

# **Attachment A**

## **New Specifications Section 15**

### **Sound Barriers**

# SECTION 15: DESIGN OF SOUND BARRIERS

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## 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.

#### 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.

*Post-and-Panel Construction*—Type of sound barriers construction consisting of vertical posts supported on a structure or on the foundations and panels spanning horizontally between adjacent posts.

*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 point on the traffic face of the sound barrier wall that is closest to traffic and the closest point on the traffic face of the traffic railing the sound barrier is mounted on or located behind as defined in Article 15.8.5.

*Structure-Mounted Sound Barriers*—Sound barrier supported on bridges, crashworthy traffic railings 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)
$V_0$	=	friction velocity, a meteorological wind characteristic for various upwind surface characteristics (mph) (15.8.2)
$V_{30}$	=	wind speed at 30.0 ft above low ground or water level (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 ( $^{\circ}$ ) (C15.4.2)
$\gamma_p$	=	load factor for permanent loads (15.9.9)

## **15.4—GENERAL FEATURES**

### **15.4.1—Functional Requirements**

#### **15.4.1.1 General**

Consult a roadway professional for requirements for sight-distance and sound barrier height and length requirements.

#### **15.4.1.2 —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.

#### **C15.4.1.2**

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 from the edge of traffic lanes to the face of the traffic barrier is 10.0 ft. Lateral clearances greater than 10.0 ft. 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.

#### **15.4.2—Drainage**

Adequate drainage shall be provided along sound barriers.

#### **C15.4.2**

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

#### **15.4.3—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**

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.

#### **15.4.4—Differential Settlement of Foundations**

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

#### **C15.4.4**

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.

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

#### **15.5.2—Service Limit State**

The resistance factors for the service limit states for post, wall panel and foundation 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, 6.5.2, 7.5.1 and 8.5.1.

#### **C15.5.1**

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

### **15.5.3—Strength Limit State**

The resistance factors for the strength limit states for post, wall panel and foundation 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 panel and foundation 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—Structure-Mounted Sound Barriers**

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

Where post-and-panel construction is utilized, wall panels may be allowed to bridge the expansion joints in, or at the ends of, the deck of the supporting structure where the panels seat width on the posts is sufficient to accommodate the expansion joint movements and the dimensional and installation tolerances, otherwise, posts shall be placed on either side of any expansion joint in the supporting structure.

### **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 supporting structure. Therefore, expansion devices are required in the sound barriers at expansion joint locations in order not to restrict the movement of the expansion joints of the supporting structures.

Sound barriers mounted on bridges stiffen the supporting bridge superstructures 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.

Where mounted on bridges, 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.

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 posts 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 and installation tolerances and dimensional changes caused by panel deformations due to applied loads and temperature changes. For smaller post flange widths, unless a post is provided on either side of an expansion joint in the supporting structure, the change in the opening of the structure expansion joint may be larger than the panel seat width on the post and may cause the failure of the panel straddling the structure 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.

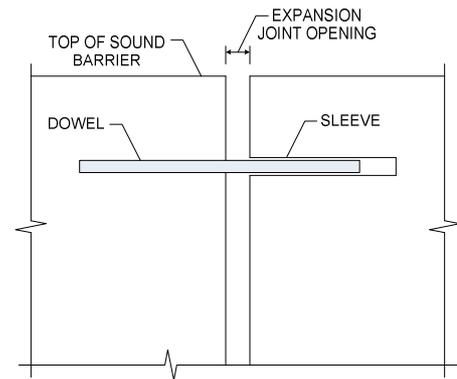


Figure C15.6.3-1—Sliding Dowel-and-Sleeve Connection

### 15.7—SOUND BARRIERS INSTALLED ON EXISTING BRIDGES

Where sound barriers are installed on existing bridges, the effects of the sound barrier forces on existing bridge components shall be investigated including the effect of unbalanced mass.

### 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.

Where sound barriers are added on an existing bridge, the bridge should be reanalyzed to determine its load rating taking into account the forces applied to the sound barriers. The stiffening effect of the sound barriers may be considered when determining the load rating of the bridge.

### 15.8—LOADS

#### 15.8.1—General

Unless explicitly modified below, all applicable loads shall 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.

### C15.8.2

For sound barriers, wind velocity at 30.0 ft above low ground or above design water level,  $V_{30}$ , shall be taken as 1.07 times the wind velocity at the sound barrier location determined from Figure 15.8.2-1.

For sound barriers, the factors  $V_o$  and  $Z_o$  shall be taken from Table 15.8.2-1.

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 that Figure 15.8.2-1 is based on to 75 year return period to be consistent with the design 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 (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 and described in Article C3.8.1.1. The description of these categories is repeated below. 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  $V_o$  and  $Z_o$  variables for these two upstream surface conditions were selected to yield wind pressures approximately equal to those obtained for Upstream Surface Conditions B2 and D in the *Guide Specifications for Structural Design of Sound Barriers (1989)*.

- Coastal— Flat unobstructed areas and water surfaces directly exposed to wind. This category includes large bodies of water, smooth mud flats, salt flats, and unbroken ice.
- Open Country—Open terrain with scattered obstructions having heights generally less than 30.0 ft. This category includes flat open country and grasslands.
- Sparse Suburban— Areas with fewer obstructions than described for Suburban conditions below but still more than described for Open Country conditions above.
- 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.

Wind loads on structure-mounted sound barriers located in areas that can be characterized as City, Suburban, Sparse Suburban and Open Country shall be determined using the values for  $V_o$  and  $Z_o$  specified for Open Country conditions in Table 15.8.2-1.

Typically, the collapse of structure-mounted sound barriers poses higher danger to life and property than ground-mounted sound barriers. Therefore, in areas with low wind pressure, structure-mounted sound barriers are designed to a higher minimum wind load than ground-mounted sound barriers having the same upwind surface characteristics. This is accomplished by designing structure-mounted sound barriers to Open Country conditions as a minimum.

**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

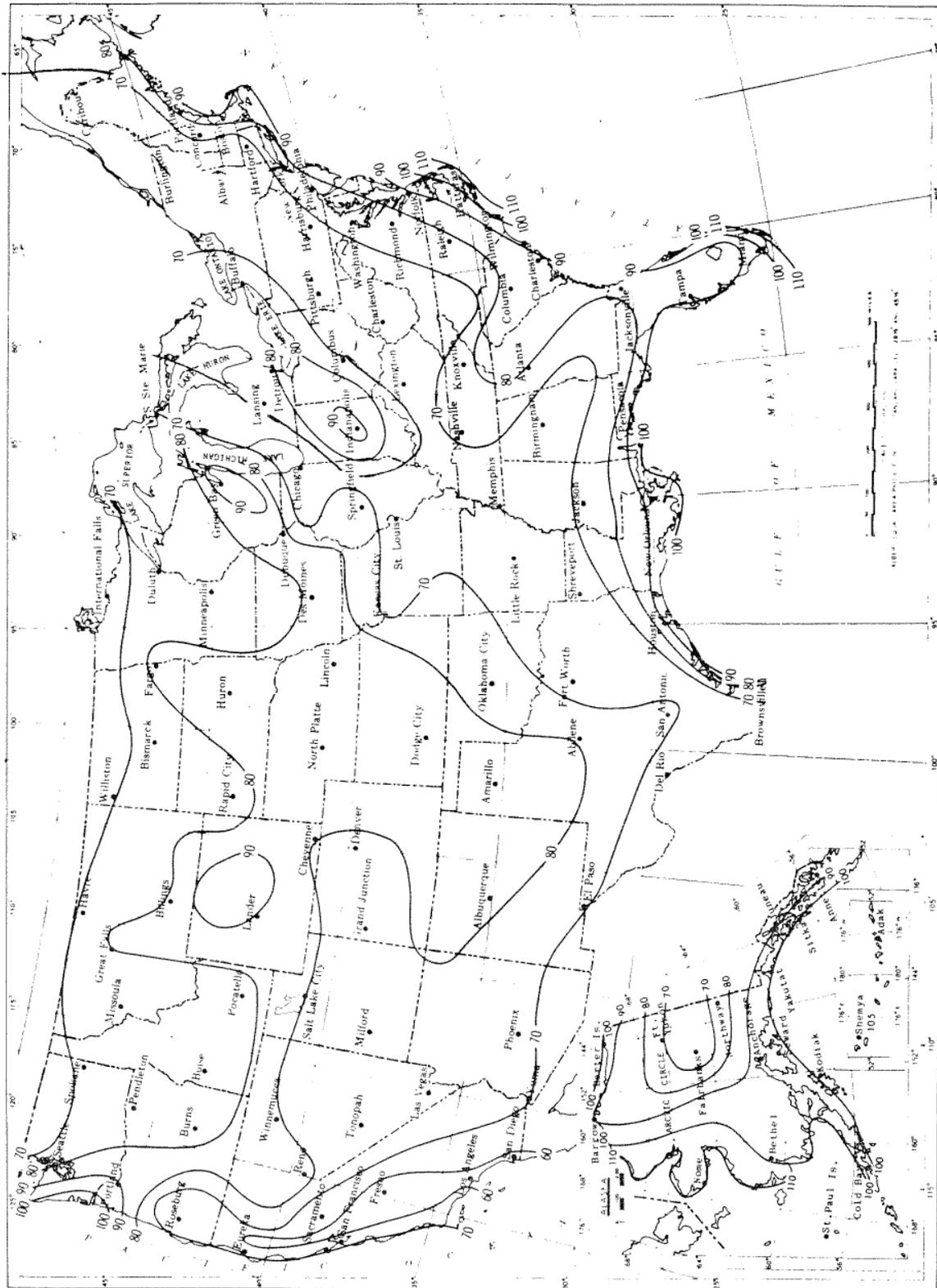


Figure 15.8.2-1—Isotach .02 quantiles, in miles per hour: Annual extreme-mile 30.0 ft. above ground, 50 years mean recurrence intervals

### 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

### 15.8.4—Earth Load

The provisions of Article 3.11 shall apply.

The possibility of difference between the actual finished grade and that shown on the contract documents should be considered in the design.

### 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.

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.

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

In lieu of crash-testing, the resistance of components and connections to Extreme Event II force effects may be

### 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 a limited number 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. A distance of 0.7 the wall height was selected to result in a force effect close to the upper bound observed in the study.

### C15.8.4

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

Soil build up against sound barriers have been observed in some locations. Owners may determine the earth loads for the worst load case assuming an allowance in the finished grade elevation.

### C15.8.5

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 barrier systems may contain sacrificial components or components that could need repair after vehicular collision. 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 structure-mounted sound barriers, 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.

The bridge overhang or moment slabs need not to be designed for more force effects than the resistance of the base connection of the sound barrier.

The design strategy involving a controlled failure scenario is similar in concept to the use of capacity

determined based on a controlled failure scenario with a load path and sacrificial elements selected to assure desirable performance of a structural system containing the soundwall. Vehicular collision forces shall be applied to sound barriers located within the clear zone as follows:

- Case 1: For sound barriers 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 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 behind a crashworthy 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 behind a crashworthy traffic railing with a sound barrier setback more than 4.0 ft.: vehicular collision forces need not be considered.

protected design to resist seismic forces. Some damage to the soundwall, traffic barrier, or connections is often preferable to designing an overhang or moment slab for force effects due to vehicular collision. The bridge overhang or moment slabs need not be designed for more force effects than the resistance of the base connection of the sound barriers.

Some guidance on desirable structural performance of sound barriers can be found in European Standard EN1794-2 (2003).

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 portion of such systems.

Crash Test Levels 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.

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.

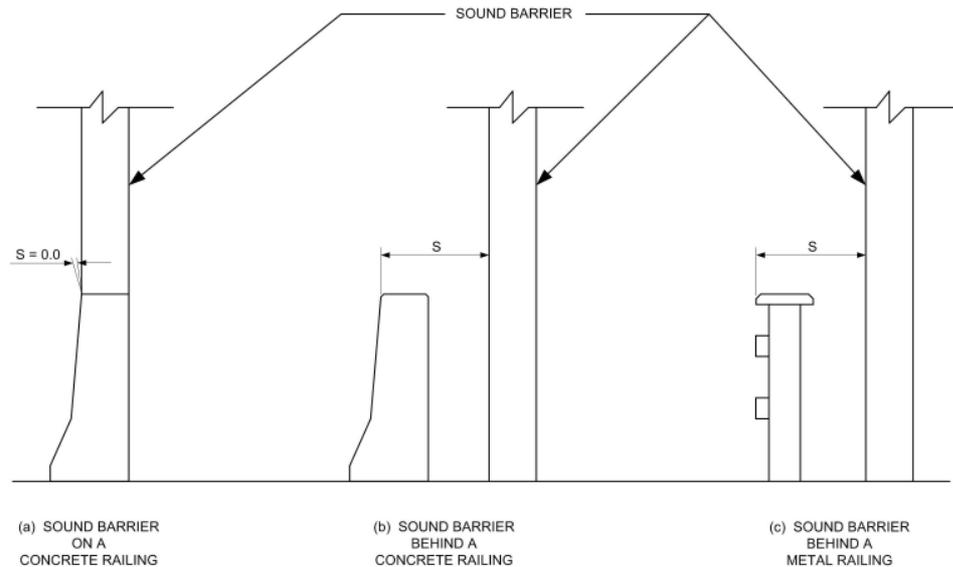
For sound barriers mounted on crashworthy traffic barriers or with a small setback, assumed to be less than 1.0 ft., the full crash force is expected to act on the sound barrier. The point of application of this force is assumed to be at the level of the cargo bed; taken as 6.0 ft. above the surface 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 on sound barriers shall be applied as a line load with a length equal to the longitudinal length of distribution of collision forces,  $L_c$ , specified in Article A13.

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.

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.

Unless otherwise specified by the Owner, vehicular collision forces shall be considered in the design of sound barriers.

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.

Owners may select to ignore vehicular collision forces in the design of sound barriers at locations where the collapse of the sound barrier, or portions of thereof, has minimal safety consequences.

## 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.

### 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 principles specified in this section and Sections 10 and 11.

Sound barriers shall be investigated for 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 10.5.5.1, 10.5.5.2, 10.5.5.3, 11.5.6 or 11.5.7.

### 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.

### 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 shall be as 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.

Bullard, Jr. D., L., Sheikh, N., M., Bligh, R., P., Haug, R., R., Schutt, J., R., and Storey, B., J. 2006. , *Aesthetic Concrete Barrier Design*, NCHRP Report 554. Transportation Research Board, National Research Council, Washington, DC.

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

White, M., Jewell, J., and Peter, R., *Crash Testing of Various Textured Barriers*, FHWA/CA/TL-2002/03. California Department of Transportation, Sacramento, California, September 2002.

**Agenda Item 48 (WAI 41)**

**Attachment B**

**Additions to Section 3  
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 3.11.5.10-1, 3.11.5.10-2, and 3.11.5.10-3, 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 3.11.5.10-4 and 3.11.5.10-5, 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.

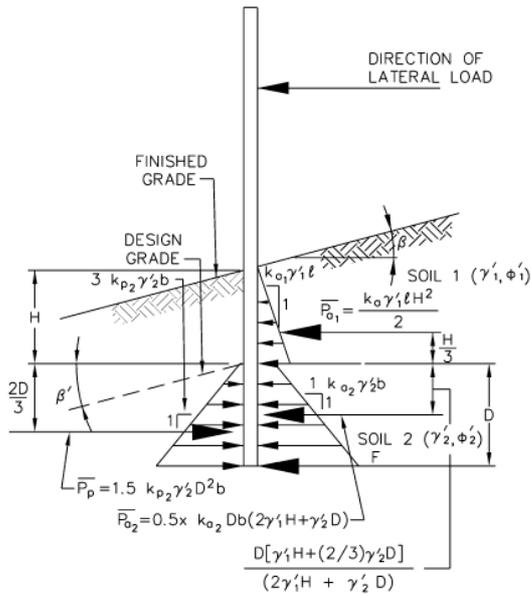
The reversal in the direction of applied lateral forces on sound barriers shall be considered in the design.

### 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.

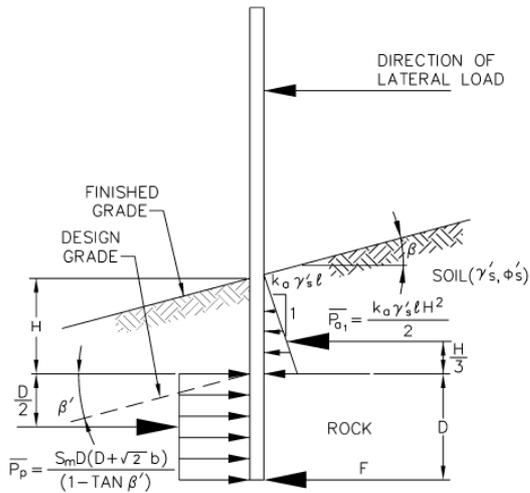
In Figures 3.11.5.10-1 and 3.11.5.10-3, the width,  $b$ , of discrete vertical elements effective in mobilizing the passive resistance of the soil is based on a method of analysis by Broms (1964a, 1964b) for single vertical piles embedded in cohesive or granular soil. Additional information on the background 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 3.11.5.10-1 through 3.11.5.10-5 correspond to the lateral load direction shown in these figures.



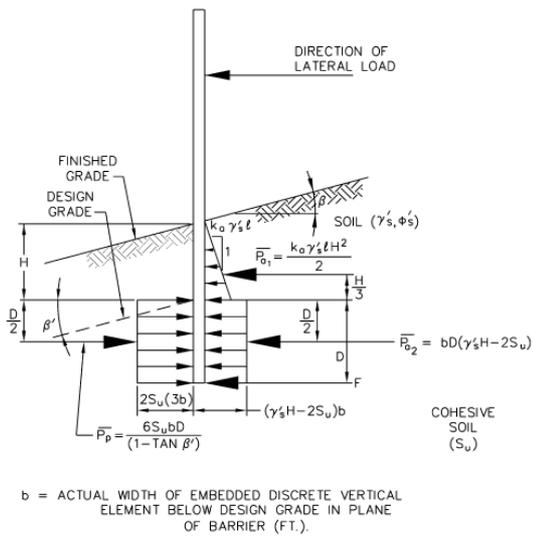
$b$  = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL ELEMENT BELOW DESIGN GRADE IN PLANE OF BARRIER (FT.).

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

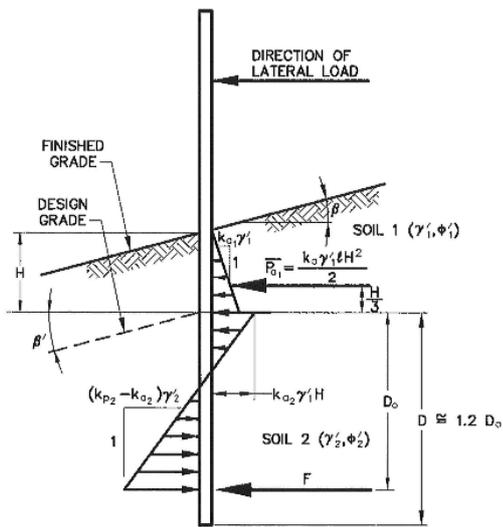


$b$  = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL ELEMENT BELOW DESIGN GRADE IN PLANE OF BARRIER (FT.).

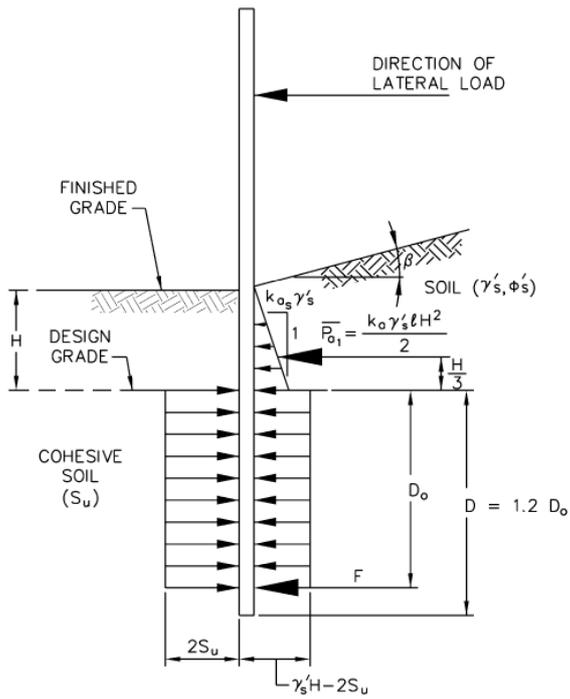
**Figure 3.11.5.10-2—Unfactored Simplified Earth Pressure Distributions for Discrete Vertical Wall Elements Embedded in Rock**



**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)**

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**Attachment C**

**Revisions to existing Articles 3.8.1.1 and 3.8.1.2.1**

### 3.8—WIND LOAD: WL AND WS

#### 3.8.1—Horizontal Wind Pressure

##### 3.8.1.1—General

Pressures specified herein shall be assumed to be caused by a base design wind velocity,  $V_B$ , of 100 mph.

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 and sound barriers more than 30.0 ft. above low ground or water level, the design wind velocity,  $V_{DZ}$ , should be adjusted according to:

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

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 3.8.1.2.1 and 3.8.1.2.2

$Z$  = 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 3.8.1.1-1, for various upwind surface characteristics (mph)

$Z_0$  = friction length of upstream fetch, a meteorological wind characteristic taken as specified in Table 3.8.1.1-1 (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 and sound barriers, 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. 3.8.1.1-1 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.

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

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 3.8.1.1-1. 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 3.8.1.1-1 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

Except for sound barriers,  $V_{30}$  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.

For Sound Barriers,  $V_{30}$  shall be taken as specified in Article 15.8.2.

### 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:

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

$P_B$  = base wind pressure specified in Table 3.8.1.2.1-1 (ksf)

The wind force on the structure shall be calculated by multiplying the design wind pressure,  $P_D$ , calculated using Eq. 3.8.1.2.1-1, 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.

**.....NO OTHER REVISIONS TO END OF ARTICLE.....**

#### 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 3.8.1.2.1-1. 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.

Due to the lack of information on the wind force on sound barriers, the wind pressure specified in Article 15.8.2 for the design of sound barriers is based on producing similar wind pressures to those used for the design of sound barrier under the AASHTO (1989). Such values of wind pressures proved to produce safe designs in the past.....NO OTHER REVISIONS TO

**END OF ARTICLE.....**

*3.8.1.2.2—Loads from Superstructures*

Except where specified herein, where the wind is not taken as normal to the structure, the base wind pressures,  $P_B$ , for various angles of wind direction may be taken as specified in Table 3.8.1.2.2-1 and shall be applied to the centroid of a single plane of exposed area. The skew angle shall be taken as measured from a perpendicular to the longitudinal axis. The wind direction for design shall be that which produces the extreme force effect on the component under investigation. The transverse and longitudinal pressures shall be applied simultaneously.

*C3.8.1.2.2*

For trusses, columns, and arches, the base wind pressures specified in Table 3.8.1.2.2-1 are the sum of the pressures applied to both the windward and leeward areas.

**Table 3.8.1.2.2-1—Base Wind Pressures,  $P_B$ , for Various Angles of Attack and  $V_B = 100$  mph**

Skew Angle of Wind (degrees)	Trusses, Columns and Arches		Girders	
	Lateral Load (ksf)	Longitudinal Load (ksf)	Lateral Load (ksf)	Longitudinal Load (ksf)
0	0.075	0.000	0.050	0.000
15	0.070	0.012	0.044	0.006
30	0.065	0.028	0.041	0.012
45	0.047	0.041	0.033	0.016
60	0.024	0.050	0.017	0.019

For the usual girder and slab bridges having an individual span length of not more than 125 ft and a maximum height of 30.0 ft above low ground or water level the following wind loading may be used:

- 0.05 ksf, transverse
- 0.012 ksf, longitudinal

Both forces shall be applied simultaneously. These forces shall not be used in determining the forces on sound barriers.

Wind pressure on sound barriers should be determined using the provisions of Article 15.8.2.

**Add the following Reference to Section 3 of AASHTO LRFD:**

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