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 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 provided at the end of this chapter. If existing regulation or guidance is revised, or if additional regulation or guidance is published after the date this chapter was published, the new material takes precedence.

18.1 NOISE FUNDAMENTALS

Noise 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 which condenses a large range of several magnitudes of sound pressure levels. For the purposes of highway traffic, an “A-scale” weighting is applied to noise levels because the human ear does not perceive all sound frequencies equally. These are referred to as A-weighted decibels (dBA).

Because the sound intensity of highway traffic is not constant, a descriptor is needed to describe the source in a steady-state condition. The most common descriptor, which is used for CDOT projects, is the hourly equivalent sound level (L_{eq}(h)). For highway traffic noise analyses, noise levels are expressed in terms of hourly equivalent A-weighted decibels and expressed in this manner: dBA L_{eq}(h).

Since noise levels in the decibel scale are logarithmic, they cannot be added arithmetically. For example, adding two 70-decibel sources results in a noise level of 73 decibels. 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, increases the overall decibel level 3 decibels. Studies have shown that a 3-decibel change in noise levels is 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 when noise levels are highest. It is used for comparison with 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 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 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 methods that must be followed in the evaluation and mitigation of highway traffic noise in Federal-aid highway projects. The FHWA will not approve plans or specifications for any federally aided highway project unless the project includes noise abatement measures, if the measures have been 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.

The project type will be determined in conjunction with a CDOT noise specialist. Type I definitions are in 23 CFR 772 and *CDOT Noise Analysis and Abatement Guidelines* (2). Projects that are or may be Type I include but are not limited to:

- Constructing a new road on a new location
- Adding a lane, auxiliary lane, or ramp
- Changing the elevation of the road or ramp
- Moving the road closer to receptors
- Adding a new or substantial alteration of a weigh station, rest stop, ride-share lot, or toll plaza

Type II projects are defined as the construction of noise abatement on existing highways ("retrofit" projects) in absence of major highway construction. State funding has been unavailable for this program since 1999.

A Type III project is any project that does not meet criteria for either a Type I or Type II project. Noise analyses are not required for these non-noise sensitive projects. Examples of Type III projects include resurfacing, bridge rehabilitation including bridge reconstruction with minor non-capacity widening, and most shoulder and maintenance projects.

A noise analysis study is required for all Type I projects if noise sensitive properties (receptors) are present in the project study zone, which is defined as a 500-foot halo from the proposed edge of the traveled lane(s). A noise sensitive receptor is any location for which highway traffic noise may be detrimental to the outdoor enjoyment and functional use of the property. Noise sensitive receptors include residences, parks, hotels, schools, and noise-sensitive businesses such as recording studios. A complete list of receptor types is in Table 1 of 23 CFR 772 and Table 18-1 of this document.

The purpose of a noise analysis is to identify receptors that are impacted by noise. Noise is determined at existing conditions and is projected for the project design year, which is usually 20 years in the future. As defined in the regulations, a traffic noise impact occurs when projected noise levels approach or exceed the Noise Abatement Criteria (NAC) or when the noise from projected traffic levels substantially exceeds the existing noise levels. NACs are noise thresholds in units of dBA and vary by land use category. A substantial increase in noise level is defined as being 10 dBA or more.

An impact due to a substantial increase in noise is rarely encountered in situations other than the construction of a new highway on a new location. Table 18-1 identifies the NAC levels for different land use categories.

Table 18-1: CDOT Noise Abatement Criteria for Receptor Activity Descriptions

Activity Category	Activity Leq(h)[2]	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
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, time-share resorts, vacation rental properties, 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.
2 Hourly A-weighted sound level in dBA; reflects values that are 1 dBA less than 23 CFR 772 values

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 are 1 dBA less than FHWA levels. The most common land use activity category included in noise analyses is Category B, residences, which has a NAC of 66 dBA.

Noise regulations require that any receptor determined to be impacted by noise, based on modeling, is entitled to mitigation consideration. Mitigation must be provided if it is found to be feasible and reasonable.

The feasibility determination considers the physical constructability of the abatement measure. Factors include construction complexity, required area needed for foundations or equipment, and compatibility with utilities and drainage. Complex construction techniques require more time to install, more cost in labor and equipment, and may cost more to maintain. 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 receptor. Walls cannot be more than 20 feet in height. Walls 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.

Any mitigation that is deemed to be feasible must also meet the three reasonableness socio-economic criteria before it is implemented: a minimum noise reduction, cost-effectiveness, and the preference of the benefited residents and property owners to have noise abatement measures constructed. The minimum noise reduction is a noise reduction design goal of at least 7 dBA at a minimum of one receptor. Documentation of the analysis and mitigation decision-making process must be clear and complete.

18.3 CDOT NOISE ANALYSIS AND ABATEMENT GUIDELINES

Applicable procedures for conducting a project level highway traffic noise analysis are detailed in the *CDOT Noise Analysis and Abatement Guidelines*. 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 were approved by FHWA. Additional guidance is available from FHWA **(3 through 10)** and CDOT *Procedural Directive 1601: Interchange Approval Process*. **(11)**

The *CDOT Noise Analysis and Abatement Guidelines* include a sample Benefited Receptor Preference Survey and CDOT Form 1209, the Noise Abatement Determination worksheet. The survey is the third required criteria of the reasonableness test. Form 1209 documents the feasibility and reasonableness determination for each evaluated mitigation measure.

The guidelines also discuss public involvement, coordination with local officials, construction considerations, and National Environmental Policy Act (NEPA) documentation requirements. NEPA requirements are also discussed in the CDOT Environmental Stewardship Guide. **(12)**

Information provided in this chapter gives a general overview of noise regulations and analysis procedures. However, the *CDOT Noise Analysis and Abatement Guidelines* describe these issues in much greater detail and should be consulted, especially if there are any issues regarding a specific project.

18.4 HIGHWAY TRAFFIC NOISE MITIGATION MEASURES

FHWA allows use of several noise mitigation measures, but only requires that noise barriers (berms, walls, or a combination) be considered as mitigation for impacted receptors. If analyzing another mitigation measure, a determination as to the validity and practicality of successfully implementing the 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.

Vegetation does not function as noise mitigation unless it consists of 200 to 300 feet of dense, permanent foliage ground floor to treetop coverage of at least 16 feet high. While vegetation can be of aesthetic and psychological benefit, and can enhance an area where it is placed and successfully maintained, it is usually only provided for visual, privacy, or aesthetic treatment.

The rest of this section provides information about mitigation measures that are allowed but not required by FHWA.

18.4.1 Traffic Management Measures

Traffic management measures may reduce traffic noise levels. Examples 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 cited by the public as a mitigation method. However, generally a speed reduction of at least 20 mph is needed to sufficiently decrease noise levels. Therefore, this option has operational issues.

18.4.2 Alteration of Horizontal or Vertical Alignments

Altering the design of the roadway can be very effective in reducing noise levels and noise impacts. Although several techniques are possible, certain projects and areas will not be conducive to some or any of these mitigation measures. In most 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 receptors.

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

If the roadway can be depressed through a cut section, noise levels will be reduced for the area that is shielded by the adjacent slope. This is most effective when vehicles can be screened from view. Elevated sections of roadway create a shadow zone for receptors that are close to the embankment or structure. Noise is reduced in shadow zones. However, elevated sections may cause slight noise increases to receptors farther from the roadway 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 (e.g., “Jake”) brakes. However, there is a tradeoff with this option: gentler grades have the potential to increase noise levels due to the longer exposure time.

Pavement type is often cited as a possible means to reduce highway traffic noise. The majority of noise emitted from highways is due to the tire-pavement interaction. Research on this issue has been ongoing since the 1970s. 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 to 5 dBA of noise level reduction. However, after 6 months to 2 years, the aggregate becomes polished and voids in the pavement fill so 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, results in reduced noise levels compared to 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.

FHWA policy says that pavement type cannot 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 NACs, 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 areas that are already developed because the cost for acquiring already developed property (e.g., homes, businesses) is prohibitive.

Property owners cannot receive Federal funds as monetary compensation in lieu of noise abatement. 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

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. New buildings can have sound absorbing material installed in the walls during construction. Noise insulation does nothing to improve the noise levels at adjacent outdoor use areas.

Federal funding can only be used for noise insulation for NAC D activity categories, which are listed in Table 18-1. If this option must be considered because no other feasible or reasonable mitigation measures are 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. Post installation maintenance and operational costs for noise insulation are not eligible for Federal-aid funding.

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. It may be a wall, a berm, or a combination of both. The barrier works by blocking the path of 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. Therefore, privacy fences do not function well as noise barriers.

Noise barriers are designed to reduce noise beginning at the first-row receptors, which are receptors closest to the barrier. Barriers may benefit receptors beyond the first row, depending on the configuration of the development. Normally, barriers are effective for receptors 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.

A noise reduction benefit of 5 dBA is generally fairly simple to achieve; however, a 7 dBA reduction is required at a minimum of one receptor along the wall in order for the barrier to be found reasonable. A reduction of 15 or more dBA is difficult to achieve, since it requires a reduction of at least 97 percent of the initial acoustic energy of the source.

18.5.1 Noise Barrier Walls

Noise barrier walls are a common means for reducing roadway noise levels. They can be constructed from a variety of materials. Although many wood walls were constructed in the past, life cycle and maintenance issues have resulted in the majority of new walls being constructed out of concrete, masonry block, or brick. The *CDOT Landscape Architecture Manual* (13) no longer allows wood to be used. Walls are preferred in many areas because they can be constructed where a limited amount of space precludes construction of an earth berm or a wall-berm combination.

Most noise walls are ground-mounted. In some situations, a barrier needs to be placed on a structure. This is most common for highway bridges, when the barrier needs to be constructed on the bridge to prevent a major gap in the barrier.

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

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

18.5.2 Berms

Earth berms are a good alternative to noise barrier 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. This will help preserve the corridor visual and environmental qualities.

Feasibility of berm construction should be considered within the highway overall grading and drainage plan, particularly if an irrigation system will be part of the project. One advantage 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.

Slopes of an earth berm should be 2:1 or flatter, for safety and erosion control purposes, 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. Slope stabilization should be done as soon as possible after construction.

18.5.3 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 18-6: Recycled Sand Berm: I-70 East of Vail

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

18.5.4 General Design Guidelines

The following are general considerations for noise barrier design:

- 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 and the barrier material should meet minimum impact standards to prevent shattering. Light reflected to motorists should be minimized.
- 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 barrier placement. This consideration should also be given to shadow coverage in adjacent yards and parking lots. This should not be an issue with barriers that are oriented north-south.

- Protrusions on barriers near traffic lanes or facings, which can become missiles in a crash, or which can 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 ensure soil stability.
- For noise wall structural design considerations, refer to the AASHTO *Guide Specifications for Structural Design of Sound Barriers.* **(14)** Some structural aspects to consider on a project –specific basis are: Can the barrier be easily mounted to a bridge? Can it be retrofitted in the future? Does it accommodate through-the-wall access doors? Is it capable of supporting signs or lighting? It is preferred that signs and lighting have their own foundations.
- Barriers should be integrated with other project elements, such as foundations impacts on underground facilities and barrier impacts to overheat facilities.

Project environmental documents or noise analysis studies, 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 receptors. 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.

- 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 receptor end, the line-of-sight is always checked from a point 5 feet above the ground elevation, which approximates the height of the average human ear.
- Building the barrier closer to either the receptor or the noise source provides more noise reduction compared to locating the barrier in the middle between the receptor and source. However, this is not practical in all cases.
- To prevent noise from flanking around the barrier ends, the barrier should extend past the end receptor at least four times the perpendicular distance from the receptor to the barrier. If this is not possible, the barrier can be bent back towards the receptor (wrapping the barrier) in order to reduce noise at the receptor. Also, combining the barrier with natural terrain features and existing structures may help reduce noise at the receptors.
- 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 may 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 receptors, 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.

18.5.5 General Aesthetic Guidelines

The visual impact on adjacent land users is a consideration in noise barrier design. A primary factor is scale relationship between the noise 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. Additional information regarding aesthetic guidelines for noise barriers can be found in the *CDOT Landscape Architecture Manual*. **(13)**

18.5.5.1 Visual Analysis

An important step in the design process is the visual analysis of the proposed site and consideration of relationships that occur between the neighborhood, community, and geographical area for which the design is intended. Community context and passing motorists' perspective should be documented in the visual aesthetics assessment. 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. 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 neighborhood's character. 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 considered for visual design. Noise barriers should be carefully considered in relationship to the setting so, when possible, they reflect the community's character and neighborhood's style.

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. In 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.

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

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. This process is described in the Chief Engineer's Policy Memo 26 (Context Sensitive Solutions [CSS] Vision for CDOT). Citizen participation in the design process results in fewer post-construction complaints.

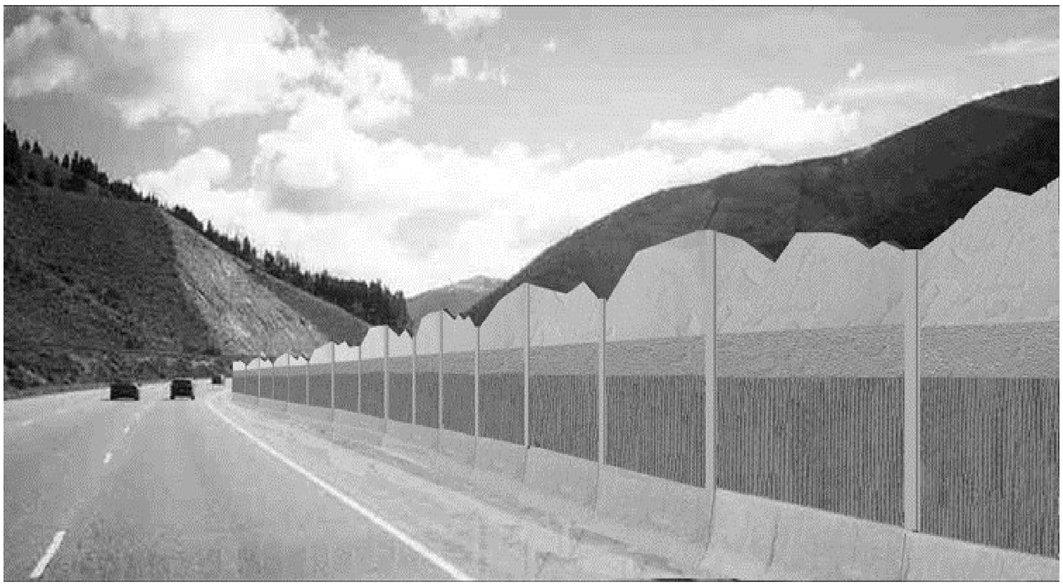
18.5.5.2 Visual Design Principles

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 noise barrier design that reduce the effect an 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 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.
- 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. **(13)**
- 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. They also may reflect noise, which is discouraged. Coarser surface textures can be seen and recognized from greater distances. Coarse surface wall texture may be a slight deterrent to graffiti artists. **(13)**
- 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 when trying to blend 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 for long stretches of highway, which is normally a monotonous setting.
- 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.

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



18.5.5.3 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 and match aesthetics of existing structures, such as bridges, bridge abutments, and retaining walls.

18.5.5.4 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 noise wall line. 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

18.5.6 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 in either design or operation. Examples of these factors include maintenance of the barrier, 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.

Access to the barrier backside is usually 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.

18.6 General Materials Guidelines for Noise Barrier Walls

To ensure that all materials used to build noise barrier walls meet acoustic requirements, material information and test results must be submitted to the CDOT Product Evaluation Coordinator for approval to be added to CDOT's Approved Products List. To be approved, the material must meet testing requirements, as described in Section 18.6.1. CDOT also evaluates materials based on additional criteria for which testing methods do not apply, as described in Section 18.6.2.

CDOT may request to view, in person, a sample or a full size section of the barrier product, at CDOT's discretion. Tests shall be performed by a certified independent third party. To obtain valid results, specimens that get tested should be taken from a finished production run product and not from small handmade pieces that were specifically made to be tested.

18.6.1 Acoustic Testing Requirements

- Materials shall have a minimum acceptable Sound Transmission Class (STC) of 30, as tested using ASTM E90 and ASTM 413 or a CDOT approved equivalent specification.

- Materials shall have a minimum Noise Reduction Coefficient (NRC) of 0.70 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."

18.6.2 Additional Considerations for Noise Barrier Materials

18.6.2.1 Acoustic Properties

- 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.

- Project plans should indicate if the noise wall surface is reflective or absorptive

18.6.2.2 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. Noise walls are generally built using concrete and concrete durability properties and coating properties for concrete are not unique to noise walls. If noise walls are designed with another material, durability and coating properties would be examined on a case-by-case basis. The CDOT Landscape Architecture Manual (14) does not allow use of wood.

- Barriers shall be designed and constructed without gaps, or, if an opening is required, the gap shall be minimalized.

- Generally, barrier heights are a minimum 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.

18.6.2.3 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.

18.7 CONSTRUCTION NOISE

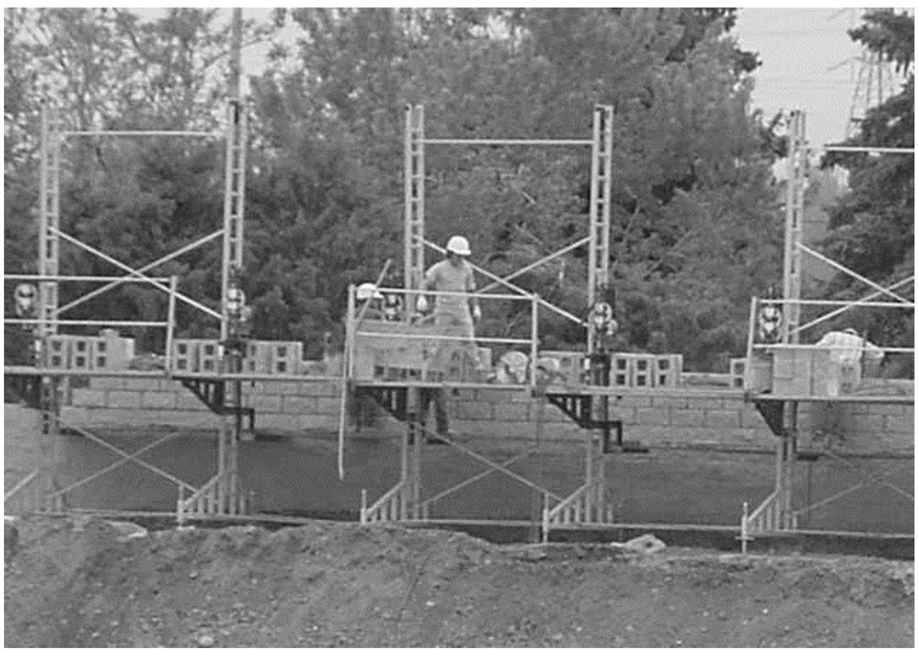
The approach to construction noise should be general in scope and consider the temporary nature of construction activities. Although the public generally views construction noise as a short-term issue that is tolerable and necessary, types of activities that are expected to be performed and equipment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

Although a detailed analysis of mitigation measures is not generally required, the noise analysis should at least identify low-cost, practical mitigation measures that can be included on the project. Examples are limiting work to daytime hours, ensuring that equipment uses properly maintained mufflers, modification of backup alarm systems, location of haul roads, construction of feasible and reasonable noise barriers as soon as possible, and public outreach. Noise mitigation may be a larger 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 local government agencies have local noise ordinances that restrict how much noise may be emitted during certain hours or in certain areas (e.g., residential neighborhoods). These noise ordinances must be obeyed unless a variance has been approved. Such a variance may be needed if the work will be very extensive or lengthy.

For additional assistance, refer to the following references or contact the CDOT Noise Program Manager at: http://www.coloradodot.info/programs/environmental/noise.

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



REFERENCES

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

1. Code of Federal Regulations (CFR), Title 23, Part 772: Procedures for Abatement of Highway Traffic Noise and Construction Noise, revised July 2010.
2. *CDOT Noise Analysis and Abatement Guidelines*, January 15, 2015.
3. FHWA. *Entering the Quiet Zone: Noise Compatible Land Use Planning*, Washington, D.C.: Federal Highway Administration, U.S. Department of Transportation, May 2002. http://www.fhwa.dot.gov/environment/noise/noise_compatible_planning/federal_approach/land_use/qz00.cfm
4. FHWA. *Highway Noise Barrier Design Handbook*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.: February 2000.
5. FHWA. *Highway Construction Noise Handbook*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.: 2006.
6. FHWA *Highway Noise: A Guide to Visual Quality in Noise Barrier Design*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.: , April 1994.
7. FHWA. *Highway Traffic Noise: Analysis and Abatement Guidance*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.: December 2011.
8. FHWA. *Insulation of Buildings Against Highway Noise*, Federal Highway Administration, Washington, D.C.: 2011.
9. FHWA. Lee, Cynthia S.Y., Gregg G. Fleming. *Measurement of Highway-Related Noise*. Report No. FHWA-PD-96-046 and DOT-VNTSC-FHWA-96-5. Cambridge, MA: John A. Volpe National Transportation Systems Center, Acoustics Facility, May 1996.
10. FTA. *Transit Noise and Vibration Assessment,* Federal Transit Administration, May 2006.
11. CDOT Procedural Directive 1601, "Interchange Approval Process," October 16, 2008.
12. *CDOT Environmental Stewardship Guide,* May 2005.
13. CDOT *Landscape Architecture Manual*, August 18, 2014
14. AASHTO. *LRFD Bridge Design Specifications, Customary U.S. Units, 6th Edition, with*

2013 Interim Revision, Washington, D.C.: American Association of State Highway and Transportation Officials, 2013. [Content formerly included in AASHTO *Guide Specifications for Structural Design of Sound Barriers*.]