a formal Type II program.

A Type III project is any project that does not meet the criteria for either a Type I or Type II project. No noise analyses are required for these typically non-noise sensitive projects. Examples of Type III projects include resurfacing, bridge rehabilitation including bridge reconstruction with minor non-capacity widening, most shouldering and maintenance projects.

For all Type I projects, a noise analysis study is required whenever there are noise sensitive receivers present in the project study zone, which is defined as a 500-foot "halo" around the extent of the project. A noise sensitive receiver is any location for which highway traffic noise may be detrimental to the outdoor enjoyment and functional use of the property. Noise sensitive receivers include residences, parks, hotels, schools, and noise-sensitive businesses.

The purpose of the noise analysis study is to identify properties (receptor) that are impacted by noise. As defined in the regulations, a traffic noise impact occurs when either the projected traffic levels (usually 20 years in the future; project design year) approach or exceed the Noise Abatement Criteria (NAC) or when the noise from projected traffic levels substantially exceeds the existing noise levels. A substantial increase in noise level is 10 dBA or more.

The following table identifies the approach NAC levels for different land use categories:

Activity Category	Activity Leq(h)*	Evaluation Location	Activity Description
A	56	Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B[1]	66	Exterior	Residential

Activity Category	Activity Leq(h)*	Evaluation Location	Activity Description
C[1]	66	Exterior	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreational areas, Section 4(f) sites, schools, television studios, trails, and trail crossings.
D	51	Interior	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.
E[1]	71	Exterior	Hotels, motels, offices, restaurants/bars, and other developed lands, properties or activities not included in A-D or F.
F	NA	NA	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, ship yards, utilities (water resources, water treatment, electrical), and warehousing.
G	NA	NA	Undeveloped lands that are not permitted for development.

1 Includes undeveloped lands permitted for this activity category.
* Hourly A-weighted sound level in dBA, reflecting a 1-dBA approach value below 23CFR772 values

Table 18-1 CDOT Noise Abatement Criteria (NAC)

The NAC values in Table 18-1 are based on speech communication interference. These noise levels are not legal standards or mitigation design goals, but are the levels for which mitigation must be considered. The levels shown reflect the CDOT "approach" criterion, which is 1 dBA lower than the FHWA levels. The noise level that is usually considered is the Category "B" criterion, which reflects an approach value for residences of 66 dBA (projected design year levels, usually 20 years in the future). An impact due to a substantial increase in noise (10 dBA or more) is rarely encountered in situations other than the construction of a new highway on a new location.

The noise regulations require that any receptor that is deemed to be impacted by noise is entitled to consideration of mitigation, which must be provided if it is found to be feasible and reasonable.

The feasibility determination considers the physical constructability of the abatement measure. The reasonableness determination addresses socio-economic criteria, requiring a minimum noise reduction, cost-effectiveness, and the preference of the benefited residents and property owners to have noise abatement measures constructed.

For a mitigation measure to be feasible, it must be able to be constructible to normal engineering standards to provide a perceivable noise reduction of at least 5 dBA at a minimum of one receiver. Walls cannot be more than 20 feet in height, and must not cause unsafe visibility or maintenance concerns such as obscuring egress visibility or creating a shadow zone resulting in persistent icing within a travel lane.

Since 5 dBA is only a perceivable change in noise levels, the requirement of noise mitigation is to provide a more substantial noise reduction design goal of at least 7-dBA at a minimum of one receptor. Any mitigation that is deemed to be feasible must also meet the three reasonableness criteria before it is implemented. In any case, the documentation of the analysis and mitigation decision-making process must be clear and complete.

18.3 CDOT NOISE ANALYSIS AND ABATEMENT GUIDELINES

All the applicable procedures for conducting a project level highway traffic noise analysis are detailed in the CDOT *Noise Analysis and Abatement Guidelines* **(2)**. The guidelines provide a consistent and equitable approach and decision-making process for addressing highway traffic noise on highway projects. These guidelines are compliant with 23 CFR 772, and provide the overarching noise analyses and procedures for Colorado per CDOT Noise Mitigation Policy Directive 1900.0 (3). The guidelines supplement the content of other FHWA guidance material and CDOT Procedural Directive 1601, “Interchange Approval Process” **(3)**. Documentation guidance of the noise impact and mitigation analyses is included, which requires the completion of a Benefited Receptor Preference Survey and the CDOT Form 1209, the Noise Abatement Determination worksheet. The survey completes the third required criteria of the reasonableness test while the form documents the feasibility and reasonableness determination for any evaluated mitigation measure.

Other topics covered in the guidelines include public involvement, coordination with local officials, construction considerations, NEPA documentation requirements, and extenuating circumstances.

The information provided in this and previous sections of this chapter give a good general overview of the noise regulations and the noise analysis procedures. However, the noise guidelines describe these issues in much greater detail and should always be consulted, especially if there are any lingering issues or questions regarding a specific project.

18.4 HIGHWAY TRAFFIC NOISE MITIGATION MEASURES

FHWA cites several different noise abatement techniques, all of which must be considered for impacted receivers. The determination as to the validity and practicality of successfully implementing any of these measures must be made. CDOT guidelines are developed to be in compliance with the Federal Policies and Regulations. CDOT guidelines are approved by the FHWA as the method of determining and abating noise in Colorado on Federal-aid projects.

18.4.1 Traffic Management Measures

Certain traffic management measures can sometimes reduce traffic noise levels. Possibilities include:

- Lane use restrictions for certain vehicle types
- Time use restrictions for certain vehicle types
- A combination of lane and time use restrictions
- Installation and proper timing of traffic control devices
- Reduction of speed limits.

The feasibility of providing specified truck routes or utilizing lane restrictions on truck usage should be determined on a case-by-case basis.

Lowering speed limits can reduce noise and is often cited by the public as a solution to the problem. However, it normally requires a speed reduction of at least 20 mph for there to begin to be a sufficient decrease in noise levels to warrant a major speed reduction. There are also operational issues with this option.

18.4.2 Roadway Design Alternatives

Altering the design of the roadway can be very effective in reducing noise levels and noise impacts. Although there are several different techniques that are possible, certain projects and areas will not be conducive to some or any of these considerations. In most of these cases, reductions in noise levels are based on increasing the distance between the roadway and the receptors, or by providing for terrain between the highway and the receptors.

Proper siting of the highway alignment in relationship to any noise sensitive areas is the most effective way to reduce noise impacts. Any increase in the distance between the highway and receivers will reduce noise levels. For divided highways, use of natural terrain features and barriers to separate the individual roadway sections can provide additional noise attenuation.

If the roadway can be depressed through a cut section, noise levels will also be reduced for the area that is shielded by the adjacent slope. This is most effective when the vehicles can be screened from view. Elevated sections of roadway do create a shadow zone for receivers that are close to the embankment or structure. However elevated sections may cause slight noise increases (or a perception change) to receivers farther back due to the loss of shielding by adjacent structures.

In some cases, especially where there is a high percentage of heavy truck traffic, grade reductions can reduce noise levels due to the reduction in the need for vehicles (especially heavy trucks) to accelerate and decelerate. This is particularly useful on long downgrades where trucks are inclined to engage their engine compression (“Jake”) brakes. However, there is a tradeoff with this option in that longer, gentler grades do have the potential to increase noise levels due to the longer exposure time.

Pavement type has often been mentioned as a possible means to reduce highway traffic noise. The majority of the noise that is emitted from any highway is due to the tire-pavement interaction. Research on this issue has been ongoing for the past 30 years. At this point, the effect of different pavements over long periods (20 years or more) has still not been clearly established. Studies have indicated that open-graded asphalt pavements, when first placed, can produce a benefit of 2-5 dBA of noise level reduction. However, as time passes and the aggregate becomes polished and voids in the pavement fill (6 months to 2 years), noise reduction benefits are lost. Concrete pavement, while perhaps louder than asphalt when it is initially placed, will become quieter over time. Longitudinal tining or diamond grinding of the concrete, where possible, does result in reduced noise levels over smooth concrete surfaces. Transverse tining, or tining of the concrete perpendicular to the direction of travel, creates an annoying high-pitched whine and should not be used.

It is currently FHWA policy that pavement type not be used as noise mitigation in lieu of other feasible and reasonable noise abatement measures. Noise mitigation must provide a “readily perceptible" noise reduction over a long period of time (20 years), and it is difficult to forecast the overall pavement condition under a future condition. Noise may be used as a factor to be considered in pavement selection if the life cycle cost analysis among pavement options yields similar results.

18.4.3 Acquisition of Property or Property Rights

In undeveloped areas, the acquisition of additional right of way or development rights can be an effective means of providing a buffer between the highway and any future land development. The purpose of this practice is to prevent dwellings from being constructed in areas in which the future noise levels would approach or exceed the noise abatement criteria, while also providing an improved roadside appearance.

This measure, however, can become very expensive due to rising land costs and is almost never an option in presently developed areas since the cost for acquiring already developed property (homes, businesses, etc.) is prohibitive.

Funds should never be used for the purchase of a noise easement, which is essentially compensation to the property owners for damages, real or perceived, due to highway noise. FHWA regulations prohibit the use of Federal funds for such purposes, since they do nothing to reduce the noise levels or abate the highway noise impacts.

18.4.4 Noise Insulation or other Extraordinary Abatement Measures

Insulation of buildings can greatly reduce traffic noise, especially when windows are sealed and cracks and other openings are filled. However, once windows are sealed, an air conditioning system will likely be necessary. Noise insulation for a building does nothing to improve the noise levels at any of the adjacent outdoor use areas.

At the present time, federal funding can only be used for noise insulation or other extraordinary abatement measures are considered only NAC D activity categories indicated in Table 18-1. If this is an option that must be considered as a result of no feasible or reasonable mitigation measures being available, the condition of the structure, its amenities, and overall use characteristics must be thoroughly evaluated. Determinations such as these must be completely documented and are done on a case-by-case basis.

The only situation in which noise insulation would be considered for private dwellings is if extraordinary traffic noise impacts are found. Such a situation might exist where the projected noise levels are 75 dBA or greater or where the projected increase over existing levels is 30 dBA or more and no other possible abatement is reasonable and feasible. Under these conditions the project may use state and/or local agency funding to implement an insulation abatement solution only if the mitigation meets reasonable and feasible abatement criteria as is required for conventional noise mitigation. This determination must be made on a case-by-case basis.

18.5 NOISE BARRIERS

Construction of noise barriers is the most common noise abatement method. Essentially, a noise barrier is a solid structure that is constructed for the purpose of reducing noise levels. The barrier works by blocking the path of the sound waves from the highway source, forcing it around or over the barrier. The incident sound wave is either reflected or absorbed by the barrier surface. Sound can also be transmitted through the barrier, which is why the barrier must be constructed without gaps and be sufficiently dense (4 pounds per square foot). Therefore, "privacy fences" do not function as noise barriers. Vegetation, while often suggested as a noise barrier, is not a solution because it requires 200 to 300 feet of dense, permanent foliage ground floor to tree top coverage of at least 16-feet high to effectively reduce noise levels. While vegetation can be of aesthetic and psychological benefit, and always enhances any area where it is placed and successfully maintained, it is usually only provided for visual, privacy, or aesthetic treatment.

Noise barriers are designed to reduce noise beginning at the first-row receivers, those receivers which are directly adjacent to the barrier. They can also benefit receivers beyond the first row, depending on the configuration of the development. Normally, noise barriers are effective for receivers within 300 feet of the noise source if they are high enough to block the view of the roadway and are long enough to prevent sound from bending around the ends.

Illustration 18-1 Cast-in-Place Masonry I-76 East of York Street

A noise reduction benefit of 5 dBA is fairly simple to achieve, but a 7 dBA reduction is required at a minimum of one receptor along the wall. Reductions of 15 or more dBA are difficult to almost impossible to achieve, since to do this requires a reduction of at least 97 percent of the initial acoustic energy of the source.

18.5.1 Walls

Walls are a common means for reducing noise levels. Noise barrier walls can be constructed from a variety of materials. Although many wood walls have been constructed in the past, life cycle and maintenance issues have resulted in the vast majority of new walls being constructed out of concrete, masonry block, or brick. Walls are preferred in many areas because they can be constructed where a limited amount of space precludes construction of an earth berm or some type of combination.

While most noise walls are ground-mounted, there are situations where a barrier needs to be placed on a structure. This is most common where a highway bridge is encountered and the barrier needs to be constructed on the bridge to prevent a major gap in the barrier.

Illustration 18-2 Post-and-Panel Noise Barrier Mounted on Type 7 Barrier: US-6 in Lakewood

18.5.2 General Design Guidelines

The following are general considerations during the design of a noise barrier:

- Barriers should not be installed where they will present a safety hazard. A desirable location is just inside of the right of way line or outside the clear zone. If a barrier needs to be located inside of the clear zone, a guardrail or other traffic barrier may be warranted.

- A barrier should not block the line-of-sight between a vehicle on a ramp and approaching vehicles on a major roadway. For entrance and exit ramps, ramp intersections and intersecting roadways, the proper barrier location should be determined based on stopping distance requirements. Barrier end points should be approved by the CDOT Region Traffic Engineer.

- Barriers which are oriented in an east-west fashion and have a long barrier face should have the shadow cast checked for encroachment into the shoulder or near traffic lane. Since barriers obstruct light as well as noise, special consideration should be given to icing or other environmental conditions caused by the placement of the barrier. This consideration should also be given to shadow coverage in adjacent yards and parking lots. This should not be a major issue with barriers that are oriented north-south.

- Protrusions on barriers near traffic lanes or facings which can become missiles in a crash or create excessive glare should be avoided.

- Positive mechanical connection of the individual noise barrier panels to the posts is required when the noise barrier is on a bridge or retaining wall in the vicinity of pedestrian or vehicular traffic or immediately adjacent to private property.

- Provisions may be necessary to allow firefighters or HAZMAT crews access to fire hydrants on the opposite side of the barrier. This should be coordinated with the appropriate jurisdictional entity.

- Drainage considerations need to be taken into account to assure soil stability.

- For noise wall structural design considerations, refer to the AASHTO "Guide Specifications for Structural Design of Sound Barriers" **(4)**.

The environmental documents or noise analysis studies for projects, if available, specify recommendations regarding general locations, noise reductions, barrier heights, and barrier lengths. These are some of the considerations that are taken into account when the acoustical analyst arrives at barrier recommendations:

- The barrier should be high enough and long enough to cause an effective "sound shadow zone" for the adjacent receivers. Receptors located within the shadow zone do not have direct line-of-sight to the noise source (highway).

- The barrier location should take advantage of local terrain conditions to benefit from higher elevations if possible.

- Normally, the noise barrier should not exceed a height of 20 feet above the traveled way, nor should it be shorter than 8 feet. If the barrier is constructed on the shoulder, 12 feet is a recommended maximum height. Special geographic considerations, however, may warrant taller walls or allow a shorter wall to provide the desired noise reduction.

- The design plans should always indicate the top and bottom elevations of the barrier. References to barrier height should be to the centerline of the nearest traffic lane.

- The relationship between the height of the barrier and its noise reduction characteristics is not linear. As a rule, a barrier breaking the line-of-sight will provide a 5-dBA reduction, with an additional 1-dBA reduction resulting with each additional 2 feet in height. At the receiver end, the line-of-sight is always checked from a point 5 feet above the ground elevation (to approximate the height of the average human ear).

- If possible, moving the barrier closer to the receiver or the source provides some additional noise reduction. This is not practical, however, in all cases.

- To prevent noise from flanking around the barrier ends, the barrier should extend past the end receiver at least four times the perpendicular distance from the receiver to the barrier. If this is not possible, the barrier can be bent back towards the receiver (wrapping the barrier). Also, combining the barrier with natural terrain features and existing structures may help in this case.

- When barriers are placed opposite each other on different sides of the same highway (parallel barriers), there is the possibility for degradation of the performance of the barrier system if the width-to-height ratio (distance between the barriers vs. the barrier height) is 10:1 or less due to multiple reflections. In these cases, raising the barrier heights or providing absorptive treatments need to be considered.

- Noise absorption (materials or treatments) should be considered for single highway barriers that have the potential to reflect noise into unprotected areas.

- Gaps in the noise barrier can significantly degrade barrier performance. These include breaks for structures, drainage ditches, emergency accesses, frontage roads, driveways, and ramps. If barrier gaps are inevitable, degradation in the barrier performance can be reduced by providing tight fitting access doors, using small openings for drains and culverts, wrapping the barrier back toward the receivers, or overlapping two barrier segments. If overlapping barriers are used, the length of the overlap should be at least four times the width of the gap or opening to prevent any further degradation in the barrier's performance.

18.5.3 General Aesthetic Guidelines

A major consideration in the design of a noise barrier is the visual impact on the adjacent land users. A primary factor is scale relationship between the acoustic barrier and activities adjoining the highway right of way. A high noise barrier alongside low, single-family residences could have a severe visual effect, or create adverse shadows that affect property and landscaping by reducing overall sunlight. In general, a barrier should be at least four times its height from residences (to prevent alteration of residential microclimates), and the area between should be landscaped. Due to all of the issues which must be addressed when considering noise barrier construction, an interdisciplinary team of highway engineers, structural engineers, noise analysts, environmental personnel, and landscape architects should be formed to provide specialized input and expertise early on in the process.

18.5.3.1 Visual Analysis

An important step in the design process is the visual analysis of the proposed site and consideration of the relationships that occur between the neighborhood, community, and geographical area for which the design is intended. The community context and the perspective of the passing motorists should be included in the visual aesthetics assessment and documented. Ultimately, the proposed design will become a part of the neighborhood or community. Local public involvement should be incorporated into design of visually aesthetic elements to gain input and feedback from the affected community stakeholders. The development of visual design guidelines should be used as a planning tool to emphasize visual quality, continuity, and consistency for transportation corridors with multiple noise wall projects.

One of the key elements of a visual analysis is character. Each community has a distinct character; thus a visual analysis should include a determination of the character of the neighborhood. The site and surroundings should be classified into rural, urban, and suburban categories. Each of these categories has unique environmental and social characteristics that should be the criteria considered for visual design. Noise barriers should be carefully considered in relationship to the setting so that they reflect the character of the community and style of the immediate neighborhood where possible.

Illustration 18-3 Artistically Treated Precast Concrete Noise Barrier: SH-47 in Pueblo

The character of a rural environment is one of open spaces, native trees, shrubs, grasses, and earth and sky which promote a random, natural appeal. Noise barriers in these areas should be constructed so that they will appear to be associated with the rural atmosphere. The adjacent area should be planted with native plant materials in random groupings. By contrast, the urban environment is one of geometric lines, orderly development, human activity, confined spaces, structures, and pavement. Random, natural groupings of plant materials can be used to complement noise barriers in urban areas where a community desires to make a statement about its image, connection, and support of the natural environment.

Visual analysis and landscape inventory data is useful at public meetings and neighborhood workshops where citizens can be offered a choice of wall type, materials, colors, and textures. Many objections from the public relate to a loss of scenic views or to the visual appearance of the noise barrier. A barrier is more likely to be accepted by the public if it is a visual complement to the community.

Including community leaders and representatives in the design process enables them to share their ideas and discuss how local character might be incorporated into the noise wall design. Citizen participation in the design process results in fewer post-construction complaints.

18.5.3.2 Visual Design Principles

Visual quality is a product of the design process, and a visually attractive wall can be built without excessive additional expense. In general, a highway setting with a noise barrier can be described as an enclosed space, which can result in negative reactions by motorists traveling on the roadway or residents who border the barrier. Several design principles can be applied to the design of a noise barrier that reduce the effect that enclosure has on the senses:

- LINE. A line is a direct connection of two points, and can be either real or implied. Long straight lines, like those associated with noise barriers, rarely occur in nature. As a result, the barrier “line” tends to dominate the surrounding area. Techniques that can be used to de-emphasize the long lines are placement of horizontal and vertical lines in proper locations, use of curves, altering the vertical locations of wall sections, and use of lines to reflect skylines, buildings, or natural landforms such as rivers or mountains.

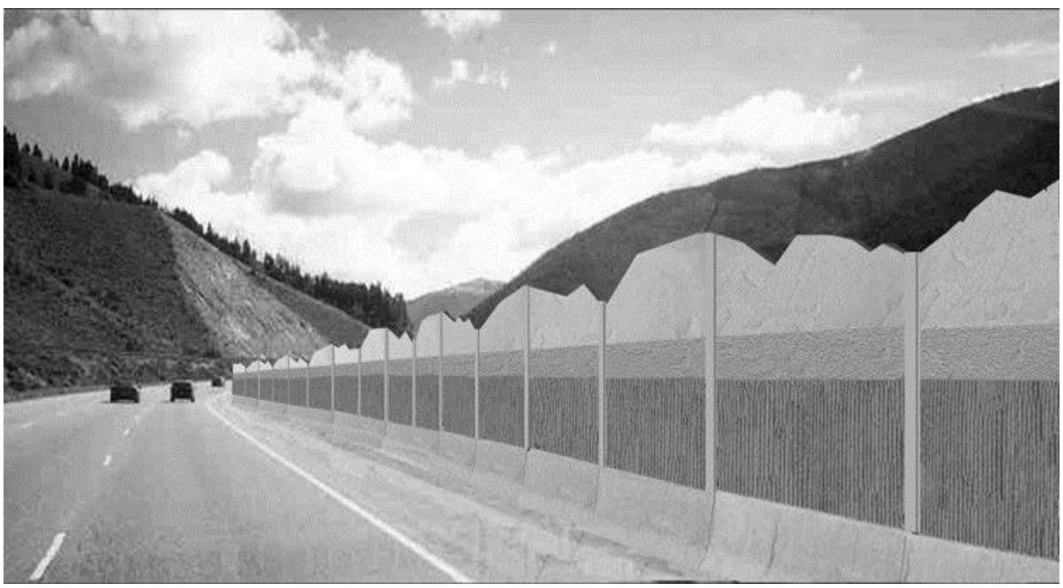

Illustration 18-4 I-70 Dillon Valley Noise Barrier (Photo Simulation Courtesy of PKM Design Group)

- FORM. Form exists in nature as mountains, boulders, or landforms. Separate objects can create forms when viewed from a distance or at highway speeds such as several trees forming a grove or many buildings forming a single skyline.

- COLOR. Color is the breakdown of light into individual visual elements. Color reactions are intuitive in most people. Generally, bright and vivid color combinations, such as those used in billboards or commercial signage, produce startling and sometimes aggressive effects. Noise barriers can use more neutral, subdued colors like those found in natural materials to create a more soothing effect.

- TEXTURE. Texture usually refers to varying degrees of coarseness or smoothness of an object's surface. Whether natural or manmade, texture is a factor in the visual interest of the surrounding area. Smooth surfaces tend to blend into monotone, making them hard to differentiate. Coarser surface textures can be seen and recognized from greater distances. Coarse surface wall texture may be a slight deterrent to graffiti artists.

- CONTRAST: The natural environment is generally of low to medium contrast. High contrast is desired where it is important that objects stand out, such as pavement markings and road signs, but it may be detrimental blending a noise barrier into its surroundings.

- SEQUENCE. Sequence is a progression of the visual experience of movement or change. This principle can be used to visually link one event with another to direct the eye to a desired point. Sequences in noise barriers can be created by selective end treatments, repeating attractive landscape planting groups, or repeating patterns in noise wall panels.

- AXIS. Axis is a visible or invisible line that divides a view. Most axes in nature are asymmetrical, while in manmade environments they tend to divide a view into equal parts. Symmetrical axes tend to be monotonous. The proper use of both concepts is desirable in what is normally a monotonous setting (long stretches of highway).

- DOMINANCE. Dominance refers to a comparison between adjacent objects in terms of visual importance. Since they are usually large structures, noise barriers tend to dominate areas in which they are placed. This is a result of the difference in scale between a noise barrier and the typical human environment.

18.5.3.3 End Treatments

Noise walls should appear to be part of the existing landscape and not give the impression that they were placed as an afterthought. Noise walls should begin and end in a natural transition, if possible, from the ground level to the desired height.

Where space allows, the best transition is a natural earth berm or terrain feature in which the end of the wall can be incorporated. Through this technique, the wall appears to originate from the landscape rather than be dropped onto it. If there are no terrain features in the area, a “step-down” technique at the end of the barriers can provide the same effect. Any tapering of the wall should be gradual to a point where the wall is no longer visually dominant. Walls should tie into existing structures, such as bridges, bridge abutments, and retaining walls.

18.5.3.4 Design Elements for Landscape Plantings

Landscape plantings may be the most effective and economical means available to reduce adverse visual impacts of a noise barrier. When used in combination with a structure, plantings serve to link the structure of the wall with the natural surroundings. Trees, shrubs, and grasses may provide all of the design elements of line, form, color, and texture and mitigate problems with scale and dominance of the noise wall in the landscape. They also provide a living, changing element in a hard-edged manmade environment and provide psychological and visual relief to adjacent communities.

Massing shrubs and trees can create a natural transition area for the end of a wall. Plant materials can provide color and texture variety and can have positive effects on scale and dominance. Vegetation can also provide shade, reduce reflection of noise and light, cool and filter the highway environment, provide slope stabilization, and reduce erosion control problems.

Following are some landscape plantings design guidelines:

- Design planting “pockets” by creating offsetting recesses within the line of the noise wall. Even small jogs can provide protected microclimates and visually soften wall impacts on the motorist.

- Use vines and shrubs in combination to reduce the dominance of a wall.

- Vary heights and textures to get a good combination of plant masses.

- Vary spacing and tree groupings to improve the visual effect, where possible.

- Use trees to reinforce rhythm and sequence and provide a vertical element in predominantly horizontal walls.

- Use ground covers and shrubs to smooth the transition between the wall and ground plane.

- Install plantings against the wall and opposite the wall to provide an asymmetrical axis and reduce visual dominance.

- Use plantings that are drought tolerant and relatively maintenance free. Select plant species from regional and local reference sources that document their hardiness, microclimate appropriateness, and relative longevity.

- Use good planting practices, such as appropriate soil amendments, groupings of plants with like water needs, and low-cost, attractive mulches to conserve water and moderate summer and winter soil temperatures.

Illustration 18-5 Terraced Landscaping With Noise Barrier: US-287 Lafayette Bypass

18.5.4 General Maintenance Guidelines

When considering construction of a noise barrier, maintenance factors should be addressed and any fatal flaws identified as early as possible to prevent problems later on in either design or operation. Examples of these factors include maintenance of the barrier itself, protective coatings, replacement of materials damaged by impact, cleaning of the barrier, graffiti prevention and removal, snow storage, and de-icing of the roadway in the winter months if shadowing is a problem. Plantings should be tolerant of the roadside environment and require little to no maintenance. It is particularly important to maintain a stock of replacement materials (i.e., posts, panels, blocks), which are compatible with the barrier in case damage does occur. Additional quantities should be considered in the construction package for contingency purposes.

Usually access to the backside of the barrier is needed. Access can be provided with an access road, a walk path, gates, or access panels built into the barrier. Access must be designed so that it does not compromise the noise reduction effectiveness of the barrier. If the barrier is constructed on the right of way line, provisions should be made to coordinate the location of the access points with the appropriate agencies or landowners.

18.5.5 General Materials Guidelines for Manufactured Noise Barrier Walls

Note: This subsection is from the 2013 CDOT Roadway Design Manual, Chapter 18 entitled Noise Guide. It is a select revision with an effective date of August 1, 2015.

18.5.5.1 Physical Properties

- Noise wall materials of concrete panels, masonry blocks, or brick are used most frequently because of their life cycle cost and maintenance considerations. Other materials may be used if they meet all of the applicable requirements.

- Designed and constructed without gaps or if an opening is required the gap is minimalized.

- Generally, minimum height of 8 feet and a maximum of 20 feet. For barriers constructed on the shoulder, 12 feet is a recommended maximum height. Project design may adjust these dimensions if required.

- “Privacy fences” rarely have the acoustic properties to function as noise barriers.

18.5.5.2 Acoustic Properties

- Materials shall have a minimum acceptable Sound Transmission Class (STC) of 25, as tested using ASTM E90 and ASTM 413 or a CDOT approved equivalent specification.

- Materials shall have a minimum Noise Reduction Coefficient (NRC) of 0.65 if seeking an “absorptive” classification, as tested using ASTM C423 or a CDOT approved equivalent specification. Materials that are not tested or do not meet this requirement shall be classified as "reflective."

- Materials must be acoustically durable over the design life. Absorptive surface treated walls must resist degradation of sound-absorbing properties after installation. The materials should not require cleaning in order to maintain sound-absorbing properties.

18.5.5.3 Non-Acoustic Properties

- Concrete or cementitious materials must pass a 250-cycle freeze-thaw test. The test shall be performed according to ASTM C 666 and AASHTO T 161 or a CDOT approved equivalent specification.

- Materials must pass a 2500-hour "weatherability" test without significant surface deterioration. The test shall be performed according to ASTM G 23, Type D or a CDOT approved equivalent specification.

18.5.5.4 Maintenance Requirements

- Materials must be resistant to impact or easily replaceable or repairable using CDOT-owned equipment.

- Surface texture, coating, or combination thereof of walls in areas subject to graffiti should make the graffiti difficult to place and easy to remove. Details of the process to remove graffiti should be provided to CDOT.

A list of pre-approved Absorptive and Reflective Sound Walls is available on CDOT's Approved Products List at www.codot.gov/business/apl.

18.5.6 Berms

Earth berms are a good alternative to walls, since they have a more natural appearance and are aesthetically pleasing. Berms should be considered in areas where sufficient right of way is available to install them and preserve the visual and environmental qualities of the corridor.

The feasibility of berm construction should be considered within the overall grading and drainage plan for the highway, particularly if an irrigation system will be part of the project. One of the advantages of berm construction is that a variety of materials, such as soil, stone, rock, or rubble can be used. Typically, berms can be constructed from surplus material available directly on the project site or from waste material from other areas. This can result in decreased costs compared to the cost of a noise barrier.

For safety and erosion control purposes, the slopes of an earth berm should be 2:1 or flatter, although a 3:1 slope is preferable. The ends of the berm should have a lead-in slope of 10:1 and curve toward the highway. Berms can be either vegetated or seeded, and slope stabilization should be done as soon as possible after construction.

Illustration 18-6 Recycled Sand Berm: I-70 East of Vail

18.5.7 Combination Barriers

For areas where a full berm cannot be constructed, such as a situation where there is limited right of way, a combination barrier can be constructed. This involves building up the earth berm to a desired height and constructing a wall on the berm. The soil in the berm must be stable enough to support a wall structure foundation.

Illustration 18-7 Combination Barrier: I-25 @ Exit 188

18.6 CONSTRUCTION NOISE

The approach to construction noise should be general in scope and consider the temporary nature of construction activities. Although the public generally views construction noise as a short-term issue that is tolerable and necessary, the types of activities that are expected to be performed and the equipment that will be used should be disclosed.

No detailed analysis or mitigation measures are required, but the noise analysis should at least identify low-cost, common sense mitigation measures that can be included on the project. Examples are limitations of work to daytime (or specified) hours, ensuring that equipment uses properly maintained mufflers, modification of backup alarm systems, location of haul roads, construction of permanent noise barriers (if warranted) as soon as possible, and public outreach. Noise mitigation may be more of an issue on large, complex projects in major urban areas. For these projects, a more detailed discussion is necessary and may require a separate report detailing monitoring and mitigation measures.

Some entities have passed local noise ordinances that restrict the amount of noise that may be emitted from a construction operation during certain hours or in certain areas (i.e., residential neighborhoods). These noise ordinances must be obeyed unless a variance has been requested from and approved by the local agency of authority. Such a variance may be needed if the work will be very extensive or lengthy in nature.

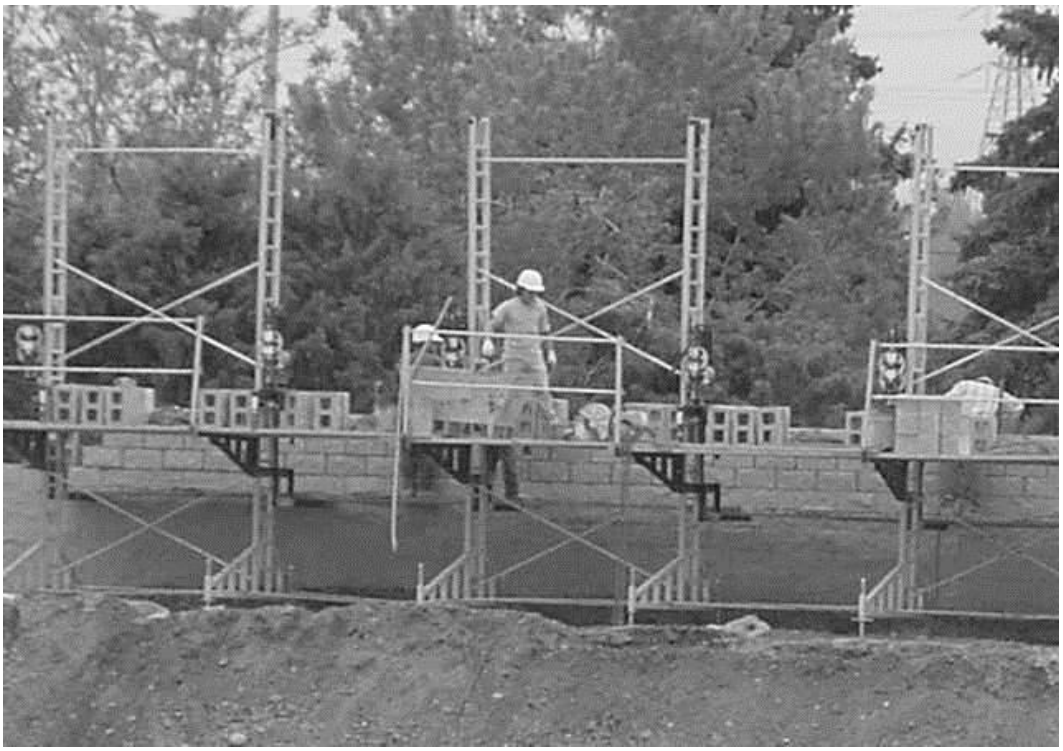

Illustration 18-8 Masonry Noise Barrier Construction: I-270 West of York Street

For additional assistance contact the CDOT Noise Program Manager at:
https://www.codot.gov/programs/environmental/noise
Or refer to the following references.

REFERENCES

Updated versions of various FHWA references also found at http://www.fhwa.dot.gov/environment/noise/

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8. FHWA. *Highway Construction Noise: Measurement, Prediction, and Mitigation*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.: 1977.
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