# Application of AASHTO LRFD Specifications to Design of Sound Barriers

*Prepared for:*

The National Cooperative Highway Research Program (NCHRP)

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## Disclaimer

## CONTENTS

# SECTION 1

# INTRODUCTION

The current design criteria for sound barriers are based on the AASHTO Standard "Guide Specifications for Design of Sound Barriers" dated 1989 and interims through 2002. The content of the AASHTO Guide Specifications for Design of Sound Barriers is not consistent with the requirements of the AASHTO LRFD Bridge Design Specifications. The load and load combinations of the AASHTO Guide Specifications Article 1.2.1 and 1.2.2 do not conform to the ones specified in the AASHTO LRFD Section 3.4.1. In addition, the vehicular impact load and load factors included in the Guide Specifications for design of sound barriers adjacent to roadways are different from the ones required by the AASHTO LRFD Specifications.

NCHRP Project 20-07/Task 270, was initiated to produce updated sound barriers design provisions suitable for inclusion in the AASHTO LRFD Bridge Design Specifications.

This report includes the proposed design provisions and an example of the determination of the design loads on a sound barrier using the proposed specifications. The proposed specifications included in this report has been prepared assuming that the design provisions for sound barriers will be included in a separate new section (Section 15) to be added to the AASHTO LRFD Bridge Design Specifications. In addition, required revisions to relevant existing design provisions are also included.

## SECTION 2

## PROPOSED SPECIFICATIONS

## SECTION 15: DESIGN OF SOUND BARRIERS

## TABLE OF CONTENTS

## SECTION 15

# DESIGN OF SOUND BARRIERS

### 15.1 SCOPE

This Section applies to the structural design of sound barriers which are either ground-mounted or structure-mounted and the design of the foundations of ground-mounted sound barriers.

Structure-mounted sound barriers are those mounted directly on bridge decks, retaining walls, or on top of vehicular railings mounted on bridge decks or retaining walls.

### C15.1

This Section specifies the design forces, and the design requirements unique to sound barriers constructed along highways. This Section does not cover sound barriers constructed adjacent to railroad tracks or the acoustical requirements for sound barriers.

These provisions are largely based on the requirements of the *Guide Specifications for Structural Design of Sound Barriers (1989)*.

### 15.2 DEFINITIONS

*Clear Zone*—The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles.

*Crashworthy*—A traffic railing system that has been successfully crash-tested to a currently acceptable crash test matrix and test level or one that can be geometrically and structurally evaluated as equal to a crash-tested system.

*Ground-Mounted Sound Barriers*—Sound barriers supported on shallow or deep foundations.

*Right-of-Way*—The land on which a roadway and its associated facilities and appurtenances are located. The highway right-of-way is owned and maintained by the agency having jurisdiction over that specific roadway.

*Right-of-Way Line*—The boundary of the right-of-way

*Sound Barrier*—A wall constructed along a highway to lower the highway noise level in the area behind the wall.

*Sound Barrier Setback*—The distance between the traffic face of the sound barrier wall and the traffic face of the traffic railing the sound barrier is mounted on or behind it.

*Structure-Mounted Sound Barriers*—Sound barrier supported on bridges, crashworthy traffic railing or retaining walls.

*Traffic Railing*—Synonymous with vehicular railing; used as a bridge or structure-mounted railing, rather than a guardrail or median barrier as in other publications.

### 15.3 NOTATION

| | | |
|---|---|---|
| $S$ | = | setback distance of sound barrier (15.8.5) |
| $V_B$ | = | base wind velocity (mph) (15.8.2) |
| $V_0$ | = | friction velocity, a meteorological wind characteristic for various upwind surface characteristics (mph) (15.8.2) |
| $Z_0$ | = | friction length of upstream fetch, a meteorological wind characteristic (ft.) (15.8.2) |
| $\Phi$ | = | soil angle of internal friction (°) (C15.4.3) |
| $\gamma_p$ | = | load factor for permanent loads (15.9.9) |

## 15.4 GENERAL FEATURES

### 15.4.1 Aesthetics

#### 15.4.1.1 Standard Aesthetic Treatments

The depth of aesthetic treatments into the traffic face of sound barrier that may be subjected to vehicular collision shall be kept to a minimum.

Standard aesthetic treatments for various alternative materials should be considered.

#### C15.4.1.1

Minimizing the depth of aesthetic treatment into the traffic face of sound barriers that may be in contact with a vehicle during a collision reduces the possibility of vehicle snagging.

Sound barriers are highly visible components. Using standard treatments encourages aesthetic continuity, simplifies construction and maintenance, and reduces construction cost.

#### 15.4.1.2 End Treatment

Sound barriers should not be designed with abrupt beginnings or ends, unless approved by the Owner.

Generally, the ends of the sound barrier should be tapered or stepped if the height of the wall exceeds 6.0 ft. to produce a more aesthetically pleasing wall.

#### C15.4.1.2

#### 15.4.1.3 Cost

Some moderate additional cost to enhance the sound barrier's aesthetic quality is warranted.

#### C15.4.1.3

Elaborate or costly individualized designs which significantly increase the cost of the sound barrier shall be avoided. When landscaping is to be placed adjacent to the sound barrier which will eventually screen a substantial portion of the wall, only a minimal aesthetic treatment of the wall is justified.

### 15.4.2 Sound Barrier Materials

Sound barriers may be constructed from any material deemed suitable by the owner. The materials selected for the sound barrier shall be appropriate for the environment in which it is placed.

Sound barrier materials shall be selected to limit shattering of the sound barrier during vehicular collision.

Sound barriers material selection shall take into consideration the potential long-term effects of material deterioration, seepage, stray currents, and other potentially deleterious environmental factors on each of the material components comprising the structure.

### C15.4.2

Sound barriers may be constructed from a variety of material, most commonly concrete, wood, steel, and masonry. Other materials, such as plastics, may also be used if approved by the Owner.

In some areas, sound barriers are subjected to graffiti. In these locations, the surface texture selected should be such that it is difficult to place the graffiti or such that the graffiti is easily removed.

Limiting shattering of sound barriers is particularly important for sound barriers mounted on bridges crossing over other traffic. When reinforced concrete panels are utilized for sound barriers on bridges, it is recommended that two mats of reinforcement are used to reduce the possibility of the concrete shattering during vehicular collision. Restraint cables placed in the middle of concrete panels may be used to reduce shattering while avoiding the increased panel thickness required to accommodate two layers of reinforcement.

For most applications, sound barriers should be designed for a minimum service life of 75 years during which the structures shall retain an aesthetically pleasing appearance and be essentially maintenance-free.

### 15.4.3 Functional Requirements

#### 15.4.3.1 Lateral Clearance

Unless dictated by site conditions and approved by the owner, sound barriers shall be located outside the clear zone or, when the clear zone is wider than the distance between the edge of the traffic lanes and the edge of the available right-of-way, just inside the right-of-way.

#### C15.4.3.1

Locating the sound barrier farther from the edge of the traffic lanes reduces the possibility of vehicular collision with the barrier. The most desirable location for a sound barrier is outside the clear zone which minimizes the possibility of vehicular collision. In many cases, because sound barriers are typically used in urban areas, the width of available right-of-way is less than the width of the clear zone.

When the conditions make it impractical to locate the sound barrier at adequate distance from the edge of traffic lanes, and the sound barrier is mounted on a traffic barrier, the recommended minimum clearance to the traffic barrier should be 10 feet from the face of the traffic barrier. Lateral clearances greater than the minimum of 10 feet should be used when feasible. Guardrail or other traffic barriers should be considered for use when the sound barrier is located inside the clear zone.

In addition to safety considerations, maintenance requirements should be considered in deciding the location of sound barriers. Sound barriers placed within the area between the shoulder and right-of-way line complicate the ongoing maintenance and landscaping operations and lead to increased costs, especially if landscaping is placed on both sides of the sound barrier. Special consideration should be given to maintaining the adjoining land behind the sound barrier and adjacent to the right-of-way line.

#### 15.4.3.2 Sight Distance Requirements

Lateral clearances which reduce the stopping sight distance shall be avoided.

Unless otherwise approved by the Owner, the ends of the sound barrier located near a gore area shall be at least 200 feet from the theoretical curb nose location.

#### C15.4.3.2

The stopping sight distance is of prime importance for sound barriers located on the edge of shoulder along the inside of a horizontal curve.

#### 15.4.3.3 Sound Barriers Height

Unless proven adequate by site-specific acoustics study and approved by the owner, sound barriers shall have a minimum height consistent with that of a right-of-way fence.

#### C15.4.3.3

When sound barriers higher than 16.0 ft. are required, surrounding features should be evaluated such that an exceptionally high wall does not create an unsightly impact on the locale.

#### 15.4.3.4 Sound Barriers Length

The length of sound barriers shall be determined to provide adequate attenuation to end dwellings and commercial buildings.

#### C15.4.3.4

Where there is no residential area beyond the end dwelling, consideration should be given to terminating the sound barrier with a section of the barrier perpendicular to the freeway which could reduce the overall barrier length. However, this could require an easement from the property owner to permit construction of the sound barrier off the right-of-way.

#### 15.4.3.5 Sound Barrier Location

Special consideration shall be given to possible roadway icing and other induced environmental conditions caused by the placement of the sound barrier.

#### C15.4.3.5

Sound barriers located near the edge of the roadway can obstruct sunlight as well as noise.

#### 15.4.3.6 Type of Foundation

The type and depth of sound barrier foundations shall be selected based on geotechnical recommendations to minimize the possibility of foundation heaving due to frost and soil swelling.

#### C15.4.3.6

Foundations must extend below the frost line to resist tilting or lifting of wails. Sound barriers and traffic barriers on piles are subject to being lifted off the piles as the ground heaves. The pile and the connection to the wall or pile cap should either be strong enough to resist the heaving force or the bottom of the barrier should be extended beneath the frost area.

#### 15.4.3.7 Drainage

Adequate drainage shall be provided along sound barriers.

#### C15.4.3.7

It is important to have drainage facilities along sound barriers to assure soil stability. Soils with angle of internal friction, $\varphi$, of 25 degrees or less may develop flowing characteristics when saturated. Limits on fines, especially clay and peat, should be specified.

#### 15.4.3.8 Emergency Responders and Maintenance Access

Provisions for emergency and maintenance access shall be provided. Local fire department requirements for fire hose and emergency access shall be satisfied.

#### C15.4.3.8

Provisions may be necessary to allow fire fighters and hazardous material clean-up crews access to fire hydrants on the opposite side of the sound barrier. The designer should consult with local fire and emergency officials regarding their specific needs.

Shorter barriers may be traversed by throwing the fire hose over the wall. Taller barriers may require an opening through which the hose is passed. Such openings can consist of formed or cored holes, a hollow masonry block turned on its side, a maintenance access gate, etc. A small sign may be placed adjacent to the emergency access location on the traffic side of the sound barrier. This sign would bear the street name on which the hydrant is located, thus aiding emergency crews in identifying the hydrant nearest the opening.

Access to the back side of the sound barrier must be provided if the area is to be maintained. In subdivision areas, access can be via local streets, when available. If access is not available via local streets, access gates or openings are essential at intervals along the sound barrier. Offset barriers concealing the access opening must be overlapped a minimum of 2.5 times the offset distance in order to maintain the integrity of the sound attenuation of the main barrier. Location of the access openings should be coordinated with the appropriate agency or land owner.

#### 15.4.3.9 Deferential Settlement of Foundations

For long masonry sound barriers supported on spread footings, provisions should be made to accommodate differential settlement.

#### C15.4.3.9

Provisions should be made to accommodate differential settlement when sound barriers are supported on continuous spread or trench footings or cap beams.

## 15.5 LIMIT STATES AND RESISTANCE FACTORS

### 15.5.1 General

Structural components shall be proportioned to satisfy the requirements at all appropriate service, strength, and extreme event limit states.

Limit states applicable to sound barrier foundations design shall be in accordance with Article 15.9. Limit states applicable to the structural design of sound barrier components shall be as presented herein.

The limit states shall apply using the applicable load combinations in Table 3.4.1-1 and the loads specified herein.

When masonry or other proprietary walls are utilized, the owner shall approve the design specifications to be used.

### C15.5.1

These specifications do not include design provisions for masonry structures. Design provisions for masonry structures should be taken from other specifications.

### 15.5.2 Service Limit State

The resistance factors for the service limit states for post, wall panels and foundations components shall be as specified in Article 1.3.2.1. Design for service limit states shall be in accordance with the applicable requirements of Articles 5.5.2, 7.5.1 and 8.5.1.

### 15.5.3 Strength Limit State

The resistance factors for the strength limit states for post, wall panels and foundations components shall be as specified in Articles 5.5.4, 6.5.4, 7.5.4 and 8.5.2.

### 15.5.4 Extreme Event Limit State

The resistance factors for the extreme-event limit states for post, wall panels and foundations components shall be as specified in Article 1.3.2.1.

## 15.6 EXPANSION DEVICES

### 15.6.1 General

Adequate noise sealant material shall be placed at expansion joints of sound barriers.

### 15.6.2 Bridge-Mounted Sound Barriers

Except for post-and-panel construction, as a minimum, expansion joints shall be provided in the sound barriers at bridge expansion joints, at bridge intermediate supports and at the centerline of bridge spans.

### C15.6.2

When the type of construction utilized for sound barriers does not inherently allow movements between the sound barrier components, allowance should be made to accommodate the movement and deformations of the bridge girders. Therefore, expansion devices are required in the sound barriers at bridge expansion joint locations in order not to restrict the movement of the bridge expansion joints.

Bridge-mounted sound barriers stiffen the supporting bridges resulting in longitudinal stresses developing in the sound barriers. The higher curvature of bridge girders at high moment locations near midspans and, for continuous bridges, at intermediate supports increases the magnitude of

these stresses. Providing expansion joints in the sound barriers at these locations reduces the effect of the stiffness of the sound barrier on the deformations of the girders and the stresses in the barrier due to live load deflection of the bridge.

Additional expansion devices in the sound barrier may be utilized as required to further minimize the stresses on the barrier due to the live load deflection of the bridge.

Where post-and-panel construction is utilized, posts shall be placed on either side of any expansion joint in, or at the ends of, the deck.

Post-and-panel sound barriers inherently provide an expansion joint at either end of each wall panel. Typical posts are made of steel rolled I-shapes or concrete I-sections. Characteristically, the seat width of the wall panels on the post is relatively small as it corresponds to the width of the post flange overhang on either side of the post web. These typical seat widths provide for dimensional changes caused by panel deformations due to applied loads and temperature changes. Unless a post is provided on either side of an expansion joint in the bridge, the change in the opening of the bridge expansion joint may be larger than the panel seat width on the post and may cause the failure of the panel straddling the bridge expansion joint due to the loss of panel seat width.

### 15.6.3 Ground-Mounted Sound Barriers

Except for post-and-panel construction, expansion devices shall be provided at adequate spacing to allow for thermal expansion of the sound barriers. For sound barriers prone to vehicular collision, relative deflection between the sound barriers on either side of an expansion joint shall be restricted.

### C15.6.3

For sound barriers not utilizing post-and-panel construction, minimizing the relative deflection between the wall sections on either side of an expansion joint improves the performance of the barrier during vehicular collision near the expansion joint. This can be accomplished by installing a sliding dowel-and-sleeve connection similar to the one shown in Figure C15.6.3-1 near the top of the wall.

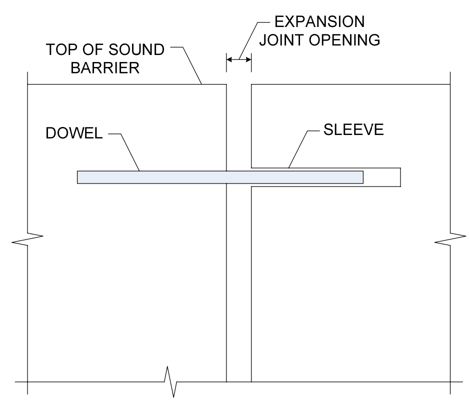



**Figure C15.6.3-1 Sliding Dowel-and-Sleeve Connection.**

## 15.7 SOUND BARRIERS INSTALLED ON EXISTING BRIDGES

When installing sound barriers on existing bridges, the effects of the sound-barrier forces on existing bridge components shall be investigated. The stiffening effect of added sound barrier may be ignored.

### C15.7

Sound-barrier forces transmitted to the bridge include the weight of the barrier, wind loads, seismic loads, vehicular collision forces and any other forces that may act on the sound barriers. These forces affect railings, bridge deck overhangs, floorbeams and girders.

Existing bridges where sound barriers are added need to be reanalyzed to determine their load rating taking into account the dead load of sound barriers.

## 15.8 LOADS

### 15.8.1 General

Unless explicitly modified below, all applicable loads will be applied in accordance with the provisions of Section 3 of these specifications.

### 15.8.2 Wind Load

Except for as modified below, the provisions of Article 3.8.1 shall apply.

Wind load shall be applied to the entire surface of sound barriers as a uniformly distributed load. Where post-and-panel construction is utilized, the wind load effects on the posts shall be determined by applying the resultant wind loads from the uniformly loaded panels as concentrated loads to the posts at the mid-height elevation of the exposed portion of the sound barrier.

Base design wind velocity, $V_B$, for sound barriers shall be taken 1.07 times the wind velocity at the sound barrier location determined from Figure 15.8.2-1.

For sound barriers, Table 3.8.1.1-1 shall be replaced with Table 15.8.2-1.

### C15.8.2

The wind velocities in Figure 15.8.2-1 have a 50 year return period. The 1.07 multiplier is meant to convert the wind speed return period from the 50 years Figure 15.8.2-1 is based on to 75 year return period to be consistent with the life span assumed in these specifications.

The *Guide Specifications for Structural Design of Sound Barriers* (*1989*) included four upstream surface conditions; B1, B2, C and D. Based on a limited study by Washington State Department of Transportation (Washington State Department of Transportation 2006). Upstream Surface Conditions B1 and C are approximately equivalent to the Suburban and Country upstream surface conditions shown in Table 3.8.1.1-1. Table 15.8.2-1 includes two upstream surface conditions, designated as Sparse Suburban and Coastal that do not exist in Table 3.8.1.1-1. The values of the $V_0$ and $Z_0$ variables for these two upstream surface conditions were selected to yield wind pressures approximately equal to those obtained for Upstream Surface Conditions B2 and C in the *Guide Specifications for Structural Design of Sound Barriers (1989)*.

**Table 15.8.2-1 Values of $V_0$ and $Z_0$ for Various Upstream Surface Conditions.**

| Condition | Coastal | Open Country | Sparse Suburban | Suburban | City |
|---|---|---|---|---|---|
| $V_0$ (mph) | 7 | 8.20 | 9.4 | 10.90 | 12.00 |
| $Z_0$ (ft.) | 0.025 | 0.23 | 0.98 | 3.28 | 8.20 |

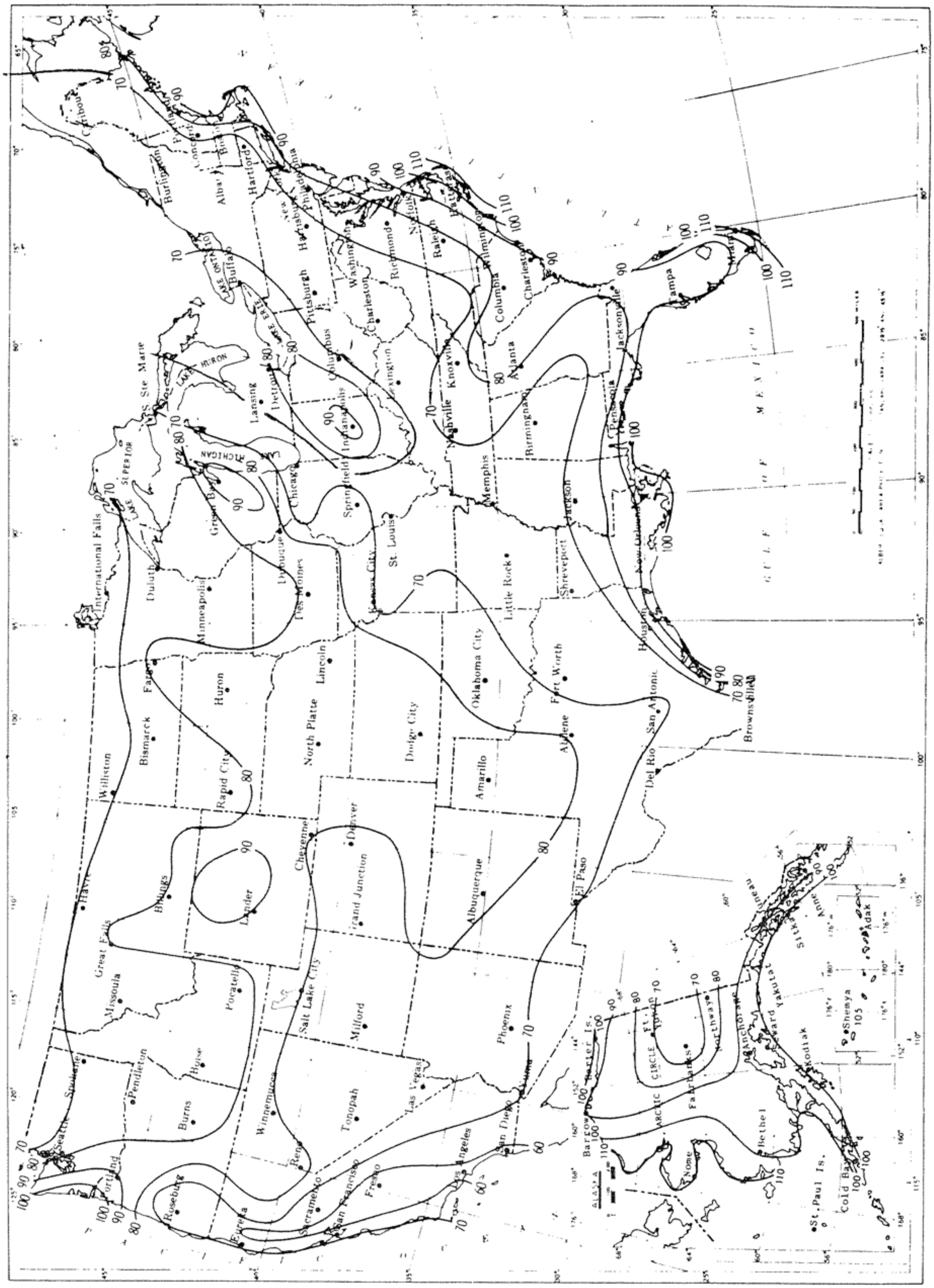



**Figure 15.8.2-1 Isotach .02 quantiles, in miles per hour: Annual extreme-mile 30.0 ft. above ground, 50 years mean recurrence intervals.**

### 15.8.3 Seismic Load

The provisions of Article 3.10 shall apply.

For the design of the sound barrier wall panels, seismic loads shall be applied to the entire elevation area of the sound barriers as a uniformly distributed lateral load. Where post-and-panel construction is utilized, in lieu of a more refined analysis, seismic loads shall be applied to the posts at a point located no less than 0.7 the exposed height of the wall panels measured from the base of the panels. For the purpose of determining the point of application of seismic loads on the posts, the base of the panels shall be taken as:

- For ground-mounted sound barriers: the ground surface adjacent to sound barrier, and
- For structure-mounted sound barriers: the bottom of the lowest wall panel

### C15.8.3

The point of application of seismic loads may be calculated by dividing the post base moment by the post base shear. Trial analysis of post-and-panel sound barrier systems that are 10.0 and 20.0 ft. high and are constructed in highly active seismic zones indicated that the location of the point of application of the seismic load on the posts, measured from the bottom of the wall, varied between 0.62 and 0.72 the wall height .

### 15.8.4 Earth Load

The provisions of Article 3.11 shall apply.

### C15.8.4

Article 3.11.5.10 contains specific requirements for the determination of earth pressure on sound-barrier foundations elements.

### 15.8.5 Vehicular Collision Forces

Sound barrier systems, consisting of a traffic railing and a sound barrier, that have been successfully crash-tested may be used with no further analysis.

In lieu of crash-testing, vehicular collision forces may be applied to sound barriers located within the clear zone as follows:

Case 1: For sound barriers mounted on a crashworthy traffic railing and for sound barriers mounted behind a crashworthy traffic railing with a sound barrier setback no more than 1.0 ft.: vehicular collision forces specified in Section 13 shall be applied to the sound barrier at a point 4.0 ft. above the surface of the pavement in front of the traffic railing for Test Levels 3 and lower and 6.0 ft. above the surface of the pavement in front of the traffic railing for Test Levels 4 and higher.

Case 2: For sound barriers mounted behind a crashworthy traffic railing with a sound barrier setback of 4.0 ft.: vehicular collision force of 4.0 kips shall be applied. The collision force shall be assumed to act at a point 4.0 ft. above the surface of the pavement in front of the traffic railing for Test Levels 3 and lower and 14.0 ft. above the surface of the pavement in front of the traffic railing for Test Levels 4 and higher

Case 3: For sound barriers mounted behind a crashworthy

### C15.8.5

Very limited information is available on crash-testing of sound barrier systems. The requirements of this article, including the magnitude of collision forces, are mostly based on engineering judgment and observations made during crash-testing of traffic railings without sound barriers.

In the absence of crash-test results for sound barrier systems, sound barriers that have not been crash-tested are often used in conjunction with vehicular railings that have been crash-tested as stand-alone railings, i.e. without sound barriers. The collision forces specified herein are meant to be applied to the sound barriers part of such systems. The vehicular railing part of the sound barrier/railing system does not need to satisfy any additional requirements beyond the requirements specified in Section 13 of the specifications for the stand-alone railings; including the height and resistance requirements.

Crash Test Level 3 and lower are performed using small automobiles and pick-up trucks. Crash Test Levels 4 and higher include single unit and/or tractor trailer trucks. The difference in height of the two groups of vehicles is the reason the location of the collision force is different for the two groups of sound barriers.

For crash Test Levels 3 and lower, the point of application of the collision force on the sound barriers is assumed to be always 4.0 ft. above the pavement.

traffic railing with a sound barrier setback between 1.0 ft. and 4.0 ft.: vehicular collision forces and the point of application of the force shall vary linearly between their values and locations specified in Case 1 and Case 2 above.

Case 4: For sound barriers mounted with a sound barrier setback more than 4.0 ft.: vehicular collision forces need not be considered.

During crash-testing of traffic railings for crash Test Level 4 and higher, trucks tend to tilt above the top of the railing and the top of the truck cargo box may reach approximately 4.0 ft. behind the traffic face of the traffic railing. For such systems, the point of application of the collision force is expected to be as high as the height of the cargo box of a truck, assumed to be 14.0 ft. above the pavement surface.

For sound barriers mounted on crashworthy traffic barriers or with a small setback, assumed to be less than 1.0 ft., the full crash force is expected to act on the sound barrier. The point of application of this force is assumed to be at the level of the cargo bed; taken as 6.0 ft. above the surface of the pavement.

For a sound barrier mounted with a setback more than 1.0 ft. behind the traffic face of the traffic railing, it is expected that the truck cargo box, not the cargo bed, will impact the sound barrier. It is expected that the top of the cargo box will touch the sound barrier first. Due to the soft construction of cargo boxes, it is assumed that they will be crushed and will soften the collision with the sound barrier. The depth of the crushed area will increase with the increase of the collision force; thus lowering the location of the resultant of the collision force. The magnitude of the collision force and the degree to which the cargo box is crushed are expected to decrease as the setback of the sound barrier increases.

In the absence of test results, it is assumed that a collision force of 4.0 kips will develop at the top of the cargo box when it impacts sound barriers mounted with a setback of 4.0 ft.

The collision force and the point of application are assumed to vary linearly as the sound barrier setback varies between 1.0 ft. and 4.0 ft.

The setback of the sound barrier, S, shall be taken as shown in Figure 15.8.5-1.

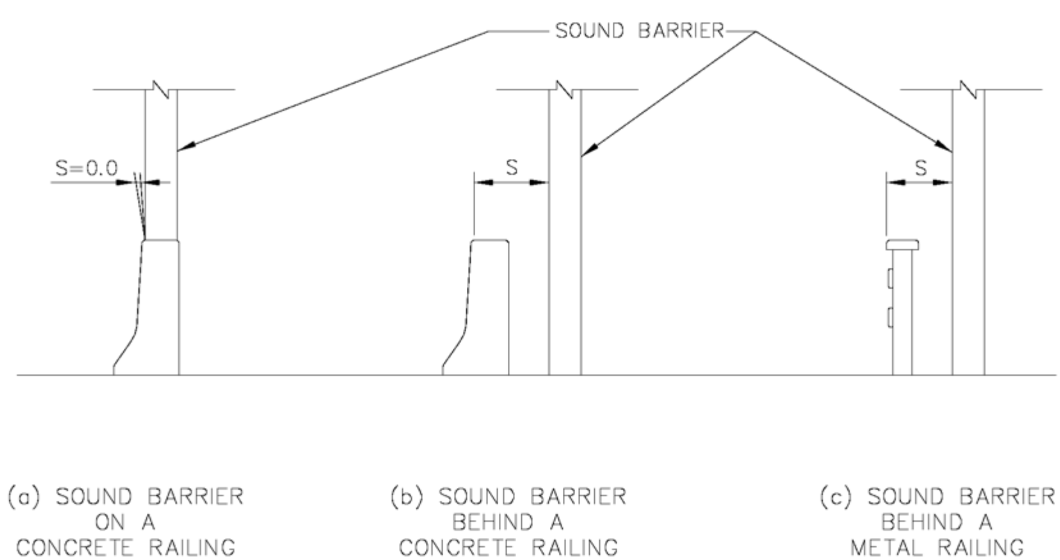



Figure 15.8.5-1 Sound barrier setback distance

Collision forces shall be applied as a line load with a length equal to the longitudinal length of distribution of collision forces, $L_t$, specified in Article A13.2 for the design test level of the traffic railing and sound barrier system.

For sound barriers prone to vehicular collision forces, the wall panels and posts and the post connections to the supporting traffic barriers or footings shall be designed to resist the vehicular collision forces at the Extreme Event II limit state.

For post-and-panel construction, the design collision force for the wall panels shall be the full specified collision force placed on one panel between two posts at the location that maximizes the load effect being checked. For posts and post connections to the supporting components, the design collision force shall be the full specified collision force applied at the point of application specified in Cases 1 through 3 above.

In some cases the wall panel is divided into a series of horizontal elements. In these situations, each horizontal strip should be designed for the full design force.

### 15.8.6 Ice and Snow Drifts Load

Potential of snow drifts and ice accumulation on the surfaces of sound barriers shall be investigated. Forces from the weight of ice and pressure from snow drifts shall be considered in the design and shall be approved by the Owner.

### C15.8.6

The thickness of ice accumulation and height of snow drifts and the equivalent hydrostatic pressure of snow drifts should be based on historical records at the site. The selected values should be approved by the Owner before design.

## 15.9 FOUNDATION DESIGN

### 15.9.1 General

Unless otherwise specified by the owner, the geotechnical resistance of materials supporting sound-barrier foundations shall be estimated using the procedures presented in Article 10.6 for spread footings, 10.7 for driven piles, and 10.8 for drilled shafts.

### C15.9.1

Although sound barriers may be supported on spread footing or driven pile foundations, drilled shafts are more commonly used because drilled shafts facilitate controlling the vertical alignment of sound barrier structural wall supports and the lateral spacing between them.

### 15.9.2 Determination of Soil and Rock Properties

The provisions of Articles 2.4 and 10.4 shall apply.

### 15.9.3 Limit States

Sound barriers shall be designed to withstand lateral wind and earth pressures, self weight of the wall, vehicular collision loads, and earthquake loads in accordance with the general principals specified in this section and Sections 10 and 11.

Sound barriers shall be investigated for excessive vertical and lateral displacement, and overall stability at the Service I Limit State. Tolerable deformation criteria shall be developed based on maintaining the required barrier functionality, achieving the anticipated service life, and the consequences of unacceptable movements.

Sound barrier foundations shall be investigated at the strength limit states using Eq. 1.3.2.1-1 for:

- Bearing-resistance failure
- Overall stability, and
- Structural failure.

Sound barrier foundations shall be investigated at the extreme event limit states using the applicable load combinations and load factors specified in Table 3.4.1-1.

**15.9.4 Resistance Requirements**

The factored resistance, $R_R$, calculated for each applicable limit state shall be the nominal resistance, $R_n$, multiplied by an appropriate resistance factor, $\phi$, specified in Articles 10.5.5.2 or 11.5.6.

**C15.9.4**

Procedures for calculating nominal geotechnical resistance of footings, driven piles, and drilled shafts are provided in Articles 10.6, 10.7 and 10.8. These methods are generally accepted for barriers supported on spread footings or footings on two or more rows of driven piles or drilled shafts. The nominal geotechnical resistance of a single row of driven piles or drilled shafts, or by a continuous embedded foundation wall (commonly referred to as a "trench footing"), is more appropriately calculated using the provisions in Article 11.8 for nongravity cantilever walls.

Procedures for calculating nominal structural resistance for concrete and steel components are provided in Sections 5 and 6.

**15.9.5 Resistance Factors**

The resistance factors for geotechnical design of foundations are specified in Table 10.5.5.2.2.-1 for spread footing foundations, Table 10.5.5.2.3-1 for driven pile foundations, Table 10.5.5.2.4-1 for drilled shaft foundations, and Table 11.5.6-1 for permanent retaining walls.

If methods other than those prescribed in these Specifications are used to estimate geotechnical resistance, are used, the resistance factors chosen shall provide equal or greater reliability than those given in Tables 10.5.5.2.2-1, 10.5.5.2.3-1, 10.5.5.2.4-1, and 11.5.6-1.

**15.9.6 Loading**

The provisions of Section 3, as modified by Article 15.8, shall apply.

**15.9.7 Movement and Stability at the Service Limit State**

**15.9.7.1 Movement**

The provisions of Articles 10.6.2, 10.7.2, 10.8.2, or 11.8.3, as appropriate, shall apply.

**15.9.7.2 Overall Stability**

The provisions of Article 11.6.2.3 shall apply.

### 15.9.8 Safety Against Geotechnical Failure at the Strength Limit State

Spread footings or footings supported on two or more rows of driven piles or drilled shafts shall be designed in accordance with the provisions of Articles 10.6.3, 10.7.3 or 10.8.3, respectively.

Footings supported on a single row of driven piles or drilled shafts or on a continuous embedded foundation wall ("trench footing") shall be designed in accordance with the provisions of 11.8.4 using the earth pressure diagrams provided in Article 3.11.5.10.

### 15.9.9 Seismic Design

The effect of earthquake loading shall be investigated using the Extreme Event I limit state of Table 3.4.1-1 with load factor $\gamma_p = 1.0$, and an accepted methodology.

### 15.9.10 Corrosion Protection

The provisions of Article 11.8.7 shall apply.

### 15.9.11 Drainage

Where sound barriers support earth loads or can impede water flow, the provisions of Article 11.8.8 shall apply.

# REFERENCES


AASHTO. 1989. *Guide Specifications for Structural Design of Sound Barriers*. American Association of State Highway and Transportation Officials, Washington, DC.

Washington State Department of Transportation. 2006. Wind Loading Comparison. Washington State Department of Transportation, Olympia, Washington.

# Additions to Section 3: All-new Article 3.11.5.10.

**3.11.5.10 Lateral Earth Pressures for Sound Barriers Supported on Discrete and Continuous Vertical Embedded Elements**

For sound barriers supported on discrete vertical wall elements embedded in granular soil, rock, or cohesive soil, the simplified lateral earth pressure distributions shown in Figures 1, 2, and 3, respectively, may be used. For sound barriers supported on continuous vertical elements embedded in granular soil or cohesive soil, the simplified earth pressure distributions shown in Figures 4 and 5, respectively, may be used. For sound barriers supported on retaining walls, the applicable provisions of Section 11 shall apply.

Where discrete vertical elements are used for support, the width, *b*, of each vertical element shall be assumed to equal the width of the flange or diameter of the element for driven sections and the diameter of the concrete-filled hole for sections encased in concrete.

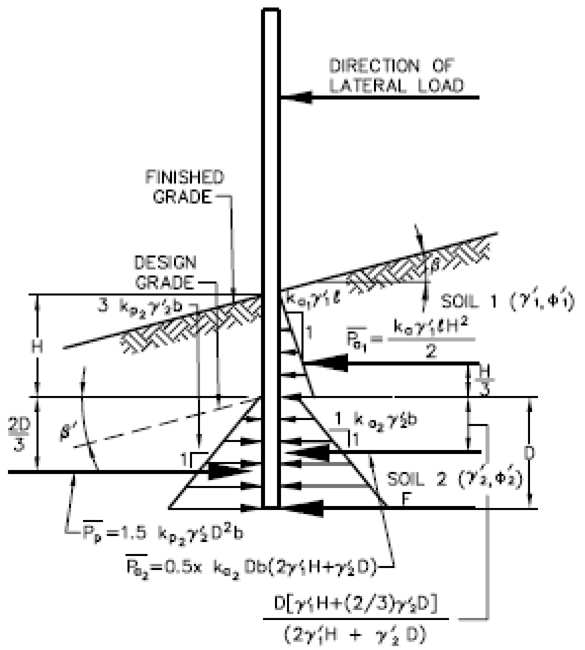
The reversal in the direction of applied lateral forces on sound barriers shall be considered in the design.

**C3.11.5.10**

Earth pressure on foundations of sound barriers is similar to that on nongravity retaining walls discussed in Article 3.11.5.6 except that the soil elevation on both sides of the wall is often the same or, if there is a difference, does not reach the top of the wall on one side. The provisions of this article are applicable to the foundations of any wall that is not primarily intended to retain earth, i.e. there is no or little difference in the elevation of fill on either side of the wall.

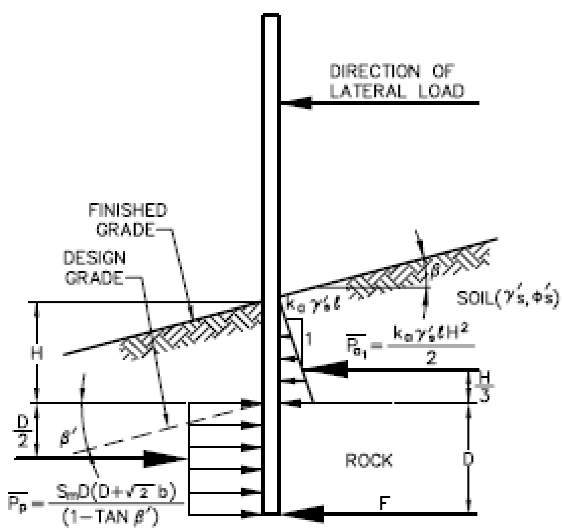
In Figures 1 and 3, the width, *b,* of discrete vertical elements effective in mobilizing the passive resistance of the soil is based on a method of analysis by Broms (*1964a, 1964b*) for single vertical piles embedded in cohesive or granular soil. Additional information on the background of the earth pressure on discrete vertical elements is presented in Article C3.11.5.6.

The main applied lateral forces on sound barriers are wind and seismic forces; both of them are reversible. When the ground surface in front and/or behind the sound barrier is not flat or the ground surface is not at the same elevation on both sides of the sound barrier, the design should be checked assuming that the lateral force is applied in either direction. The effect of the direction of ground surface slope, i.e. toward the barrier or away from the barrier should be considered in earth pressure calculations for both directions of lateral loads. The earth pressure diagrams shown in Figures 1 through 5 correspond to the lateral load direction shown in these figures. A lateral load in the opposite direction will result in reversing the earth pressure diagrams shown.




b = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL ELEMENT BELOW DESIGN GRADE IN PLANE OF BARRIER (FT.).

**Figure 3.11.5.10-1 Unfactored Simplified Earth Pressure Distributions for Discrete Vertical Wall Elements Embedded in Granular Soil.**




b = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL ELEMENT BELOW DESIGN GRADE IN PLANE OF BARRIER (FT.).

**Figure 3.11.5.10-2 Unfactored Simplified Earth Pressure Distributions for Discrete Vertical Wall Elements Embedded in Rock.**

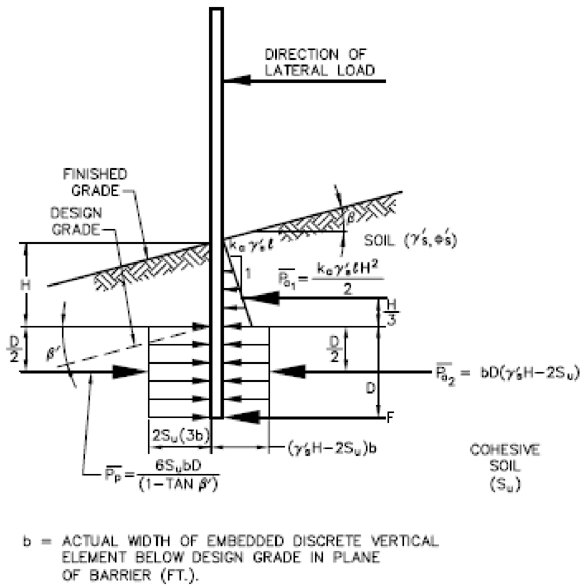



**Figure 3.11.5.10-3 Unfactored Simplified Earth Pressure Distributions for Discrete Vertical Wall Elements Embedded in Cohesive Soil.**

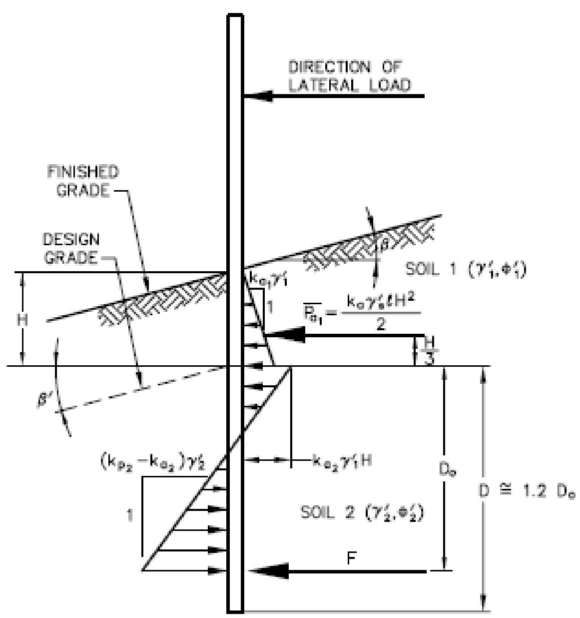



**Figure 3.11.5.10-4 Unfactored Simplified Earth Pressure Distributions for Continuous Vertical Elements Embedded in Granular Soil Modified After Teng (*1962*).**

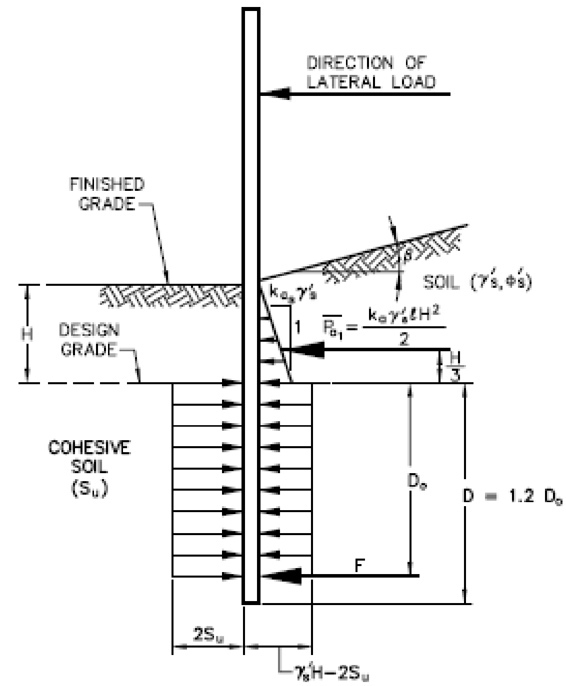



**Figure 3.11.5.10-5 Unfactored Simplified Earth Pressure Distributions for Continuous Vertical Wall Elements Embedded in Cohesive Soil Modified After Teng (*1962*).**

# Revisions to existing Article 3.8

## Proposed additions to Article 3.8 are shown in underlined, bold type font

### 3.8 WIND LOAD: *WL* AND *WS*

#### 3.8.1 Horizontal Wind Pressure

##### 3.8.1.1 General

**Except for sound barriers, p**ressures specified herein shall be assumed to be caused by a base design wind velocity, $V_B$, of 100 mph. **For sound barriers, base design wind velocity, $V_B$, shall be determined in accordance with Article 15.7.2.**

Wind load shall be assumed to be uniformly distributed on the area exposed to the wind. The exposed area shall be the sum of areas of all components, including floor system**,** railing **and sound barriers**, as seen in elevation taken perpendicular to the assumed wind direction. This direction shall be varied to determine the extreme force effect in the structure or in its components. Areas that do not contribute to the extreme force effect under consideration may be neglected in the analysis.

For bridges or parts of bridges more than 30.0 ft. above low ground or water level, the design wind velocity, $V_{DZ}$, should be adjusted according to:

$$V_{DZ} = 2.5V_0\left(\frac{V_{30}}{V_B}\right)\ln\left(\frac{Z}{Z_0}\right) \quad (3.8.1.1\text{-}1)$$

where:

$V_{DZ}$ = design wind velocity at design elevation, $Z$ (mph)

$V_{30}$ = wind velocity at 30.0 ft. above low ground or above design water level (mph)

$V_B$ = base wind velocity of 100 mph at 30.0 ft. height, yielding design pressures specified in Articles 3.8.1.2 and 3.8.2

$Z$ = height of structure at which wind loads are being calculated as measured from low ground, or from water level, > 30.0 ft.

$V_0$ = friction velocity, a meteorological wind characteristic taken, as specified in Table 1, for various upwind surface characteristics (mph)

$Z_0$ = friction length of upstream fetch, a meteorological wind characteristic taken as specified in Table 1 (ft.)

##### C3.8.1.1

Base design wind velocity varies significantly due to local conditions. For small and/or low structures, wind usually does not govern. For large and/or tall bridges, however, the local conditions should be investigated.

Pressures on windward and leeward sides are to be taken simultaneously in the assumed direction of wind.

Typically, a bridge structure should be examined separately under wind pressures from two or more different directions in order to ascertain those windward, leeward, and side pressures producing the most critical loads on the structure.

Eq. 1 is based on boundary layer theory combined with empirical observations and represents the most recent approach to defining wind speeds for various conditions as used in meteorology. In the past, an exponential equation was sometimes used to relate wind speed to heights above 30.0 ft. This formulation was based solely on empirical observations and had no theoretical basis.

$$V_{DZ} = CV_{30}\left(\frac{Z}{30}\right)^{\alpha} \quad (C3.8.1.1\text{-}1)$$

The purpose of the term $C$ and exponent $\alpha$ was to adjust the equation for various upstream surface conditions, similar to the use of Table 1. Further information can be found in Liu (*1991*) and Simiu (*1973, 1976*).

The following descriptions for the terms "open country," "suburban," and "city" in Table 1 are paraphrased from ASCE-7-93:

- Open Country—Open terrain with scattered obstructions having heights generally less than 30.0 ft. This category includes flat open country and grasslands.
- Suburban—Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family or larger dwellings. Use of this category shall be limited to those areas for which representative terrain prevails in the upwind direction at least 1,500 ft.

- City—Large city centers with at least 50 percent of the buildings having a height in excess of 70.0 ft. Use of this category shall be limited to those areas for which representative terrain prevails in the upwind direction at least one-half mile. Possible channeling effects of increased velocity pressures due to the bridge or structure's location in the wake of adjacent structures shall be taken into account.

**Table 3.8.1.1-1 Values of $V_0$ and $Z_0$ for Various Upstream Surface Conditions.**

| CONDITION | OPEN COUNTRY | SUBURBAN | CITY |
|---|---|---|---|
| $V_0$ (mph) | 8.20 | 10.90 | 12.00 |
| $Z_0$ (ft.) | 0.23 | 3.28 | 8.20 |

$V_{30}$ may be established from:

Fastest-mile-of-wind charts available in ASCE 7-88 for various recurrence intervals,

Site-specific wind surveys, and

In the absence of better criterion, the assumption that $V_{30} = V_B = 100$ mph.

### 3.8.1.2 Wind Pressure on Structures: *WS*

*3.8.1.2.1 General*

If justified by local conditions, a different base design wind velocity may be selected for load combinations not involving wind on live load. The direction of the design wind shall be assumed to be horizontal, unless otherwise specified in Article 3.8.3. In the absence of more precise data, design wind pressure, in ksf, may be determined as:

$$P_D = P_B\left(\frac{V_{DZ}}{V_B}\right)^2 = P_B\frac{V_{DZ}^{\ 2}}{10{,}000} \qquad (3.8.1.2.1\text{-}1)$$

$P_B$ = base wind pressure specified in Table 1 (ksf)

**The wind force on the structure shall be calculated by multiplying the design wind pressure, $P_D$, calculated using Equation 1, by the exposed area, including the area of sound barriers, if existing, regardless of the design wind pressure used in designing the sound barriers themselves.**

*C3.8.1.2.1*

The stagnation pressure associated with a wind velocity of 100 mph is 0.0256 ksf, which is significantly less than the values specified in Table 1. The difference reflects the effect of gusting combined with some tradition of long-time usage.

The pressures specified in klf or ksf should be chosen to produce the greater net wind load on the structure.

Wind tunnel tests may be used to provide more precise estimates of wind pressures. Such testing should be considered where wind is a major design load.

**The wind pressure specified in Article 15.8.2 for the design of sound barriers is generally less than that specified in this article for determining the wind force on bridge structures.**

## No other changes to end of Article 3.8.

SECTION 3

## EXAMPLE OF SOUND BARRIER DESIGN FORCES

## Example
## Sound Barrier Design Forces

Determine the loads on the sound barrier shown in Figure 1 assuming the following:

| | | |
|---|---|---|
| Wall Location: | Seattle area | |
| Wall height (h): | 20 | ft above ground surface in the vicinity of the wall |
| Sound barrier setback | 2 | ft. behind a crashworthy traffic barrier (Test Level 4 Traffic Barrier) |
| Site Class | E | |
| Setting | Urban setting | |

### Materials:

**Wall Panels:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pre-cast concrete Panels | | 8 | inch thick | | | |
| | 28 days compressive strength = | | 4 | ksi | | | |
| | Each wall panel is made in | | 2 | Sections | 10 | ft. high | each |
| **Posts:** | Steel H sections | 10 | x | 57 | | | |
| | Post flange width | 10.225 in. | | | | | |
| | Spacing = | 15 ft. | | | | | |
| | E = | 29000 ksi = | | 4176000 ksf | | | |
| | Stiffness = | 294 in.^4 = | | 0.0141782 ft.^4 | | | |

### Foundations:

Sound barrier is supported on 2.5 ft. diameter concrete drilled shafts
Drilled shafts extend 10 ft from the surface

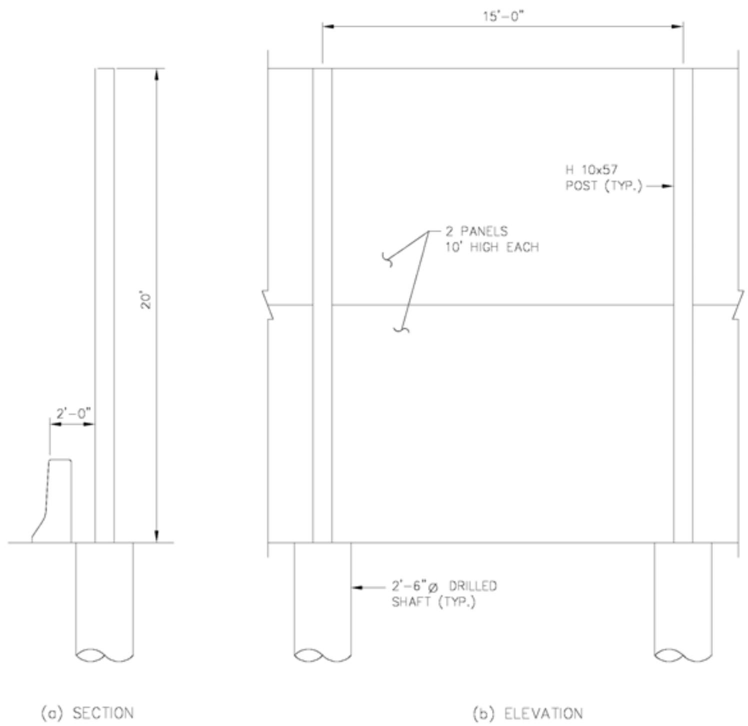



Figure 1. General Sound Barrier Dimensions

## 1. Dead Load

| | |
|---|---|
| Unit weight of panels = | 0.15 k/cu.ft. |
| Dead load of panels = | 0.10 ksf |
| For a 20 ft high panel, dead load = | 2.00 kips/ linear ft of wall |
| Dead Load (for seismic load on post) = | 1.557 kips/ ft of wall height (including weight of post) |
| Mass = | 0.048 kilo slugs/ ft of wall height |
| Dead load per drilled shaft = | 31.14 kips (including weight of post) |

## 2. Seismic Load

| | | |
|---|---|---|
| Peak Ground Acceleration (PGA) = | 0.4 | From LRFD Specifications figure 3.10.2.1-1 for Seattle area |
| Horizontal Response Spectral Acceleration Coefficient at Period of 0.2 Seconds ($S_S$) = | 1.0 | From LRFD Specifications figure 3.10.2.1-2 for Seattle area |
| Horizontal Response Spectral Acceleration Coefficient at Period of 1.0 Seconds ($S_1$) = | 0.3 | From LRFD Specifications figure 3.10.2.1-3 for Seattle area |
| Site Class | E | |

**Site Factors**

| | | | |
|---|---|---|---|
| Site Factor at Zero-Period on Acceleration Spectrum ($F_{pga}$) = | 0.9 | For Site Class E from LRFD Specifications Table 3.10.3.2-1 for PGA = | 0.4 |
| Site Factor for Short-Period Range of Acceleration Spectrum ($F_a$) = | 0.9 | For Site Class E from LRFD Specifications Table 3.10.3.2-2 for $S_s$ = | 0.9 |
| Site Factor for Long-Period Range of Acceleration Spectrum ($F_v$) = | 2.8 | For Site Class E from LRFD Specifications Table 3.10.3.2-3 for $S_1$ = | 30 |

Calculated Quantities

| | |
|---|---|
| $A_s$ = PGA x $F_{pga}$ = | 0.36 |
| $S_{DS} = S_s \times F_a$ = | 0.9 |
| $S_{D1} = S_1 \times F_v$ = | 0.84 |
| | |
| $T_S = S_{D1} / S_{DS}$ | 0.933333 |
| $T_0 = 0.2\ T_s$ | 0.186667 |

| | |
|---|---|
| Wall Ht (ft) | 20 |
| Mass per foot of post height (kilo slug) | 0.0484 |
| E (ksf) | 4176000 |
| I (ft^4) | 0.01417824 |

**Modal Periods**
**For a uniformly loaded cantilever**

| | |
|---|---|
| T1 = [(3.516/h^2*(E*I*/mass per ft)^0.5)^-1]*2*π = | 0.65 Sec. |
| T2 = [(22.03/h^2*(E*I*/mass per ft)^0.5)^-1]*2*π = | 0.10 Sec. |
| T3 = [(61.7/h^2*(E*I*/mass per ft)^0.5)^-1]*2*π = | 0.04 Sec. |
| T4 = [(120.9/h^2*(E*I*/mass per ft)^0.5)^-1]*2*π = | 0.02 Sec. |

**Elastic Seismic Response Coefficient ($C_{sm}$)**

Using LRFD Article 3.10.4.2

- For periods less than or equal $T_0$:

  For mode m, the elastic seismic response coefficient = $C_{sm} = A_S + (S_{DS} - A_S)(T_m / T_0)$

- For periods greater than $T_0$ and less than or equal $T_s$ : $C_{sm} = S_{DS}$
- For periods greater than $T_s$ : $C_{sm} = S_{D1} / T_m$

| | |
|---|---|
| For Mode 1 : $C_{sm1}$ = | 0.900 |
| For Mode 2 : $C_{sm2}$ = | 0.658248 |
| For Mode 3 : $C_{sm3}$ = | 0.466489 |
| For Mode 4 : $C_{sm4}$ = | 0.414346 |

**Modal and Total Responses**

For mode m, base shear = c1 * Mass per foot of post height * h * $C_{sm}$ * 32.2

where, for a cantilever, c1 = 0.613 For Mode 1
= 0.188 For Mode 2
= 0.065 For Mode 3
= 0.033 For Mode 4

For mode m, base moment = c2 * base shear from mode m * h

where, for a cantilever, c2 = 0.726 For Mode 1
= 0.209 For Mode 2
= 0.127 For Mode 3
= 0.090 For Mode 4

Total base shear and total base moment are determined by calculating the Square Root of Sum Squares (SRSS) for modal base shears and modal base moments, respectively.

| | Mode 1 | Mode 2 | Mode 3 | Mode 4 | SRSS |
|---|---|---|---|---|---|
| Post Base Shears (kips) | 17.180 | 3.854 | 0.944 | 0.426 | 17.64 |
| Post Base Moment (k.ft) | 249.453 | 16.108 | 2.398 | 0.766 | 249.98 |

Equivalent location of seismic force above post base =

Post base moment / post base shear = 14.17 ft.

## 3. Wind Load

From the map in Figure 15.8.2-1, annual extreme mile wind velocity at Seattle area is 80 mph

Base wind velocity 30 ft above ground =

= 1.07 annual extreme mile wind speed (Article 15.8.2) = 85.6 mph

For urban setting:

$V0$ = friction velocity = 10.9 mph

$Z0$ = friction length = 3.28 ft

From Article 3.8.1.1, Design wind velocity, $V_{DZ}$ =

$$V_{DZ} = 2.5V_0\left(\frac{V_{30}}{V_B}\right)\ln\left(\frac{Z}{Z_0}\right)$$

Z = height of structure > 30.0 ft. = 30 ft

$V_B$ = base wind velocity = 100 mph

$V_{30}$ = 85.6

$V_{DZ}$ = 51.63 mph

Base wind pressure, $V_B$, on large surfaces = 0.04 ksf (Table 3.8.1.2.1-1)

Design wind pressure , $P_D$:

$$P_D = P_B\left(\frac{V_{DZ}}{V_B}\right)^2 = P_B\frac{V_{DZ}^{\;2}}{10,000}$$

$P_D$ = 0.0107 ksf

Wind pressure is applied to the entire surface of the panels.

Assuming panel are simple spans

Panel spans length = post spacing - 1/2 post flange width = 14.57 ft.

Maximum wind moment on one panel = 2.8 k.ft for 10 ft. high panel

For posts, the resultant of wind forces is applied at mid height of the panels above ground.

Intermediate post wind force = wind pressure x wall height x post spacing

= 3.21 kips

Assuming post base elevation is at ground surface,

Intermediate post wind moment at post base= 32.1 k.ft

## 4. Vehicular Collision Force

Sound barrier is mounted behind a Test Level 4 traffic barrier

Sound barrier setback is 2 ft. For collision force calculations, the applicable case from Article 15.8.5 is Case 3 (setback between 1 and 4 ft.) which requires interpolation between collision forces for Case 1 (setback no more than 1.0 ft.) and Case 2 (setback = 4.0 ft)

For Case 1 (setback no more than 1.0 ft.):

Collision force = 54 kips

Application point = 6 ft above ground surface

For Case 2 (setback = 4.0 ft.):

Collision force = 4 kips

Application point = 14 ft above ground surface

By interpolation for Case 3 with setback 2 ft.

Collision force = 20.67 kips

Application point = 8.67 ft above ground surface

Collision forces shall be applied as a line load with a length equal to the longitudinal length of distribution of collision forces, $L_t$, specified in Article A13.2 for the design test level of the traffic railing and sound barrier system.

For Test Level 4 (TL4), collision length distribution length = 3.5 ft.

The point of application of collision forces will vary for different components. For maximum moments in the panels, the collision line load should be positioned at midspan of the panels between posts (see Figure 2). For maximum load on the posts, collision load should be centered at the post (see Figure 3).

Collision line load = collision force/distribution length = 5.91 klf

Assuming panel span length = post spacing - 1/2 post flange width = 14.57 ft.

Maximum collision moment on panels = 66.25 k.ft

For simplicity, the wall panels may be assumed as series of simple spans supported at the center of the posts.

Maximum post collision force = 19.46 kips

For point of application 8.67 ft. above the base of the posts,

Maximum post base collision moment = 168.72 k.ft.

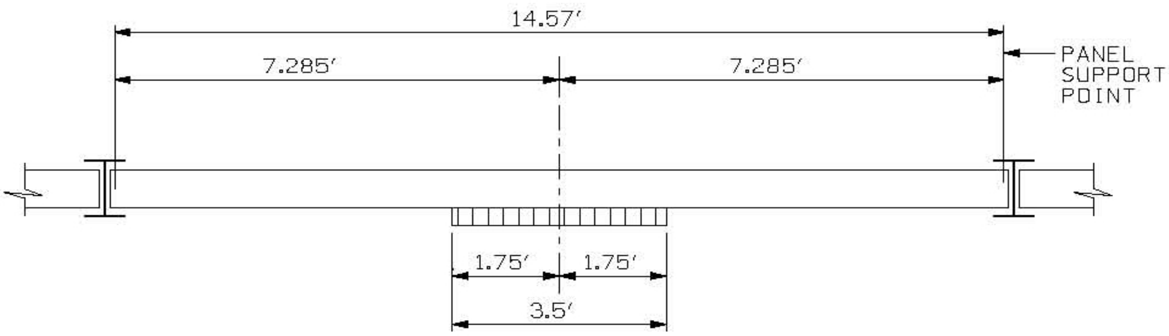



Figure 2. Position of collision load for maximum moment in panels

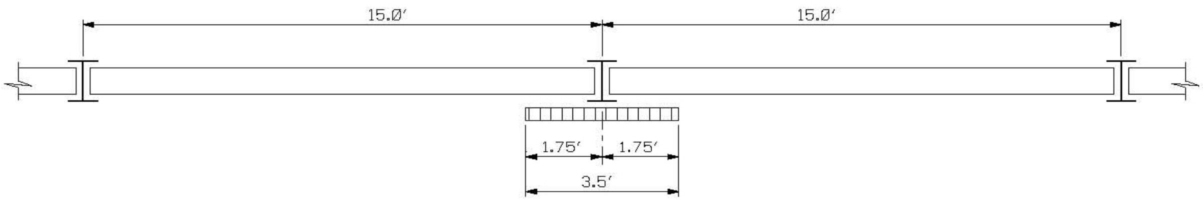



Figure 3. Position of collision load for maximum load on posts

## Summary of unfactored forces:

**Wall panels:**

Shear:

Negligible for slabs

Moment:

| | | |
|---|---|---|
| Wind Load : | 2.8 | k.ft per panel |
| Vehicular Collision : | 66.25 | k.ft per panel |

**Posts:**

Base shear:

| | | |
|---|---|---|
| Seismic Load : | 17.64 | kips |
| Wind Load : | 3.21 | kips |
| Vehicular Collision : | 19.46 | kips |

Base moment:

| | | |
|---|---|---|
| Seismic Load : | 249.98 | k.ft. |
| Wind Load : | 32.1 | k.ft. |
| Vehicular Collision : | 168.72 | k.ft. |

**Drilled shafts:**

At the top of the shaft:

| | | | | | |
|---|---|---|---|---|---|
| Dead Load: | 31.14 | kips | | | |
| Seismic load: | 17.64 | kips | applied at | 14.17 | ft above post base |
| Wind Load : | 32.1 | kips | applied at | 10.00 | ft above post base |
| Vehicular Collision : | 19.46 | kips | applied at | 8.67 | ft above post base |

Using the unfactored forces shown above, the factored loads for different limit states can be determined and different components may be designed using the same procedures used in the past by the owner agency.