# Chapter 16
# Noise Guide

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Chapter

16

# 16 Noise Guide

## 16.1 Introduction

Noise generated by highway traffic can cause varying reactions by the public involving physical, physiological, and psychological effects. Highway traffic noise should be considered in roadway design.

This chapter is intended to help designers understand issues related to highway traffic noise. This includes understanding the applicable federal and state regulations and guidelines, traffic noise analyses for specific projects, highway traffic noise mitigation measures, and construction noise mitigation measures.

Whether a project is required to build noise mitigation (e.g., noise walls) is determined by a project-specific noise analysis. Noise analyses are only required for some projects, as described in Section 16.3. Project construction generates noise, so projects must comply with local and/or state noise regulations and mitigate construction noise, as described in Section 16.11.

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 regulations or guidance is revised or published after the date this chapter was published, it takes precedence if it conflicts with this chapter.

## 16.2 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. This scale condenses a large range of several magnitudes of sound pressure levels. Sound is composed of various frequencies, but the human ear does not respond to all frequencies. It has been found that the A-scale on a sound-level meter best approximates the frequency response of the human ear. Sound pressure levels measured on the A-scale of a sound meter are abbreviated dBA.

Because the sound intensity of highway traffic is not constant, a descriptor is needed to describe the source in a steady-state condition. An equivalent sound level is the steady-state, A-weighted sound level. It contains the same amount of acoustic energy as the actual time-varying, A-weighted sound level over a specified period of time. CDOT uses a time period of one hour. The descriptor is the hourly equivalent sound level, which is represented as $L_{eq}$(h).

Since noise levels in the decibel scale are logarithmic, they cannot be added arithmetically. For example, adding two 70-dB sources results in a noise level of 73 dB. 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 dB. Studies have shown that a 3-dB change in noise levels is barely detectable by the human ear, even though the overall sound energy has doubled. It normally takes a 5-dB change in noise levels to be perceptible to most people. A 10-dB 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 dB levels are unchanged.

## 16.3 Noise Regulations

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), which describes the analysis of highway traffic noise and the evaluation of potential noise mitigation. Federal Highway Administration (FHWA) will not approve plans or specifications for any federally aided highway project unless the project includes building noise abatement[1], if abatement was found to be feasible and reasonable in the project's noise analysis, as described in Section 16.4.

Projects must comply with 23 CFR 772 if either of the following are true for highway or multimodal projects:

- Requires FHWA approval[1] regardless of funding sources (refer to 23 CFR 772.7[a]).
- Funded with Federal-aid highway funds (dollars provided to CDOT by FHWA).

Although adherence to 23 CFR 772 is only required for those two criteria per Section 772.7, CDOT's *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020) broadens the applicability of traffic noise analyses in the following two situations:

- FHWA noise regulation does not apply but the project adds capacity via through lanes, if the lane(s) requires additional pavement beyond the existing roadway geometry profile, which includes medians and inside.

[1] "Noise abatement" and "noise barrier" are terms that mean the same thing and are used interchangeably

[2] FHWA approval refers to FHWA "signing off" on a project, whether literally (an actual signature on an EA or EIS) or figuratively (such as for programmatic CatExs that don't require individual signatures but are authorized as a group). FHWA approval can also refer to a design variance, air space lease (lease of interstate right of way to third party), federal land transfer (Forest Service and Bureau of Land Management), or change in interstate access (crossing the A-line, moving the A-line, or new or revised interchange). An IAR (Interstate Access Approval) under CDOT's 1601 process requires FHWA approval. Form 128 and and a CatEx are not the same thing. Projects using a "NEPA-like" process per CDOT's Stewardship Guide do not require an FHWA approval. The noise regulation applies to all FHWA CatExs, but not to NEPA done for other federal agencies.

- FHWA noise regulation does not apply but the project is adjacent to a prior project to which the regulation applied and for which noise abatement was built, if the current project is Type I.

If 23 CFR 772 applies either under Section 772.7 or under the two criteria that broadens applicability under the *Environmental Stewardship Guide*, projects 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 projects require noise analysis, which may lead to the project being required to include noise mitigation. Type I criteria are in 23 CFR 772. Clarification is available in Section 3.1.1 of CDOT *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020). A project is Type I if it meets any of the following criteria:

- Construction of a new roadway in a new location (examples: roads, streets, freeways, expressways, and interstates.
- The physical alteration of an existing highway where there is either:
  - Substantial Horizontal Alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition;
  - Substantial Vertical Alteration. A project that removes shielding therefore exposing the line-of-sight between the receptor and the traffic noise source. This is done by either altering the vertical alignment of the highway or by altering the topography between the highway traffic noise source and the receptor.
- The addition of a through-traffic lane(s). This includes the addition of a through-traffic lane that functions as a high-occupancy vehicle (HOV) lane, high-occupancy toll (HOT) lane, bus lane, or truck climbing lane.
- The addition of an auxiliary lane, except when the auxiliary lane is a turn lane.
- The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange.
- Restriping existing pavement for the purpose of adding a through-traffic lane or an auxiliary lane.
- The addition of 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 in Colorado since 1999. Unless funding is reinstated, which is not expected, no project will be Type II.

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 Type III projects. Noise mitigation is not considered for Type III projects.

*Use this link to access the most recent CDOT Noise Analysis and Abatement Guidelines (CDOT, 2020):* *https://www.codot.gov/programs/environmental/noise/regulations-guidelines-policies*

## 16.4 Noise Analysis

Procedures for conducting project level highway traffic noise analyses are provided in the CDOT *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020). The guidelines are compliant with 23 CFR 772 and approved by FHWA. Additional guidance is available from FHWA (FHWA, 2011) and FTA (FTA, 2018).

As part of the noise analysis for highway projects, noise levels are modeled for the worst-noise hour. This is when noise levels are highest. 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.

Noise levels for the design year are compared to impact criteria to determine if the project will cause noise impacts to noise sensitive receptors. The project also causes noise impacts if the design year noise levels are 10 dB or more higher than existing noise levels, which generally only occurs if a new road is being built in a new location. If the project does not result in noise impacts, noise mitigation is not considered. Noise mitigation is evaluated if the project results in noise impacts. If noise mitigation is found to be feasible and reasonable, the proposed noise mitigation must be included in the final plans and constructed with the project to obtain FHWA approval.

Noise analyses are conducted as part of the National Environmental Policy Act (NEPA) process. The first analysis is usually conducted when design is in early stages (e.g., 30% design). The resulting traffic noise technical report indicates in a section called “Statement of Likelihood” if any noise barriers are recommended.

When the project reaches final design, an evaluation is done to determine if the original analysis is still valid or if the project noise model needs to be updated, which would include potential changes in traffic data. If a model update is required, the number and location of recommended noise barriers might change from the original noise analysis. Noise barriers that are recommended by this evaluation need to be modeled based on the project final design to determine the final barrier location, height, and length.

The final design evaluation, which culminates in a Noise Verification (email, memo, or report), considers things such as:

- Whether the project type (Type I or Type III) changed.
- Whether the final design changed enough from the design in the original noise analysis to affect the analysis and thus trigger a new noise analysis (e.g., traffic predictions for the final design have doubled or more, changes for the final design constitute a Type I project on its own).
- Whether the area around the project changed enough from what was considered in the original noise analysis to affect the noise analysis and thus triggers a new noise analysis (e.g., new development near the project).
- Whether benefitted receptors of recommended noise barriers vote for or against recommended barriers. If more than 50% of the responding benefited receptors support the proposed noise barrier, it will be built.

## 16.5 Optional Highway Traffic Noise Mitigation Measures Under 23 CFR 772

The FHWA noise regulation, 23 CFR 772, allows several noise mitigation measures to be used as mitigation for impacted receptors. Some of these measures are optional; only noise barriers (berms, walls, or a combination) must be considered (refer to Section 18.5). If analyzing an optional mitigation measure, a determination as to the validity and practicality of successfully implementing the measures must be made by a CDOT engineer.

Vegetation is not an optional measure. It does not function as noise mitigation unless it consists of 200 to 300 feet of dense, permanent foliage ground floor to tree top 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.

Pavement type not an optional measure. It 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.

Allowed optional noise mitigation measures are traffic management, alterations of horizontal or vertical alignments, acquisition of property or property rights, and noise insultation, The costs of these measures, as with noise barriers, may be included in Federal-aid participating project costs.

### 16.5.1 Traffic Management Measures

Traffic management measures may reduce traffic noise levels. Examples include:

- Traffic control devices.
- Signing for prohibition of certain vehicle types.
- Time-use restrictions for certain vehicle types.
- Modified speed limits.
- Exclusive lane designations.

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.

### 16.5.2 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.

### 16.5.3 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.

### 16.5.4 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 Activity Category D receptors, which are listed in Table 1 of the NAAG. These are 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. These receptors might also be Activity Category C; the noise analysis determines which they are, as specified in 23 CFR 772.11(c)(2)(iv). 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 by FHWA in consultation with CDOT.

## 16.6 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. Most sound waves are 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. That is why most 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 two receptors along the wall in order for the barrier to be found reasonable.

### 16.6.1 Noise Walls

Noise 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* (CDOT, 2020) 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.

*Figure 16-1 Cast-in-Place Masonry I-76 East of York Street*

*Figure 16-2 Post-and-Panel Noise Barrier Mounted on Type 7 Barrier: US-6 in Lakewood*

### 16.6.2 Berms

Earth berms are a good alternative to noise 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 need to consider the context classification and facility type of the project. The slopes and location of the berm shall be defined by the roadside design guide prior to the noise analysis.

### 16.6.3 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. Berms and noise walls may also be alternated, side by side.

*Figure 16-3 Recycled Sand Berm: I-70 East of Vail*

*Figure 16-4 Combination Barrier: I-25 at Exit 188*

## 16.7 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 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 *LRFD Bridge Design Specifications (AASHTO, 2020)*. 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.

## 16.8 General Visual Quality of Noise Walls

The *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2000) emphasizes the need for considering visual quality in the noise wall design process. The basis of the handbook is that in addition to meeting technical requirements, noise walls should be functional as well as aesthetically pleasing. Historic, natural, cultural, and architectural considerations of the surrounding area are part of the selection and design process. Two approaches or design philosophies are to design the wall to blend into surroundings or to design it to be a prominent feature in the landscape. In the planning and design phase visual and environmental effects on both sides of the noise wall should be considered. The ultimate design is dependent on many factors including the location, site constraints, and stakeholder meetings. A successful design approach will be multidisciplinary and include stakeholders, maintenance personnel, architects, planners, landscape architects, roadway engineers, acoustic engineers and structural engineers. The approach should also consider impacts to all stakeholders, including travelers and adjacent land users.

Noise wall design should consider the experience of motorists utilizing the roadway. Noise barriers create an enclosed corridor for travelers. For the motorist, noise walls can inhibit wayfinding as well as block previously existing views of surrounding community, vegetation, and background landscape including mountains and sky. The visual effect of the noise barrier on the driver depends on the speed of the vehicle, the height of the barrier, the distance of the barrier from the roadway, and the surface texture of the barrier. If vehicles are generally moving rapidly, close to the barrier, drivers do not notice the details of the barrier. If vehicles move more slowly, or if the barrier is further away, the details of the barrier are more noticeable and therefore more important. If the barrier is higher and closer to the driver, and particularly if it is on both sides of the roadway, it may produce a tunnel effect in which drivers perceive themselves as being uncomfortably enveloped by the barrier.

Another important consideration in noise barrier design is the impact on adjacent land users. A primary factor is the scale of the noise barrier in relationship to land uses 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 shadows that affect property owners and vegetation by reducing overall sunlight. In general, a barrier should be located a distance of at least four times its height from residences to prevent the alteration of local microclimates, the area between the wall should be landscaped, and maintenance access should be considered. In areas where noise barriers are visible from adjacent residential land use, landscaping should also be utilized to screen views of the wall where feasible. Landscape Architects should be consulted in selecting plantings and spacing for screening and landscaping should be integrated with both the general highway environment and surrounding uses.

Impacts on both sides of the wall - both travelers and neighboring uses - should always be considered. The character of the adjacent land use should be considered in designing a noise wall. For land uses characterized as noxious per local land use codes (i.e. heavy industrial, automotive, outdoor storage or heavy rail), noise walls can provide an additional benefit of screening visual and olfactory impacts from the roadway while reducing ambient noise on both sides of the wall.

### 16.8.1 Visual Impact Assessment Process

An important step in the planning and design of noise walls (aka sound walls) is conducting a Visual Impact Assessment (VIA) for the proposed project site. VIAs are a required clearance in NEPA projects. CDOT developed VIA Guidelines in 2019 to address the issue of FHWA's 2015 VIA Guidelines being interpreted inconsistently. CDOT's VIA guidelines can now be found on the CDOT Landscape Architecture website. Consideration of a proposed project in relation to the neighborhood, community and geographic context are part of the VIA process. Both beneficial and detrimental visual impacts to the neighborhood context and passing motorists are documented in the VIA.

The steps in the VIA process involve scoping, conducting an inventory of existing conditions, determining the environment affected by the proposed project, evaluating impacts to views, and identifying mitigation measures. One of the key elements of the VIA process is scoping the character of the community or sense of place. CDOT's VIA Guidelines go into more detail for each stage of the process.

Early on in the VIA inventory process, the project site and surroundings are categorized as rural, suburban or urban in character. Each of these categories has unique environmental, social and cultural characteristics that should be considered in design. Consideration of how noise barriers fit into the setting and their relationship with the community is important. Rural environments are characterized by open spaces, sparse trees, native shrubs and grasses, and expansive views of the sky and surrounding landscape. Noise barriers in these areas should be constructed so that they blend in with the natural environment. Adjacent areas should be planted with native plants in natural or random groupings. In contrast, urban environments are characterized by geometric lines, orderly development, human activity, and spaces confined by structures, trees, and pavement. Random, natural groupings of plant materials can be used to soften the geometric lines of noise barriers in these areas, or geometric shapes and hard lines can be used to emphasize the noise wall as a work of art or focal point in the landscape. Suburban environments usually are more built-out than rural but with less building density than urban environments. In suburban environments, a major environmental concern is fragmentation of wildlife habitat. Noise walls can address visual concerns while doubling as a barrier for wildlife to redirect them to underpasses or overpasses where they can cross a road safely. It is important to consider how noise walls can serve a wide range of functional purposes besides improving safety, noise reduction and visual screening.

Involving other agencies and the public throughout the VIA process is key to gaining a well-rounded understanding of the site and appeasing opposition to the project. Public involvement from community stakeholders allows for input and feedback to help inform design elements and community preferences. Landscape inventory data, renderings and virtual flythroughs are useful tools to visualize both existing conditions and proposed elements at public meetings, open houses and workshops. Through meetings and workshops, citizen stakeholders can provide input on preferred wall type, materials, colors, plantings, and textures, and better understand the visual impact of noise barriers. Many objections from the public relate to a loss of scenic views or to the overbearing appearance of a noise barrier. A barrier is more likely to be accepted by the public if it complements the character and context of 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 community outreach 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 and greater project acceptance.

### 16.8.2 Visual Design Elements of Noise Walls

In addition to outlining process, CDOT's VIA design guidelines can be used to inform design and select measures to mitigate visual impacts of the project. Landscape elements such as trees and shrubs can be incorporated into the design to enhance important views or buffer views deemed by the public as unsightly. By following certain visual design principles throughout the project, an aesthetically pleasing wall can be built without excessive additional expense. Collaboration with a Landscape Architect can help incorporate design elements and mitigation measures to eliminate any discomfort or claustrophobia caused by noise walls. Such design elements include line, form, scale, color, and texture that contrast or complement the surrounding environment depending on the impact desired.

Landscape plantings may be the most effective and economical means available to reduce adverse visual impacts of a noise barrier. Landscape plantings can help link the structure of the wall with the natural surroundings. Plantings provide a soft, living, dynamic element in a hard-edged manmade environment and provide both a psychological and visual relief to adjacent communities. Plant materials can provide a variety of color and texture and can have positive effects on scale and dominance. Vegetation can also provide shade, reduce reflection of noise and light, cool an otherwise paved surface, provide slope stabilization, slow and filter stormwater runoff and reduce erosion.

*Figure 16-5 Landscaping: Integration With Existing Vegetation*

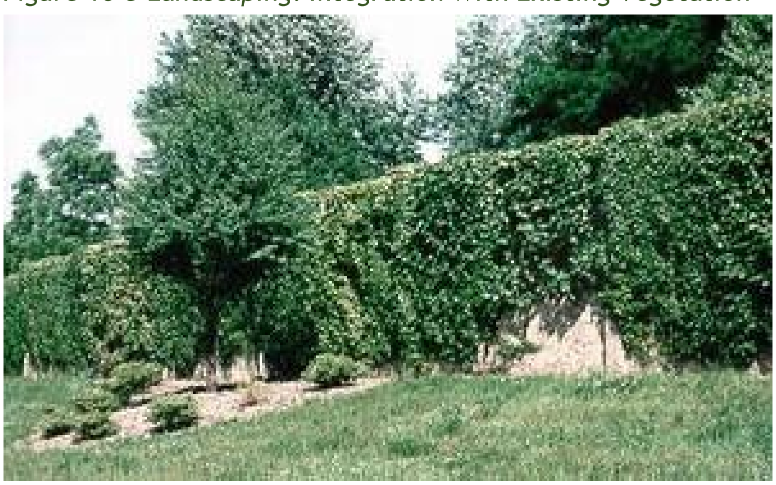
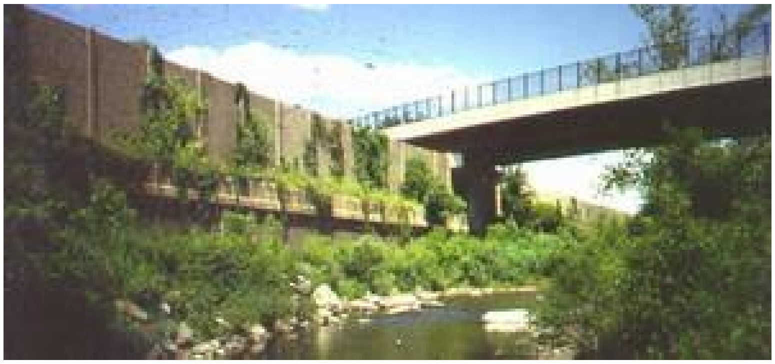


*Figure 16.6 Landscaping: Integration With Existing Vegetation*



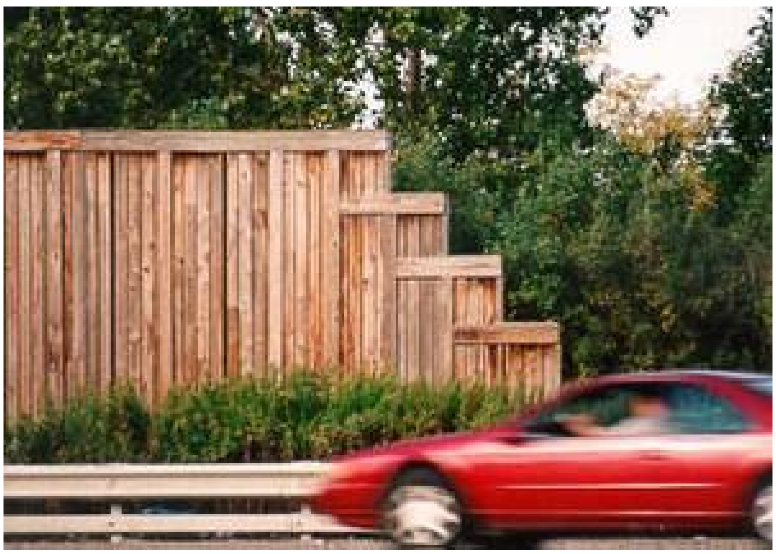
Existing vegetation should be salvaged early in the design process, if feasible, to best ensure a project blends in with its surroundings. A landscape architect or specialist should conduct a field review to flag significant trees and shrubs to save prior to setting final wall alignment. If salvaging existing vegetation is infeasible, planting new trees, shrubs, vines, and grasses can provide important design elements of line, form, color, and texture and help mitigate problems with scale and dominance of the noise wall in the landscape. Shrub and tree massing can create a natural transition area for the end of a wall. The following design elements should be considered in noise wall planning and design:

- Design offsetting recesses or planting pockets within the noise wall line. Small jogs can provide protected microclimates and visually soften wall impacts on the motorist.
- Provide open planting areas on both sides of the wall within the ROW to use vines and shrubs in combination to reduce the dominance of a wall.
- Reduce the visual dominance by providing planting areas on both sides of the wall.
- Reinforce rhythm and sequence by use of trees to provide vertical elements in predominantly horizontal walls.
- Provide appropriate soil amendments and mulches for successful for low cost and attractive solutions that help plant establishment and growth.
- Walls should tie into and match the color and texture of existing structures, such as bridges, bridge abutments, and retaining walls.
- Emphasize continuity and consistency for noise walls being incorporated into multiple projects along a corridor.

Generally speaking, noise walls should appear to be part of or complement the existing landscape; they should not give the impression that they were placed as an afterthought. They 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 tapering the end of a wall with a natural earth berm or terrain feature. Through this technique, the wall appears to originate from the landscape rather than being dropped onto it. If there are no terrain features in the area, a “step-down” technique at the end of the barriers can provide a similar effect. Any tapering of the wall should be gradual to a point where the wall is no longer visually dominant.

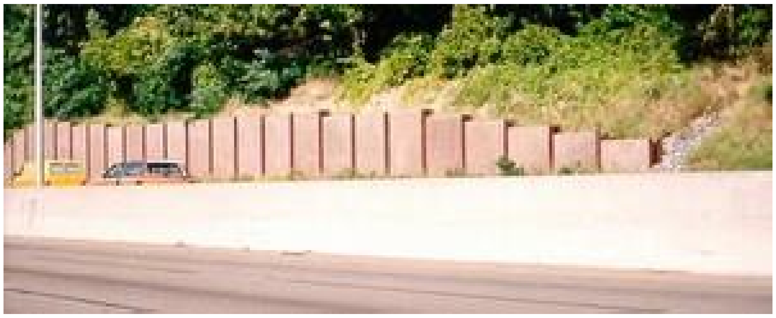
*Figure 16-7 Barrier End Treatment: Berming*

*Figure 16-8 Barrier End Treatment: Stepped Panel*



Earth berms are a good alternative to noise 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. A large amount of right of way will help preserve the corridor's 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.

*Figure 16.9. Barrier End Treatment: Buried Into Existing Ground*



It is important to note that unlike earth berms, 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.

*Figure 16.10. Landscaping: Supplementing Vegetation*

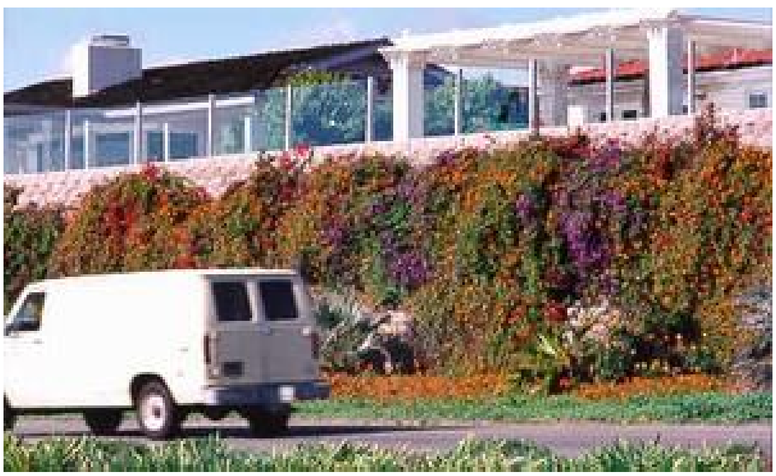
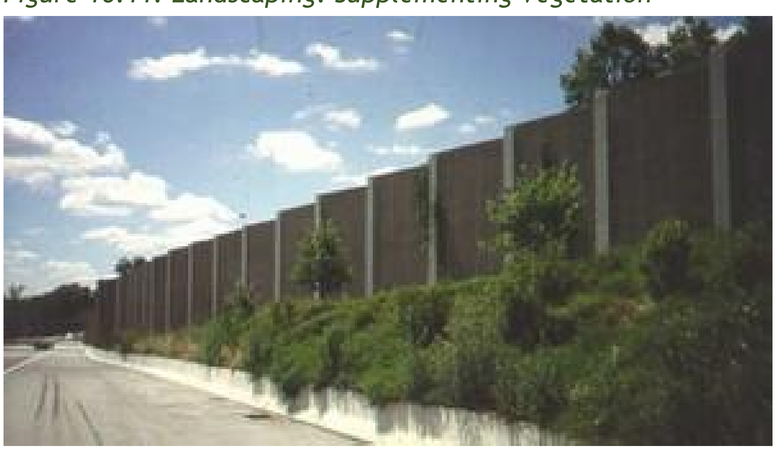


*Figure 16.11. Landscaping: Supplementing Vegetation*



For further discussion on planting design, refer to the CDOT *Landscape Architecture Manual*. Keep in mind that the landscape plan and planting plan shall be determined in consultation with, and approved by, the Region or HQ Landscape Architect during the design phase. The landscape architect can assist with plant selection and design as well as considerations for successful establishment and long-term maintenance.

## 16.9 General Maintenance Guidelines for Noise Walls

When considering materials and construction of a noise barrier, maintenance factors should be addressed, and any fatal flaws identified as early as possible to prevent problems in either construction or maintenance and operations. Examples 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. Maintenance staff should be part of the design team.

Consider access to the barrier backside for maintenance needs. 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. While access for maintenance crews should be facilitated, access to overnight camping or potential vandals should be limited. Tall growing plantings can create spaces that are easy to hide in, which can lead to increased litter and crime. For the reasons stated above, low-growing plantings along noise walls are preferred despite the potential noise mitigation benefits of taller plantings.

## 16.10 General Materials Guidelines for Noise Walls

To ensure that all materials used to build noise 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.

### 16.10.1 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." A material may be tested and classified as absorptive on the roadway side only or on both the roadway and residential sides.

### 16.10.2 Additional Considerations for Noise Barrier Materials

- 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.
- Project plans shall indicate aesthetic and material requirements.
- 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. 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* (CDOT, 2020b) does not allow use of wood.
- Barriers shall be designed and constructed without gaps, or, if an opening is required, the gap shall be minimized.
- 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.
- 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.

Pre-approved absorptive and reflective noise wall materials are included in CDOT's Approved Products List.

*Use this link to access CDOT's Approved products List:* *https://www.codot.gov/business/apl*

## 16.11 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 identifies 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, the use of temporary noise barriers or screening, 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 urban areas. For these projects, a more detailed discussion is necessary and may require a separate report detailing monitoring and mitigation measures.

Colorado Noise Statute 25-12-103 addresses maximum permissible noise levels from construction projects. The applicable local government agency may also have more restrictive requirements regarding construction noise, which would supersede the state statute. Compliance with the restrictions of local agency noise ordinances is required unless a variance has been approved. Such a variance may be needed if the work will be very extensive or lengthy.

*Use this link to access CDOT's noise resources:*
*https://www.codot.gov/programs/environmental/noise*

*Figure 16-12 Masonry Noise Barrier Construction: I-270 West of York Street*