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62

Sound Walls and Railings

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62.1 Sound Walls

62.1.1 Introduction

62.1.1.1 Need for Sound Walls

Population growth experienced during past decades in metropolitan areas has prompted the expansion and improvement of highway systems. As a direct result of these improvements, currently 90 million people in the United States live close to high-volume, high-speed highways. Rush-hour traffic on a typical high-volume, high-speed urban highway generates noise levels in the 80 to 90 dBA range. Within 50 to 100 yd (45 to 90 m) from the highway, due to absorption by the ground cover, the noise level dissipates to about 70 to 80 dBA. This ambient noise level, in comparison with a 50 to 55 dBA noise level in an average quiet house, is very intrusive to the majority of people, and should be further reduced to at least 60 to 70 dBA level by implementing noise abatement measures.

62.1.1.2 Design Noise Levels

In 1982, the Federal Highway Administration (FHWA) published the "Procedures for Abatement of Highway Traffic Noise and Construction Noise" in the Federal Aid Highway Program Manual, and therein established the acceptable noise levels at the location of the receivers (houses, schools, etc.) after the installation of the sound walls. This publication regulates the average allowable noise levels, $L_{eq}(h)$, and the peak allowable noise levels, $L_{10}(h)$ (the noise level that is exceeded more than 10% of the given period of time used to measure the allowable noise level) (Table 62.1) [1].

TABLE 62.1 Noise Abatement Design Criteria

Activity Category	L_{eq}(h), dBA	L_{10}(h), dBA	Land Use Category
A	57	60 (exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those quantities is essential if the area is to continue to serve its intended purpose; such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special quantities of serenity and quiet
B	67	70 (exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, playgrounds, active sports areas, and parks
C	72	75 (exterior)	Developed lands, properties, or activities not included in categories A and B above
D			Undeveloped lands; for requirements see paragraphs 5.a (5) and (6) of Publication PPM 90-2
E		55 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums

62.1.2 Selection of Sound Walls

62.1.2.1 Sound Wall Materials

When a sound barrier is inserted in the line of sight between a noise source and a receiver, the intensity of the noise diminishes on the receiver side of the wall. This reduction in the noise intensity is referred to as insertion loss. The main factors that contribute to the insertion loss are the diffraction and reflection of the noise by the sound wall, and transmission loss as noise travels through the wall material. The amount of diffraction and reflection can be controlled by varying the height and inclination of the wall, installing specially shaped closure pieces at the top of the wall, or coating the wall surface with a sound absorbent material. The transmission loss can be controlled by varying the thickness and density of the wall material. The transmission loss levels for several common construction materials are given in Table 62.2 [2].

Earth berms, concrete, timber, and to a certain extent steel have been the traditional choices of material for sound walls. Other materials such as composite plaster panels, concrete blocks, bricks, and plywood panels have also been successfully utilized in smaller quantities in comparison to the traditional materials. In recent years, the awareness and need have risen to recycle materials rather than bury them in landfills. This trend has led to the use of recycled tires, glass, and plastics as sound wall material.

Given the variety of materials available for use in sound wall construction, selection of an appropriate type of sound wall becomes a difficult task. An intelligent decision can only be made after investigating the major factors contributing to successful implementation of a sound wall project such as cost, aesthetics, durability/life cycle, constructibility, etc.

62.1.2.2 Decision Matrix

A decision matrix is a convenient way of comparing the performance of different sound wall alternatives. The first step in building a decision matrix is to determine the parameters that will be the basis of the evaluation and selection process. The most important parameters are cost, aesthetics, durability/life cycle, and constructibility. The cost of the sound wall should include the cost of the surface finish or treatment, landscaping, utility relocation, drainage system, right-of-way, environmental mitigation, maintenance, and future replacement. Better durability and longer life cycle almost always translate into higher initial construction cost and lower maintenance cost. Aesthetic treatment of the sound wall should provide visual compatibility with the surrounding environment. Restrictions such as right-of-way limitations and presence of nearby residential areas may affect the constructibility of certain sound wall types. Other parameters such as construction access, and

TABLE 62.2 Sound Wall Materials

Materials	Thickness, in. (mm)	Transmission Loss (TL)[a], dBA
	Woods[b]	
Fir	½ (13)	17
	1 (25)	20
	2 (50)	24
Pine	½ (13)	16
	1 (25)	19
	2 (50)	23
Redwood	½ (13)	16
	1 (25)	19
	2 (50)	23
Cedar	½ (13)	15
	1 (25)	18
	2 (50)	22
Plywood	½ (13)	20
	1 (25)	23
Particle Board[c]	½ (13)	20
	Metals[d]	
Aluminum	1⁄16 (1.6)	23
	⅛ (3)	25
	¼ (6)	27
Steel	24 ga (0.6)	18
	20 ga (0.9)	22
	16 ga (15)	25
Lead	1⁄16 (1.6)	28
	Concrete, Masonry, etc.	
Light concrete	4 (100)	36
	6 (150)	39
Dense concrete	4 (100)	40
Concrete block	4 (100)	32
	Composites	
Aluminum-faced plywood[e]	¾ (20)	21–23
Aluminum-faced particle board[e]	¾ (20)	21–23
Plastic lamina on plywood	¾ (20)	21–23
Plastic lamina on particle board	¾ (20)	21–23
	Miscellaneous	
Glass (safety glass)	¼ (6)	22
Plexiglas (shatterproof)	—	22–25
Masonite	½ (13)	20
Fiber glass/resin	¼ (6)	20
Stucco on metal lath	1 (25)	32
Polyester with aggregate surface[f]	3 (75)	20–30

[a] A weighted TL based on generalized truck spectrum.

[b] Tongue-and-groove boards recommended to avoid leaks (for fir, pine, redwood, and cedar).

[c] Should be treated for water resistance.

[d] May require treatment to reduce glare (for aluminum and steel).

[e] Aluminum is 0.01 in. thick. Special care is necessary to avoid delamination (for all composites).

[f] TL depends on surface density of the aggregate.

impacts on residences, parks, utilities, drainage systems, traffic, and environment should also be considered. In this step, the crucial issue is the identification of the relevant parameters in collaboration with the project owner. If the project owner is willing, receiving input from the local governments, residents, and the traveling public can be an invaluable asset in the success and acceptance of the project.

The second step in the process is assigning a percent weight to each parameter that is considered to be relevant in the first step (Table 62.3).

The third step involves assigning a rating ranging from 1 to 10 to each parameter. A rating of 10 represents the most desirable case, and a rating of 1 represents the least desirable case. For parameters that are associated with costs (Items 1, 3, 5, 7, 8, and 9 in Table 62.3), the rating can be based on the following formula once these costs are determined for each sound wall alternative:

$$\frac{\text{Cost of Least Expensive Alternative} \times 10}{\text{Cost of Alternative Considered}}$$

For the rating of less quantitative items such as aesthetics, constructibility, and construction access, the best approach is to define the factors which will give satisfactory results for the parameter in question. For instance, if a sound wall is considered atop an existing retaining wall, we may select balance (a pleasing proportion between the heights of the proposed sound wall and existing retaining wall), integration (presence of a fully integrated appearance between the proposed sound wall and existing retaining wall), and tonal value (uniformity of color and a pleasing contrast in textures between the proposed sound wall and existing retaining wall) as desirable parameters. We can assign a 10 rating to a sound wall alternative that displays all three factors, a 9 rating to the alternative that displays any two of the three factors, and an 8 rating to the alternative that satisfies only one of the factors.

The next step is to sum up the scores for each sound wall alternative, and rank them from the highest score to the lowest score (Table 62.3). The alternative with the highest score should be selected and recommended for design and construction.

62.1.3 Design Considerations

AASHTO *Guide Specifications for Structural Design of Sound Barriers* [3] is currently the main reference for the design loads, load combinations, and design criteria for concrete, steel, and masonry sound walls.

62.1.3.1 Design Loads

The loads that should be considered in the design of the sound barriers are dead load, wind load, seismic load, earth pressure, traffic impact, and ice and snow loads.

Dead Loads

The weight of all the components making up the sound wall are to be applied at the center of gravity of each component.

Wind Loads

Wind loads are to be applied perpendicular to the wall surface and at the centroid of the exposed surface. Minimum wind pressure is to be computed by the following formula [3]:

$$P = 0.00256\,(1.3V)^2\,C_d\,C_c \quad (0.0000473\,(1.3V)^2\,C_d\,C_c) \tag{62.1}$$

where

P = wind pressure in pounds per square foot (kilopascals)

V = wind speed in miles per hour (km/h) based on 50-year mean recurrence interval

TABLE 62.3 Decision Matrix for Sound Wall Alternatives

		Generic Post and Panel Concrete Sound Wall				Proprietary Concrete Panel Sound Wall			
		Alternative I (Sound wall at the top of a retaining wall)		Alternative II (Sound wall in front of a retaining wall)		Alternative I (Sound wall at the top of a retaining wall)		Alternative II (Sound wall in front of a retaining wall)	
Rating Parameters	Relative weight, %	Rating	Score	Rating	Score	Rating	Score	Rating	Score
1. Initial construction cost	40	7.8	3.12	10.00	4.00	6.20	2.48	7.30	2.92
2. Aesthetics	15	10.0	1.50	9.00	1.35	8.00	1.20	7.00	1.05
3. Right-of-way impact	10	10.0	1.00	10.0	1.00	10.0	1.00	10.0	1.00
4. Constructibility	10	7.00	0.70	10.0	1.00	5.00	0.50	8.00	0.80
5. Drainage impact	5	9.00	0.45	9.00	0.45	9.00	0.45	9.00	0.45
6. Construction access	5	9.00	0.45	8.00	0.40	9.00	0.45	8.00	0.40
7. Utility impact	5	10.00	0.50	9.00	0.45	10.00	0.50	9.00	0.45
8. Maintenance cost	5	10.00	0.50	8.00	0.40	10.00	0.50	8.00	0.40
9. Maintenance and protection of traffic	5	10.00	0.50	8.00	0.40	10.00	0.50	8.00	0.40
Total Score			8.72		9.45		7.58		7.87
Ranking			2		1		4		3

TABLE 62.4 Coefficient C_c

Exposure Category	Height Zone[a]		
	0 < H Û 14 (4)	14 (4) < H Û 29 (9)	Over 29 (9)
Exposure Bl — Urban and suburban areas with numerous closely spaced obstructions having the size of single-family dwellings or larger that prevail in the upwind direction from the sound wall for a distance of at least 1500 ft. (450 m); for sound walls not located on structures	0.37	0.50	0.59
Exposure B2 — Urban and suburban areas with more open terrain not meeting the requirements of Exposure Bl; for sound walls not located on structures.	0.59	0.75	0.85
Exposure C — Open terrain with scattered obstructions; this category includes flat, open country and grasslands; this exposure is to be used for sound walls located on bridge structures, retaining walls, or traffic barriers	0.80	1.00	1.10

[a] Given as the distance from average level of adjacent ground surface to centroid of loaded area in ft (m).

$(1.3V)$ = gust speed, 30% increase in design wind velocity
C_d = drag coefficient (1.2 for sound barriers)
C_c = combined height, exposure, and location coefficient

The three exposure categories and related C_c values shown in Table 62.4 are to be considered for determining the wind pressure.

Seismic Loads

The following load applies to sound walls if the structures in the same area are designed for seismic loads:

$$\text{Seismic Load} = \text{EQD} = \text{A} \times \text{f} \times \text{D} \tag{62.2}$$

where
EQD = seismic dead load
D = dead load of sound wall
A = acceleration coefficient
f = dead-load coefficient (use 0.75 for dead load, except on bridges; 2.50 for dead load on bridges; 8.0 for dead load for connections of non-cast-in-place walls to bridges; 5.0 for dead loads for connections of non-cast-in-place walls to retaining walls)

The product of A and f is not to be taken as less than 0.10.

Earth Loads

Earth loads that are applied to any portion of the sound wall and its foundations should conform to AASHTO *Standard Specifications for Highway Bridges,* Section 3.20 — Earth Pressure, except that live-load surcharge is not to be combined with seismic loads.

Traffic Loads

It will not be necessary to apply traffic impact loads to sound walls unless they are combined with concrete traffic barriers. The foundation systems for those sound wall and traffic barrier combinations that are located adjacent to roadway side slopes are not to be less than that required for the traffic impact load alone.

When a sound wall and traffic barrier combination is supported on a bridge superstructure, the design of the traffic barrier attachment details are based on the group loads that apply or the traffic load as given in AASHTO *Standard Specifications for Highway Bridges*, whichever controls.

TABLE 62.5 Load Combinations

Working Stress Design (WSD) Load Groups		Allowable Over-stress as % of Unit Stress	Load Factor Design (LFD) Load Groups	
Group I:	D + E + SC	100%	Group I:	β × D + 1.7E + 1.7SC
Group II:	D + W + E + SC	133%	Group II:	β × D + 1.7E + 1.3W + 1.3I
Group III:	D + EQD + E	133%	Group III:	β × D + 1.3 E + 1.3 EQE
Group IV:	D + W + E +I	133%	Group IV:	β × D + 1.3 E + 1.3 EQD
			Group V:	β × D + 1.1 E + 1.1 (EQE + EQD)

β = 1.0 or 1.3, whichever controls the design; D = dead load; E = lateral earth pressure; SC = live-load surcharge; W = wind load; EQD = seismic dead load; EQE = seismic earth load; I = ice and snow loads

Ice and Snow Loads
Where snow drifts are encountered, their effects need to be considered.

Bridge Loads
When a sound wall is supported by a bridge superstructure, the wind or seismic load to be transferred to the superstructure and substructure of the bridge is to be as specified above under Wind Loads and Seismic Loads. Additional reinforcement may be required in traffic barriers and deck overhangs to resist the loads transferred by the sound wall.

62.1.3.2 Load Combinations

The groups in Table 62.5 represent various combinations of loads to which the sound wall structure may be subjected. Each part of the wall and its foundation is to be designed for these load groups.

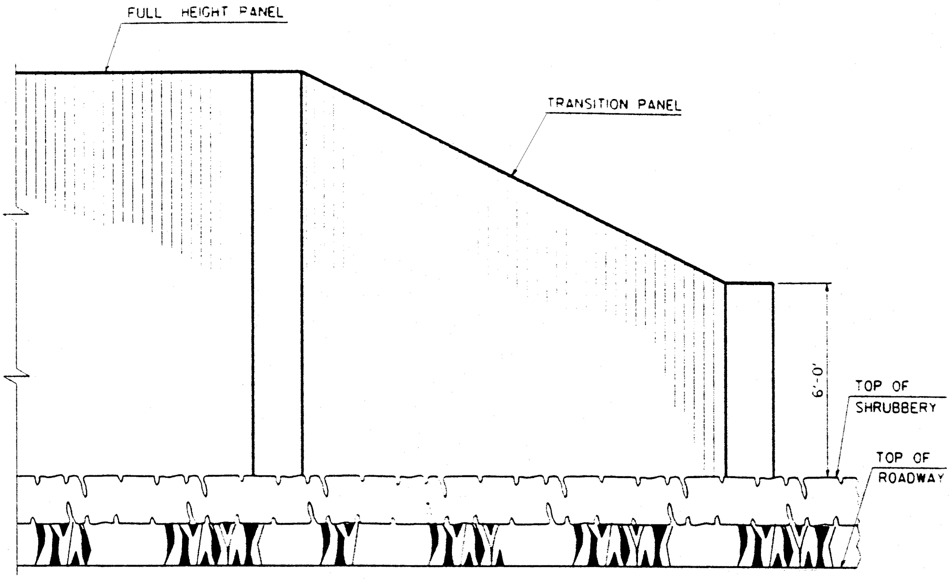
62.1.3.3 Functional Requirements

The basic functional requirements for sound walls are as follows:

- To prevent vehicular impacts the sound walls should be located as far away as possible from the roadway clear zone. At locations where right-of-way is limited, a guide rail or concrete barrier curb should be utilized in front of the sound wall.
- A sound wall, especially along curved alignments, should not block the line of sight of the driver, and therefore reduce the driver's sight distance to less than the distance required for safe stopping.
- To avoid undesirable visual impacts on the aesthetic features of the surrounding area, the minimum sound wall height should not be less than the height of the right-of-way fence, and walls higher than 15 ft (4.5 m) should be avoided.
- To prevent icing on the roadway, the sound walls should not be located within a distance of less than one and a half times the height to the traveled roadway.
- To prevent saturation of the sloped embankments and avoid unstable soil conditions, transverse and longitudinal drainage facilities should be provided along the sound wall.
- To control fire or chemical spills on the highway, fire hose connections should be provided through the sound wall to the fire hydrants on the opposite side.

62.1.3.4 Maintenance Considerations

Sound walls should be placed as close as possible to the right-of-way line to avoid creating a strip of land behind the sound wall and adjacent to the right-of-way line. If this is not practical, then consideration should be given to accommodating independent maintenance and landscaping functions behind the wall. In cases where the access to the right-of-way side of the sound wall is not possible via local streets, then access through the sound wall should be provided at set intervals along the wall by using a solid door or overlapping two parallel sound walls. Parallel sound walls



1 inch = 25.4 mm
1 foot = 0.3048 m

FIGURE 62.1 Typical transition at wall ends.

concealing an access opening should be overlapped a minimum of four times the offset distance in order to maintain the integrity of the noise attenuation of the main sound wall.

In urban settings, sound walls may be targets for graffiti. As a deterrence, the surface texture on the residential side of the wall should be selected rough and uneven so as to make the placement of graffiti difficult, or very smooth to facilitate easy removal of the graffiti. Sound walls with rough textures and dark colors are known to discourage graffiti.

62.1.3.5 Aesthetic Considerations

The selected sound wall alternative should address two aesthetic requirements: visual quality of the sound wall as a dynamic whole viewed from a vehicle in motion, and as a stationary form and texture as seen by the residents [4,5]. The appearance of the sound wall should avoid being monotonous to drivers; neither should it be too distractive. There are several ways of achieving a pleasing dynamic balance:

- Using discrete but balanced drops — 1 to 2 ft (0.3 to 0.6 m) — at the top of the walls to break the linear monotony.
- Implementing a gradual transition from the ground to the top of the sound wall by utilizing low-level slow-growing shrubbery in front of the wall and tapering wall panels at the ends of the wall (see Figure 62.1).
- Creating landmarks to give a sense of distance and location to the drivers. This can be achieved by utilizing distinct landscaping features with trees and plantings, or creating gateways with distinct architectural features such as planter boxes, wall niches, and terraces (Figure 62.2), or special surface finishes or textures using form liners (Figure 62.3). Gateways can also be used to delineate the limits of the individual communities along the sound wall by using a unique gateway design for each community.

As for the stationary view of the noise barrier, as seen by the residents, surface texturing and coloring are the most commonly used tools to gain acceptance by the public. By using a textured

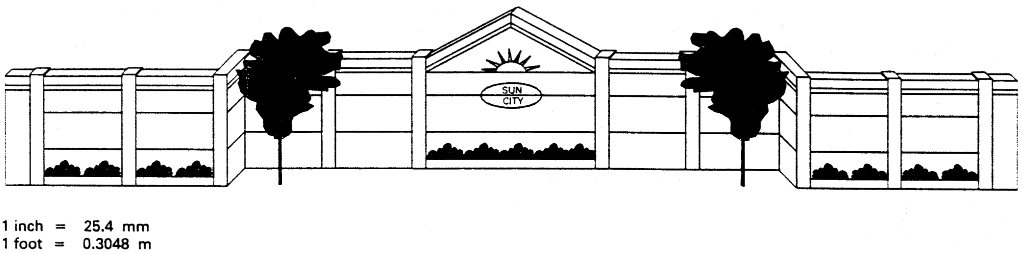


FIGURE 62.2 Gateway.

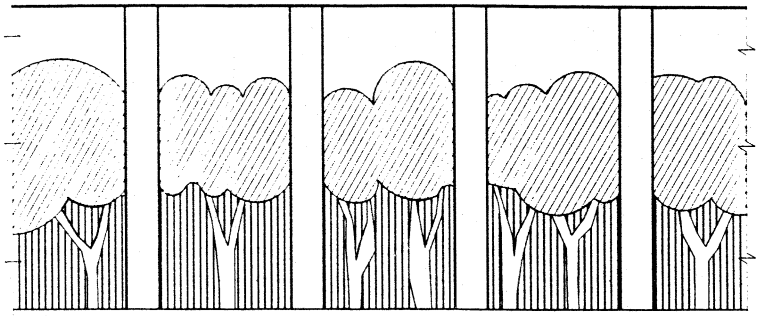


FIGURE 62.3 Architectural finish using form liners.

finish, it is possible to obtain different levels of light reflection on the wall surfaces and to evoke a sense of a third dimension. The most commonly used texturing method is raking the exposed face of the panel after concrete is placed in the formwork. Stamping a pattern in the fresh concrete surface is another texturing method. Coloring of concrete can be achieved by adding pigments to the concrete mix (internal coloring) or coating the surface of the panel with a water-based stain (external coloring). Although internal coloring would require less maintenance during the life cycle of the wall, achieving color consistency among panels is extremely difficult due to variations in the cement color and pigment dispersion rates. Staining offers uniformity in color. However, restaining of panels may be required after 10 to 15 years of service.

62.1.4 Ground-Mounted Sound Walls

62.1.4.1 Generic Sound Wall Systems

Generic sound wall systems (Table 62.6) make use of common construction materials such as earth, concrete, brick, masonry blocks, metal, and wood. With the exception of earth, all other materials are usually fabricated into post and panel systems in the shop, and installed on precast or cast-in-place concrete foundations at the site.

62.1.4.2 Proprietary Sound Wall Systems

In the late 1970s and early 1980s the regulatory actions by the Congress, Environmental Protection Agency (EPA), and Federal Highway Administration (FHWA) effectively launched a new industry. Ever since, a number of proprietary sound wall systems (Table 62.7) have been introduced and have become successful.

62.1.4.3 Foundation Types

The following foundation types are commonly used for sound walls:

TABLE 62.6 Generic Sound Wall Systems

Type	Features
Concrete walls	Approximately 45% of all existing sound walls are made of concrete; durability, ease of construction, and low construction and maintenance costs make concrete the most favored material in sound wall construction; precast posts and panels are usually used in combination with cast-in-place footings
Earth berms	Earth berms, alone or in combination with other types of sound walls, make up about 25% of existing sound walls; ease of construction, low cost, and availability for landscaping make earth berms the first choice of sound wall construction material wherever sufficient right-of-way is present
Timber walls	Timber is the choice of construction material for 15% of existing sound walls; timber is a flexible construction material, and can be used in a variety of ways in sound wall construction; timber posts can be solid sawn, glue laminated, or round pole type; the posts can be driven or embedded in concrete footings, and timber planks or plywood panels can be nailed or bolted to the posts at the site
Brick and concrete masonry block walls	These types of walls account for about 10% of the total sound wall construction; brick and masonry blocks can be preassembled into panels off site or can be mortared at the site; depending on the height of the wall, horizontal and/or vertical reinforcement may need to be used
Metal walls	These make up about 5% of sound wall construction; metal posts can be driven into the ground, embedded into concrete foundations, or attached to the top of the foundations; generally, metal panels that are made up of corrugated pans are connected to each other to form a solid surface, and then the entire panel assembly is bolted to the posts
Combination walls	It is sometimes advisable to combine two or more construction materials in a sound wall construction to take advantage of the superior characteristics of each material; a commonly encountered combination is the use of earth berms with other types of walls at locations where construction of a full-height earth berm is not feasible due to right-of-way limitations; in this case, an earth berm can be constructed to the edge of the right-of-way line, and the remainder of the height required for a full-level sound abatement can be provided by using a concrete, timber, or metal wall; another most commonly practiced combination in the field is the use of steel posts with concrete, timber, or composite wall panels or planks; the inherent advantage in this combination is the ability to make quick-bolted or welded connections between the steel posts and foundations.

Pile Foundations

Timber, steel, and concrete piles can be driven into the ground to act as a foundation, and also as a post for sound walls. One shortcoming of this foundation system is the problem of controlling the plumbness and location of driven posts. Also, damage to the pile end may often require trimming and/or repairs. On the other hand, the advantages of pile foundations are the ease and economy of installation into almost any kind of soil except rock, and completion of foundation and post installation in a single-step process.

Caisson (Bored) Foundations

Caissons are the most frequently used type of foundation in sound wall construction. It involves excavating a round hole using augering equipment (use of a metal casing may be required to prevent the collapse of the hole walls), installing a reinforcement cage, inserting the post or, alternatively, installing anchor bolt assemblies for the post connection, and finally placement of concrete. The advantages of caisson foundations are the ease of installation into any kind of soil (except soils containing large boulders), the convenience of performing the construction in tight spaces with a minor amount of disturbance to the surrounding environment, and ability to locate posts accurately in the horizontal plane and plumb in the vertical plane. The disadvantages are the high possibility of water intrusion into the excavated holes in areas with a high water table, interference of boulders with the augering process, and the presence of concurrent construction activities, such as augering, placement of reinforcement, insertion of post, and placement of concrete. In a caisson construction, all these tasks should be carefully orchestrated to achieve a cost-effective and expedited operation.

Spread Footings

Spread footings are the ideal choice where the construction site is suitable for a continuous trench-type excavation using heavy excavation equipment. Once the trench excavation is completed to the bottom of the proposed foundation, cast-in-place footings can be constructed on the ground, or

TABLE 62.7 Proprietary Sound Wall Systems

Type	Features
Siera Wall	This sound wall system consists of precast wall panels and cast-in-place foundations; each panel is precast integrally with a pilaster post along one edge, and attached to the adjacent panels with a tongue-and-groove connection; the connection between the wall panels and foundation is secured by welding the steel plates embedded at the base of the posts to the steel plates mounted on top of the foundations
Port-O-Wall	This is another sound wall system which utilizes precast panels and cast-in-place foundations; each precast concrete wall panel is secured to the adjacent panel with a tongue-and-groove connection; the panels are also mechanically connected by horizontal tie bars at the top and bottom; a rectangular hole at the bottom of each panel allows the installation of the transverse reinforcement for the construction of a continuous cast-in-place concrete footing
Fan Wall	This precast concrete wall system is a castellated freestanding wall that does not require a concrete footing; a rotatable and interlocking joint system allows the joining of panels at any angle; the joint along the sides of each panel features mating concave and convex edges and stainless steel aircraft-type cable connector assemblies
Sound Zero	This lightweight (8 lb/sf) (380 Pa) panel system is fabricated to the full wall height, and installed on top of cast-in-place footings or bridge parapets using concrete or steel posts
Carsonite© Sound Barrier	This panel system features tongue-and-groove modular sections made from a fiberglass-reinforced polymer composite shell that is filled with ground, recycled tires; the lightweight (7.5 lb/sf) (360 Pa) panels are preassembled off site and installed between posts anchored into cast-in-place footings, traffic barriers, or bridge parapets
Contech Noise Walls	This wall system consists of hot-rolled steel posts and cold-formed interlocking steel panels; all wall components are galvanized, and the panels are additionally protected by a choice of colored coating systems
Evergreen Noise Abatement Walls	This wall system consists of precast concrete units, and is supported on individual or continuous cast-in-place concrete foundations; the precast units are stacked up to form a freestanding wall; a select granular material is placed in each wall unit and compacted prior to the installation of the next higher unit; the trays of the wall units are filled with topsoil to support the planting and growth of evergreen and deciduous plants
Maccaferri Gabion Sound Walls	This sound wall system utilizes stacked-up gabion baskets to form a freestanding sound wall; zinc or PVC-coated wire baskets are filled with rock to blend with the natural environment; the cores of the baskets can also be filled with topsoil to allow planting of vegetation

precast footings can be erected. If precast footings are used, roughening of the bottom of footing in combination with placement of a crushed stone layer with a thin cement grout topping under the footing may be necessary to achieve a desired safety factor against sliding.

Tie-Down Foundations

At locations where rock is at or close to the surface, augering for caissons or excavating for spread footings may be too costly and time-consuming. A more practical solution in this case is the use of concrete pedestals anchored into rock with post-tensioned tie-downs. A pedestal detail similar to the stem of the spread footing can be constructed to allow insertion of the post into a recess in the stem, or installation of anchorage assemblies for the connection of the post to the top of the stem.

62.1.4.4 Typical Details

The sketches shown in this chapter depict a concrete sound wall system consisting of precast posts and panels supported on spread footings [6].

Precast panels (Figure 62.4) are 5 in. (130 mm) thick and reinforced with wire mesh fabric to sustain the wind loading. Additional mild reinforcement is placed along the periphery of the panels to carry the vertical loads. Two cast-in-place inserts are provided at the top of the panels for handling and erection. The panels are 4 ft (1.2 m) high and span between the posts spaced at 15 ft (4.6 m) on centers. Overlapping joints between the panels provide a leakproof surface. The roadway side of the panels is finished smooth and the residential side of the panel displays a raked finish to deter graffiti.

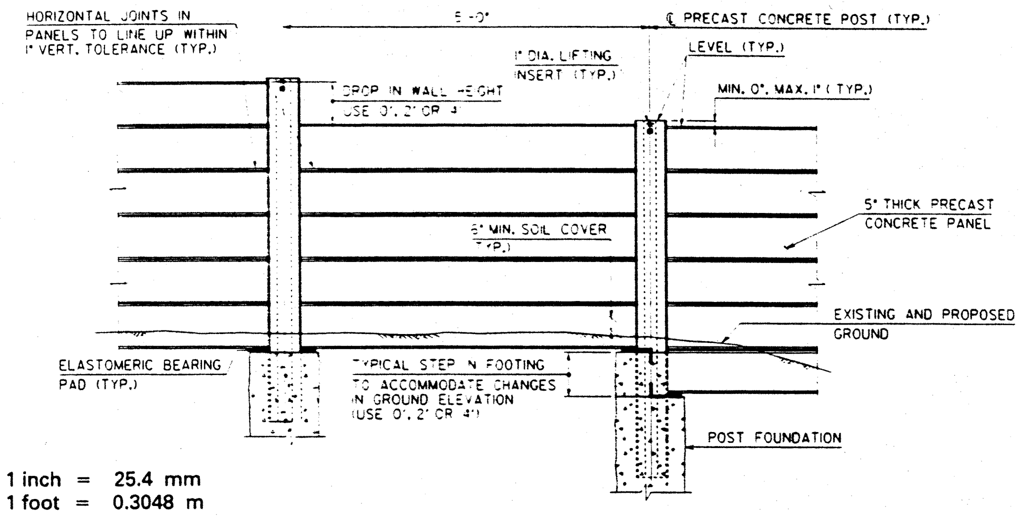


FIGURE 62.4 Precast concrete post and panel sound walls. (*Source*: Guzaltan, F., *PCI J.*, 27(4), 60, 1992. With permission.)

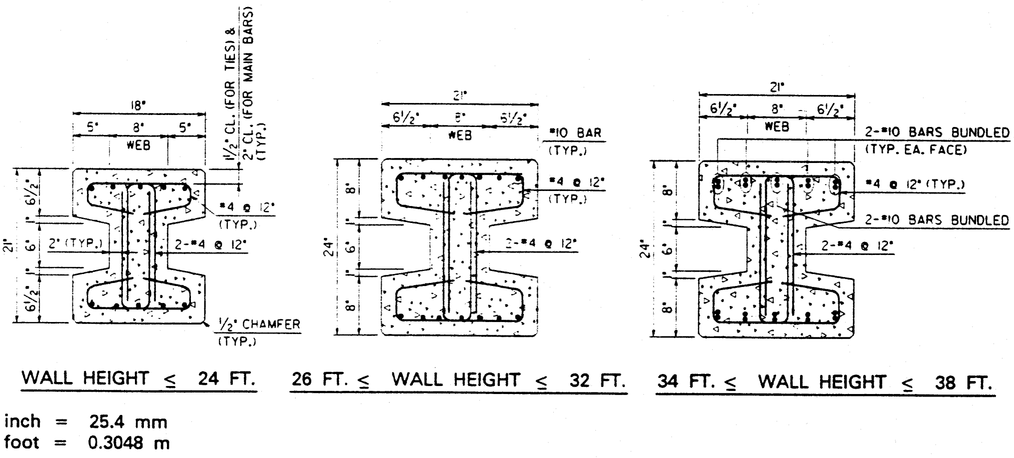


FIGURE 62.5 Concrete precast post details. (*Source*: Guzaltan, F., *PCI J.*, 27(4), 61, 1992. With permission.)

The precast concrete posts (Figure 62.5) are H-shaped to accept the insertion of panels and allow approximately a 10° angle change in the orientation of panels. Both flanges are reinforced with mild steel reinforcement to carry the wind loads that are transmitted from the panels. For posts longer than 34 ft (10 m), the use of prestressing strands may need to be considered to prevent reinforcement congestion in the flanges. Shear reinforcement wrapping the outline of the web and flanges is also provided.

Four types of foundations for use in different soil and site conditions are featured: caisson foundations (Figure 62.6) for sites without boulders; cast-in-place and precast spread footings (Figure 62.6) at sites where large boulders are frequent; and tie-down foundations (Figure 62.7) at locations where rock is close to the surface.

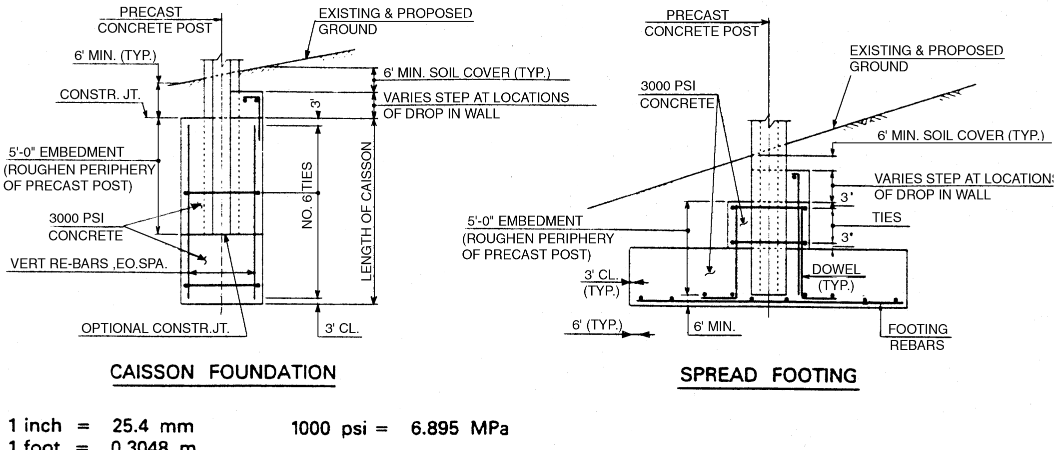


FIGURE 62.6 Caisson foundation and spread footing. (*Source*: Guzaltan, F., *PCI J.*, 27(4), 61, 1992. With permission.)

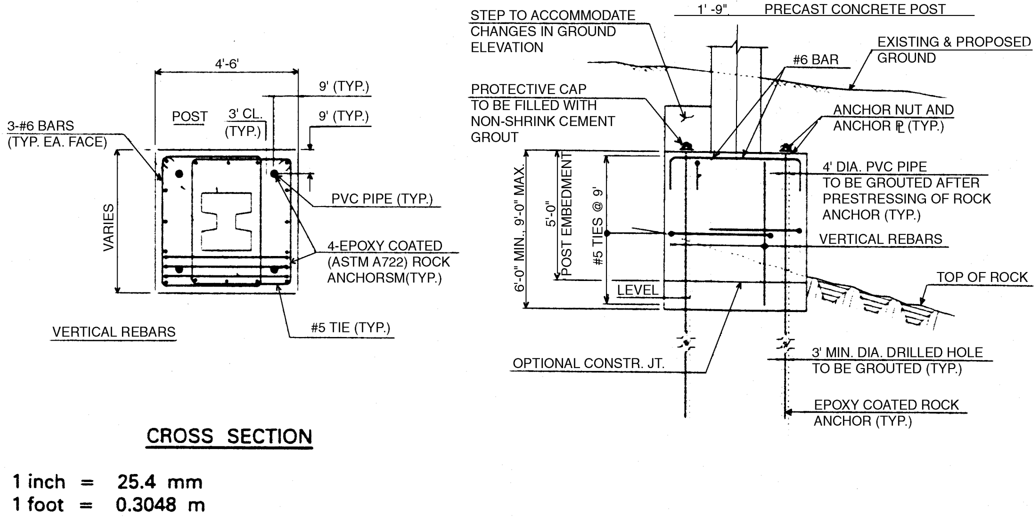


FIGURE 62.7 Tie-down foundation. (*Source*: Guzaltan, F., *PCI J.*, 27(4), 62, 1992. With permission.)

62.1.5 Bridge-Mounted Sound Walls

62.1.5.1 Assessment of an Existing Bridge to Carry a Sound Wall

The capacity of the existing superstructure components (barrier curb, deck slab, girders, and diaphragms) should be checked prior to deciding to attach sound barriers to an existing bridge. Furthermore, the capacity of the existing bearings and piers may also be investigated due to increases in the girder reactions. The main forces to be considered are the dead load of the sound wall, wind and ice loads on the panels and posts, and torsion created by the eccentricity of these forces. Quite often, the existing deck slabs, beams, girders, and floor beams tend to have excess flexural capacity to carry additional loads. However, they may not have any spare capacity to carry additional torsion.

The transmission of forces from the sound wall to the bridge superstructure can be best determined by using a three-dimensional grid or a finite-element model. The structural model should consider the stiffness of the deck slab, girders, and diaphragms, as well as the constraints introduced by the bearings at the girder ends. In any case, significant torsional impact should be expected in the deck slab, diaphragms, fascia girder, and first and second interior girders in multigirder superstructures.

62.1.5.2 Strengthening an Existing Bridge Superstructure to Carry a Sound Wall

Multisteel girder superstructures are relatively easy to strengthen to carry the superimposed moments, shear, and torsion due to the installation of a sound wall. Bolting an additional cover plate to the bottom flange may be sufficient to strengthen a steel girder. However, strengthening a precast concrete I-beam poses a greater challenge. Adding post-tensioned strands, longitudinal and shear reinforcement, and encasing the strands and reinforcing bars in a high-strength concrete mass may be a feasible way of strengthening an existing I-beam. Nevertheless, the time and cost involved in strengthening concrete I-beams should always be compared with the cost of replacing the superstructure before a strengthening alternative is seriously pursued.

Even if the deck slab and girders of an existing bridge are found to be adequate or amenable to strengthening, there may be still a need to replace at least the bridge parapets in order to be able to anchor the posts of the sound wall.

62.1.5.3 Typical Details

The typical retrofit sound wall details (Figure 62.8) on an existing bridge feature steel posts anchored into a New Jersey barrier curb. The top of the new barrier curb is oversized to accept a base plate for the sound wall post. The lightweight concrete precast panels are used to lessen the impacts of dead load.

The bridge incorporates several strengthening features. The deck slab is thickened over the new fascia girder and two adjacent girders. All new girders as well as the new bearings and diaphragms are designed to carry additional sound wall loads. At the existing hammerhead pier, the length of the pier cap cantilever is reduced by adding an auxiliary column. This measure is intended to counteract the effects of the increased girder reactions.

62.1.6 Independent Sound Wall Structures

62.1.6.1 Need for an Independent Sound Wall Structure

When it is not feasible to strengthen or replace the components of an existing bridge to carry a proposed sound wall, the alternative is to provide a freestanding structure to support the sound wall along an existing bridge.

In the design of an independent sound wall structure the following guidelines may be followed:

- There should be no noise leakage between the bridge and the independent structure. A closure device should be provided between two structures to block the noise leakage and, at the same time, permit thermal movements and differential settlement of structures without adversely affecting each other.
- In order to maintain consistency in the appearance of the sound wall, the panels on the independent structure should match the panels of the adjacent ground-mounted sound wall at least in texture and appearance.
- The independent structure should mimic the appearance of the existing bridge as much as possible and follow the span arrangement of the existing bridge. The substructure components of the independent structure should also utilize the same material and architectural treatment used on the adjacent bridge.

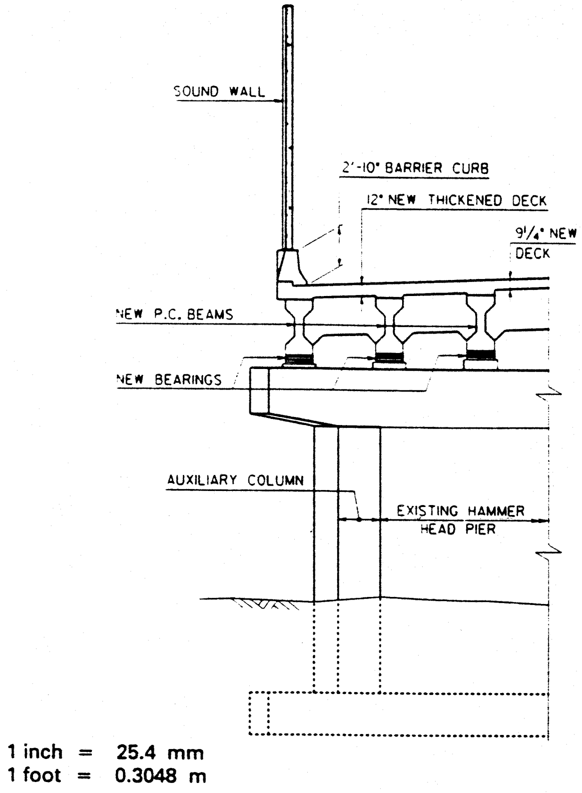


FIGURE 62.8 Bridge-mounted sound wall.

- The superstructure of the independent structure that carries the sound panels should match the horizontal lines of the bridge and be capable of carrying the dead load of the panels and the wind load acting on the panels.
- Effects of fatigue, due to the reversal of wind direction, should be considered in the design of the structural steel components of the independent structure as well as their connections.
- The independent sound barrier structure should not infringe on the lateral and vertical clearance envelope of the existing bridge.
- Since an independent sound wall structure usually carries small vertical loads (dead and ice loads) and highly eccentric transverse loads (wind loads), it should either be founded on piles with high tensile capacity or be connected with dowels to the abutments and piers of the existing bridge, providing that these bridge components display adequate capacity.

62.1.6.2 Typical Details

The following are the typical features of an independent sound wall structure (Figure 62.9) [6]:

- Cast-in-place reinforced concrete footings and pedestals that are cast against and doweled into the existing bridge abutments and piers in order to prevent the rocking of the independent sound wall structure in the transverse direction under large wind loads.
- A steel tower made of a pair of structural steel tubes is supported on the concrete pedestal and carries a twin Vierendeel truss.
- A Vierendeel truss is made of structural steel tubing, and consists of continuous top and bottom chords and groove welded struts spanning between the chords. A twin truss is formed

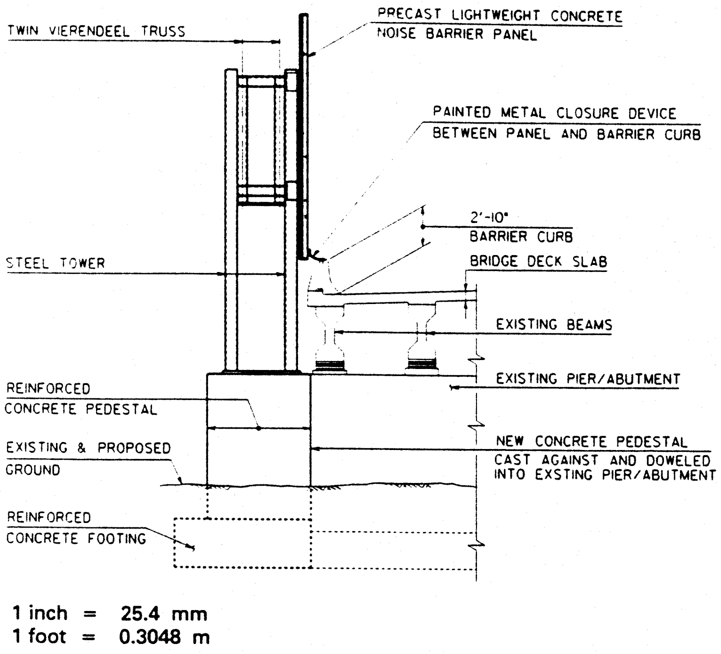


FIGURE 62.9 Independent sound wall structure. (*Source*: Guzaltan, F., *PCI J.*, 27(4), 62, 1992. With permission.)

by connecting each top and bottom chord member to the adjacent ones using groove-welded horizontal struts.

- The sound wall consists of 5-in. (130-mm)-thick lightweight reinforced concrete panels bolted to vertical posts (W shaped) spaced at 5-ft (1.5-m) intervals. The vertical posts are bolted to two spacers (W shaped) at the level of the top and bottom chords. These spacers are in turn shop-welded to the vertical struts of the truss.
- The gap between the wall panels and bridge parapet is closed using an L-shaped bent steel plate. The horizontal leg of the steel plate is bolted to the top of the parapet. The vertical leg is positioned upward and overlaps the wall panel approximately 10 in. (250 mm). A 2-in. (50-mm) gap is provided between the wall panels and upright leg of the bent plate to allow the independent movement of the bridge and sound wall.

62.2 Bridge Railings

62.2.1 Introduction

Railings are provided along the edges of structures in order to protect pedestrians, bicyclists, and vehicular traffic. Depending on the function they are designed to serve, bridge railings are classified as: pedestrian railing, bicycle railing, traffic railing, and combination railing. For each category, the AASHTO *Standard Specifications for Highway Bridges*, 16th ed. [7], has defined specific geometric requirements and the loads to be applied at various elements of the railings. An alternative approach for determining the geometries and the loads of unique or new railings is presented in the AASHTO *Guide Specifications for Bridge Railings* [8].

In the United States most states have their own standards for bridge railing geometry and design criteria. These standards generally follow the AASHTO Standard or Guide Specifications. In instances where a special design must be provided for a new railing or an existing railing must be upgraded, the following discussions are presented to help in understanding the AASHTO Standard and Guide Specifications and their differences.

By necessity, throughout the following section there are statements that paraphrase the contents of these references. Similarly, the figures and tables are those of AASHTO presented in a slightly different format to better serve the text. This treatise is not intended to substitute for the AASHTO Standard and Guide Specifications; rather it is meant to facilitate the AASHTO codes and their intention, as the author sees them.

As related to traffic railings and combination traffic and pedestrian railings, AASHTO Standard Specifications specifies only one set of loads applicable to all classes of vehicles and all types of roadways and traffic; it does not recognize variations in the vehicle type, percent of truck usage, design speeds, average daily traffic (ADT), etc. These variables are addressed in the AASHTO Guide Specifications which establishes guidelines for crash testing and evaluation of bridge railings based on three performance levels. Each performance level is based on the ADT of the roadway for which the railing is being considered. But other variables, such as design speed, percent truck use, rail offset to travel lane, and the type of highway (divided, undivided, and one-way), are also considered in the selection of the performance levels.

For each performance level the Guide Specifications establishes a certain crash test procedure and evaluation criteria. The testing procedure includes the type, weight, size, and geometry of the test vehicle as well as its speed and impact angle. Based on the crash test results, the railing is evaluated in accordance with the crash test evaluation criteria, which establishes the pertinent performance level and the type of traffic railing to suit the functional needs of a site.

Recognizing that crash tests are expensive and time-consuming, the Guide Specifications provide a table (Table 62.8), based on the results of actual crash tests conducted by the National Cooperative Highway Research Program (NCHRP). In this table design loads and traffic rail geometries are given for the three standard performance levels and two optional levels. These optional levels relate to heavier trucks and higher railings. The loads and dimensions provided in this table are applicable to four conceptual traffic rails that are representative of traffic rails or combination rails in the United States.

Table 62.8 is generally used to design the prototype railings that are to be crash tested. It is also used for the design of one-of-a-kind railings where the cost of crash testing cannot be justified. The highway agencies are encouraged to conduct crash test programs when specific traffic/combination railing is being considered for the first time. Railings that meet the crash test criteria for a desired performance level are exempt from the requirements of AASHTO Standard Specifications.

For bicycle and pedestrian railings the AASHTO Standard Specifications and Guide Specifications provide similar design requirements with minor differences in geometry. It is important to note that where pedestrian or bicycle traffic is expected, this traffic must be separated from travel lanes by a traffic railing or barrier. The height of this railing above the sidewalk or bikeway surface should be no less than 24 in. (610 mm). Also the face of the railing should have a smooth surface to prevent any snag potential. Where it is desirable to raise the height of the traffic barrier to prevent the bicycles from falling over the railing onto the roadway, or to improve the level of comfort, a traffic railing or a modified combination railing may be used.

Where a raised sidewalk curb with a width greater than 3.5 ft (1.067 m) is provided, the Guide Specifications would consider it acceptable to use only a crash-tested combination railing along the edge of the bridge. The curb must be included in the crash test that is used for determining the combination railing design. The Standard Specifications, however, makes no specific reference to raised sidewalks. Where the roadway curb projects more than 9 in. (229 mm) from traffic face of railing (construed to be a safetywalk or a sidewalk) the Standard Specifications allow the use of a combination traffic and pedestrian railing along the edge of the structure. On urban expressways where the curb projects less than 9 in. (229 mm), the Standard Specifications call for a combination railing to separate pedestrian walkways from the adjacent roadway. On rural expressways it calls for a traffic railing or barrier to separate pedestrians from vehicular traffic. A pedestrian railing must be provided along the edge of the structure where the pedestrian walkway is separated from the roadway.

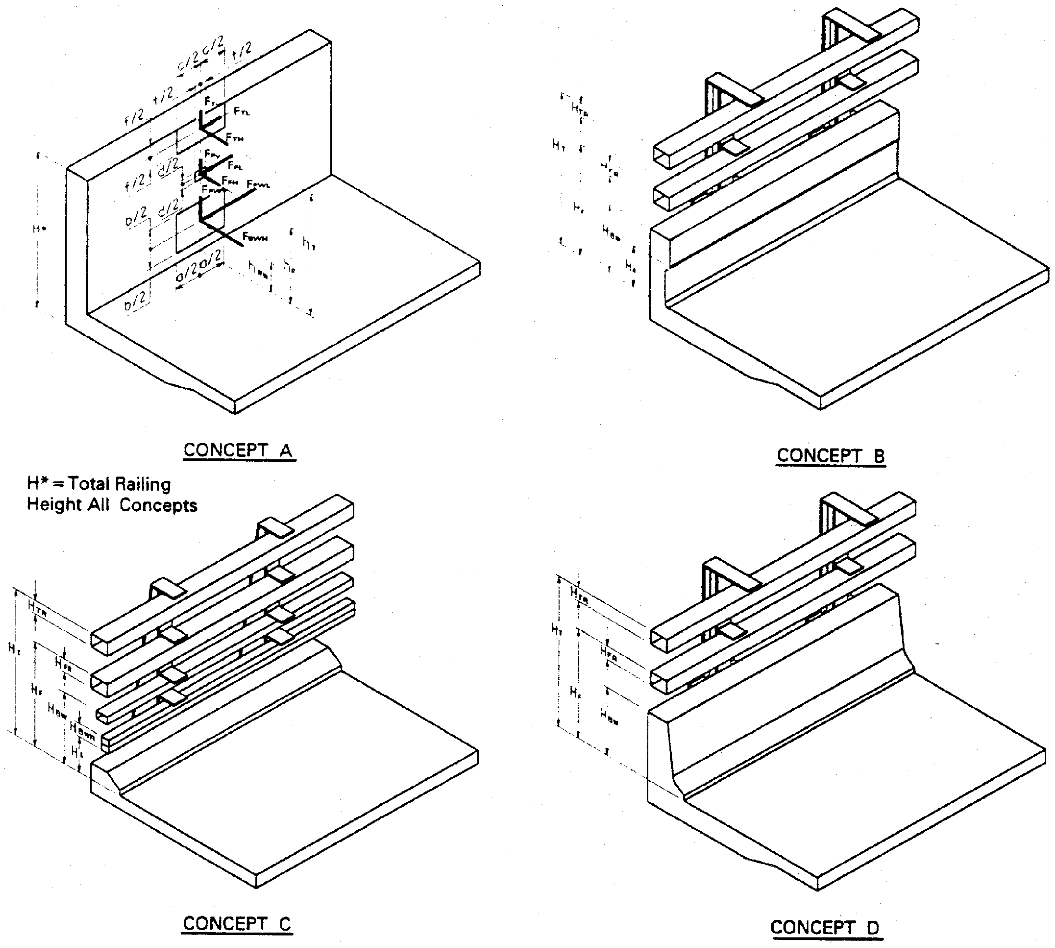
TABLE 62.8 Bridge Railing Design Information — Bridge Railing Loads, Load Distribution, and Location

Quantity Designations	Railing Performance Level				
	PL-1	PL-2	PL-3	Optional PL-4	Optional PL-4T
Group I[a] Loads (Body and Wheels)					
F_{BWH}	30 (133) kips	80 (356) kips	140 (623) kips	200 (890) kips	200 (890) kips
F_{BWL}	±9 (±40) kips	±24 (±107) kips	±42 (±187) kips	±60 (267) kips	±60 (±267) kips
	±12 (±53) kips (down)	15 (67) kips (down)	+18 (80) kips (down)	+18 (80) kips (down)	+18 (80) kips (down)
F_{BWV}	–4 (–18) kips (up)	–5 (–22) kips (up)	–6 (–27) kips (up)	–6 (–27) kips (up)	–6 (–27) kips (up)
Group II[a] Loads (Trailer Floor)					
F_{FH}	—	—	—	240 (890) kips	200 (890) kips
F_{FL}	—	—	—	±60 (267) kips	±50 (±222) kips
				–18 (80) kips (down)	+18 (80) kips (down)
F_{FV}	—	—	—	– 6 (–27) kips (up)	–6 (–27) kips (up)
Group III[a] Loads (Tank Trailer)					
F_{TH}	—	—	—	—	200 (890) kips
F_{TL}	—	—	—	—	±50 (±222) kips
					+18 (80) kips (down)
F_{TV}	—	—	—	—	–6 (–27) kips (up)

			Load Distribution Pattern Dimensions		
a	24 in. (610)	28 in. (711)	32 in. (813)	36 in. (914)	36 in. (914)
b	12 in. (305)	14 in. (356)	16 in. (406)	18 in. (457)	18 in. (457)
c	—	—	—	12 in. (305)	12 in. (305)
d	—	—	—	6 in. (152)	6 in. (152)
e	—	—	—	—	36 in. (914)
f	—	—	—	—	8 in. (203)
			Load Locations		
h_{BW}	16 in. thru (H-6 in.) [(406) thru (H-152)]	17 in. thru (H-7 in.) [(432) thru (H-178)]	18 in. thru (H-8 in.) [(457) thru (H-203)]	19 in. thru (H_{BW}-9 in.) [(483) thru (H_{BW}-229)]	19 in. thru (H_{BW}-9 in.) [(483) thru (H_{BW}-229)]
h_F	—	—	—	51 in. (1295)	51 in. (1295)
h_T	—	—	—	—	74 in. (min) 84 in. (max) (1.880 m) (2.134 m)
			Railing Geometry Dimensions		
H	27 in. (686) (min)	32 in. (813) (min)	42 in. (1067) (min)	54 in. (1372) (min)	78 in. (1981) (min)
H_A	10 in. (254) (max)	10 in. (254) (max)	10 in. (1254) (max)	10 in. (254) (max)	10 in. (254) (max)
H_{BW}	27 in. (686) (min)	32 in. (813) (min)	42 in. (1067) (min)	32 in. to 42 in. (813 to 1067)	32 in. to 42 in. (813 to 1067)
H_{BWR}	12 in. (305) (min)	12 in. (305) (min)	12 in. (305) (min)	12 in. (305) (min)	12 in. (305) (min)
H_F	—	—	—	54 in. (1372) (min)	54 in. (1372) (min)
H_{FR}	—	—	—	6 in. (152) (min)	6 in. (152) (min)
H_T	—	—	—	—	78 in. (1981) (min)
H_{TR}	—	—	—	—	8 in. (152) (min)

Note: PL = Performance Level.Where kips are indicated values in () indicate metric equivalent in kilonewtons; where inches are indicated values in () indicate metric equivalent in millimeters.

[a] Each set of Group Loads to be applied separately.



CONCEPT A

CONCEPT B

H* = Total Railing Height All Concepts

CONCEPT C

CONCEPT D

FIGURE 62.10 Bridge railing concepts — configuration and loading patterns. (*Source*: AASHTO, *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials, Washington, D.C., 1989. With permission.)

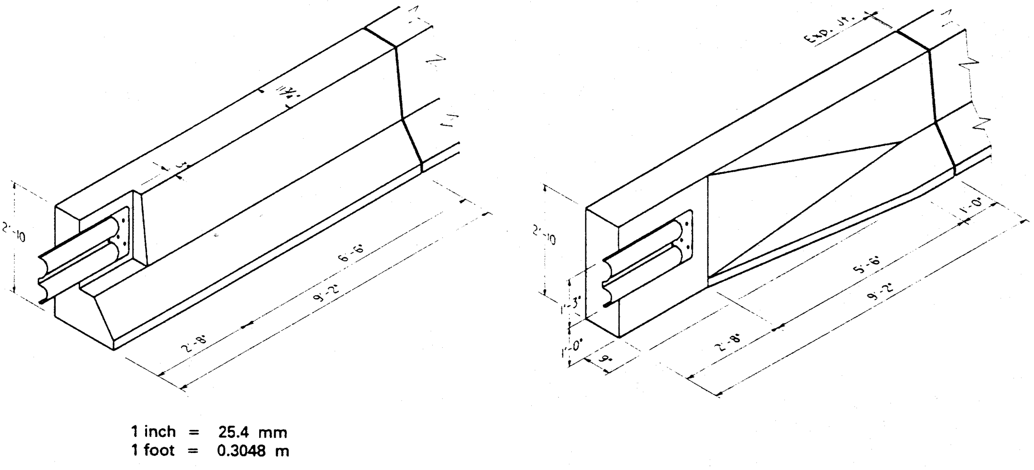
62.2.2 Vehicular Railing

62.2.2.1 Geometry

Bridge railings are primarily provided to contain the vehicles using the bridge, but they are also required to (1) protect the occupants of an errant vehicle in a collision with the railing; (2) protect other vehicles near the collision; (3) protect the people and properties on the roadways or other areas underneath the structure; and (4) have the appearance and freedom of view from passing vehicles.

Figure 62.10 shows four conceptual railing configurations identified in the Guide Specifications. The railing dimensions and the magnitude of design loads to be applied at the points of load application are given in Table 62.8. All three standard performance levels and two optional performance levels are represented in Figure 62.10. Railings for each performance level can be constructed from this figure by assuming that railing elements for which no dimension is given in Table 62.8 do not exist.

The dimensions and configurations shown for these railings are designed to provide a smooth and continuous surface for the traffic side of the railings. The geometry of the rail system should



(a) (b)

FIGURE 62.11 Guide rail attachment at end of bridge.

be such as to preclude any potential contact with the posts by major vehicle parts, should there be a penetration or opening through the railing. The Guide Specifications requires a minimum of 10 in. (254 mm) between the face of the railing and the face of the posts, where snagging is an obvious possibility.

At bridge ends where an open-face railing (guide rail) meets the bridge parapet or barrier, a transition is normally required to provide a smooth flow of traffic while eliminating any snag potential. The Guide Specifications requires that the close face railing (a parapet or a barrier) be flared a maximum of 3.5 longitudinal to one lateral, starting a minimum of 10 in. (254 mm) back of the open-face railing (a guide rail).

Figure 62.11 represents the standard details used in New Jersey for the attachment of guide rails to concrete barriers. These details can be applied at the ends of a parallel wingwall, the ends of a pylon created to provide the transition from guide rail to barrier, or at the ends of a bridge parapet where the thermal movements of the bridge can be accommodated by slotted holes in the guide rail, i.e., small movements.

Where posts are used in a bridge traffic railing, post spacing should not exceed 10 ft 0 in. (3.05 m).

The height of traffic railing is measured from the top of the highest rail or parapet to the top of the roadway, the top of the future overlay, or the top of a raised sidewalk. A raised sidewalk can be defined as a raised roadway curb located along the edge of the bridge, sufficiently wide to accommodate passage of two pedestrians shoulder to shoulder. While 4 ft (1.219 m) is the nominal minimum width, the Guide Specifications allows an absolute minimum width of 3 ft 6 in. (1.067 m).

In the past, safetywalks were used as a means of providing access for infrequent pedestrians or maintenance personnel along a long bridge where a sidewalk could not be justified. These safetywalks, varying in width from 1 ft 6 in. to 3 ft (457 mm to 914 mm), are no longer used since they do not provide sufficient protection for the pedestrians and traffic. Raised curbs supporting a railing, however, are still in use. These curbs generally have a horizontal projection of 9 in. (229 mm) or less from the railing face.

The minimum height of traffic railings or the traffic portion of combination railings is 2 ft 3 in. (686 mm). Where a parapet has a sloping face, intended to allow redirecting of vehicles back to the roadway, the minimum height allowed by the Standard Specifications is 2 ft 8 in. (813 mm). The Guide Specifications, however, lists a 2 ft 3-in. (686-mm) minimum dimension for the same height for Performance Level 1 (see Table 62.8).

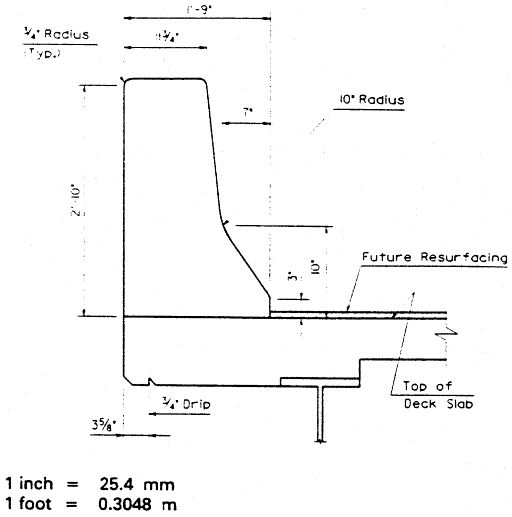


FIGURE 62.12 Standard New Jersey barrier bridge parapet to be used where there is no walkway on the bridge.

PL = Performance Level.Where kips are indicated values in () indicate metric equivalent in kilonewtons; where inches are indicated values in () indicate metric equivalent in millimeters.

The minimum height of a traffic barrier in some states exceeds the AASHTO requirements. For instance, in New Jersey, where the barrier is along the edge of the bridge, the minimum height is 2 ft 10 in. (864 mm), as shown in Figure 62.12. Where the barrier is used to separate pedestrians from highway traffic, the minimum height is 2 ft 8 in. (813 mm).

In a combination railing where the lower element is a parapet, or in a traffic railing, the height of the lower element should be no less than 1 ft 6 in. (457 mm). If a rail is the lower element, its height, measured from its center to reference surface, should be between 15 and 20 in. (381 and 508 mm).

The Guide Specifications requires that the clear distance between the bottom rail and the reference surface be no less than 10 in. (254 mm). The maximum clearance for the same dimension is given as 17 in. (432 mm) by the Standard Specifications. The maximum distance between adjacent rails should not exceed 15 in. (381 mm). Additionally, the traffic face of all rails should be within 1 in. (25 mm) of a vertical plane through the traffic face of the rail closest to traffic.

Thermal movements of the rails are normally provided for by the use of joints in sleeves in the rails. For short-length bridges these joints can be located anywhere along the bridge length. But for long-span bridges, where thermal movements are expected to exceed 2 to 3 in. (51 to 76 mm), it is prudent to place the splices at the expansion joint locations. To eliminate snag potential at these joints, sleeves for pipes (or steel hoods for concrete parapets) must be provided. The projection or depression of the rails at rail joints or steel hoods should not have a depth (thickness) greater than the rail wall thickness or ⅜ in. (10 mm), whichever is less.

62.2.2.3 Loads

Method 1 — Guide Specifications

The Guide Specifications provides criteria for the selection of performance levels of various sites based on the ADT, design speed, percent truck use, bridge rail offset from traffic, and the type of highway under consideration. Upon the selection of the performance level, Table 62.8 can be used to determine the magnitude of loads to be applied to the railing at locations shown in Figure 62.11. While the performance levels PL-1, PL-2, and PL-3 represent small automobiles, pickup trucks, medium-size single unit trucks, and van-type tractor-trailers, the optional performance levels PL-4 and PL-4T are used where heavier and larger trucks at higher volumes are likely to use the roadway. The optional level PL-4 is given for 54 in. (1.372 m) high and higher railings, and where truck volumes and truck type, size, and weight would be greater than PL-3. The optimal level, PL-4T, represents railings that have a minimum height of 6 ft 6 in. (1.981 m), and where truck volumes and highway alignment and use would justify such high railings, e.g., closed face barrier curbs over electrified tracks in high-speed, high-volume curved alignments.

The loads to be applied at the lowest level of the railing, F_{BWH}, F_{BWL}, and F_{BWW}, represent the impact loads of the body and wheels of an errant vehicle; they are given under Group 1 Loads for all five performance levels. The loads to be applied at the midrail of the railing, F_{FH}, F_{FL}, and F_{FV}, represent the impact loads of a trailer floor; they are given under Group II for optional performance levels PL-4 and PL-4T. The loads to be applied at the top level of performance level PL-T4, representing the potential impact of a tank trailer, are given under Group III Loading. While all three loads in each group should be applied simultaneously, and distributed over the designated area, only one group of loading should be applied at a time. All three loads in each group should be distributed evenly over the loaded areas. Dimensions of the load areas over which the forces for each loading category must be evenly distributed are given in Table 62.8.

Where the railing width is less than the related load area, the entire load should be distributed over the available width. Where a load area bears on more than one rail, the load applied to each rail should be prorated based on the distance from each rail to the reference surface. It is to be noted that Load F_{BWH} must be applied over a range of heights as shown in Table 62.8.

The loads on posts are transmitted through the longitudinal rail elements. These loads are to be distributed to no more than three posts.

As stated previously, the loading criteria outlined above are to be used for the design of prototype railings that are to be crash tested and for the design of one-of-a-kind railings where the cost of crash testing cannot be justified. Otherwise, the best way to ensure suitability of a particular railing for a given site is to subject it to applicable crash tests and evaluate the results in accordance with the performance criteria for a desired performance level. The crash test procedures are described in the NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features [9]. The criteria for evaluation of crash test results and the procedure for the selection of performance levels are provided in the *Guide Specifications for Bridge Railings.*

Since performance level selection is based on the assumption that a railing will be near its ultimate strength when subjected to its specific maximum containment load, it is recommended that ultimate strength approach be used in the analysis and design of the railings, posts, and supporting deck slab.

Where a railing is selected and successfully crash tested in accordance with the provisions of the Guide Specifications and NCHRP 350, it does not need to meet the requirements of AASHTO Standard Specifications, as described below.

Method 2 — Standard Specifications

The nominal transverse load $P = 10$ kips (44.5 kN) is to be applied and distributed as shown in Figure 62.13.

- Where the height of the top traffic rail exceeds 2 ft 9 in. (838 mm), the rail and the post is to be designed for a transverse load of CP, where

$$C = 1 + \frac{h-33}{18} > 1 \left(C = \frac{h-381}{457.2} \right)$$

  and h = height of top rail from reference surface in inches (millimeters). However, the maximum load applied to any element is not to exceed P.
- Where the rail face is more than 1 in. (25.4 mm) behind a vertical plane through the face of traffic rail closest to traffic, or where the rail center is less than 1 ft 3 in. (38 mm) from the reference surface, the rail should be designed for a $P/2$ or what is applied to an adjacent traffic rail, whichever is less.

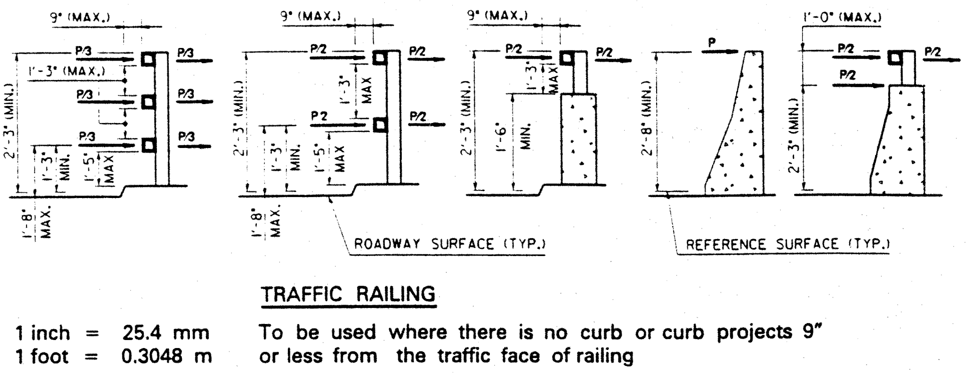


FIGURE 62.13 Traffic railing to be used where there is no curb or curb projects 9 ft or less from the traffic face of the railing. (*Source*: AASHTO, *Standard Specifications for Highway Bridges,* 16th ed., American Association of State Highway and Transportation Officials, Washington, D.C., 1996. With permission.)

- The posts are to be designed for P or CP, as shown in Figure 62.13. Simultaneous with the transverse loads a longitudinal load equal to $P/2$ or $CP/2$ is to be applied, divided among a maximum of four posts, assuming that railing is continuous. Also, posts are to be designed for an inward load, equal to ¼ of the outward loads.
- The rail attachment to the post is to be designed for a vertical load of ¼ of transverse loading, to be applied either upward or downward. This attachment should be also designed for an inward load of ¼ of transverse load.
- The rail members are to be designed for a moment of $P'L/6$, at the center of the panel and at the posts, where L is the post spacing and P' is P, $P/2$, or $P/3$, as modified by the factor C, where required. The handrail members of combination railings are to be designed for a moment of $0.1\ wL^2$ at the center and at the posts, where w is the pedestrian loading per unit length of rail; $w = 50$ lb/ft (729 N/m).

Where a concrete parapet or barrier curb is used, the transverse load of P or CP should be spread over a 5-ft (1.5-m) length of the parapet. Since AASHTO does not specify the location of load application it can be construed that even where the parapet/barrier curb ends the 5-ft (1.5-m) distribution length applies.

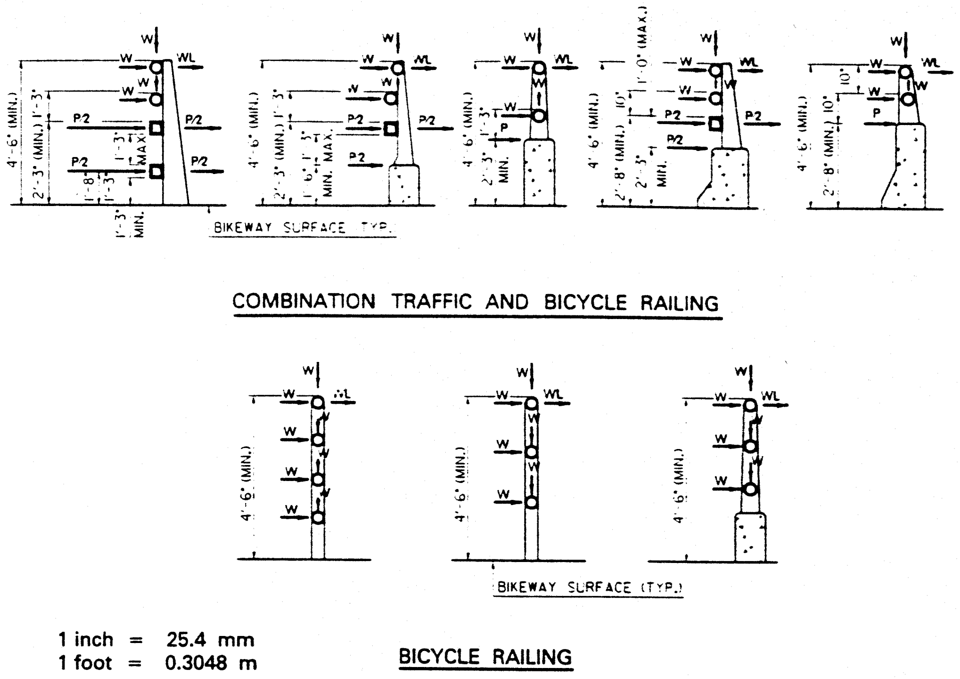
Where possible, bridge railings should preferably provide continuity for moment and shear throughout their length. To meet this goal, continuity transfer splices and expansion devices (capable of handling moments) and end anchorages (for transferring shear) must be provided for beam-and-post railings. Providing continuity transfer sleeves for concrete parapets may be more difficult because of the frequency of transverse joints in the parapets. These joints are normally provided at 10 to 20 ft (3 to 6 m) intervals to arrest potential temperature and shrinkage cracks that may otherwise develop, and to prevent parapet participation in the composite behavior of the fascia girders.

In designing the deck slab and distributing the loads from the posts to the deck slab, it is highly desirable to design the deck slab such that it would not sustain any damage due to a potential destruction of the post. This may be accomplished by providing additional reinforcement in the deck slab in order to distribute the concentrated loads from the posts over a larger area of the deck slab.

62.2.3 Bicycle Railing

62.2.3.1 Geometry

Bicycle railings are provided along the edges of the structure to contain the bicyclist where bicycle use is anticipated. Such railings are to be designed to provide safety while meeting the aesthetic



NOTES:

Loads on left are applied to rails
Loads on right are applied to posts
W = Pedestrian loading per unit length of rail
L = Post Spacing

FIGURE 62.14 Bicycle railings. (*Source*: AASHTO, *Standard Specifications for Highway Bridges,* 16th ed., American Association of State Highway and Transportation Officials, Washington, D.C., 1996. With permission.)

requirements of the bridge owner. Where it is used in conjunction with vehicular traffic, freedom of view from passing vehicles is to be maintained.

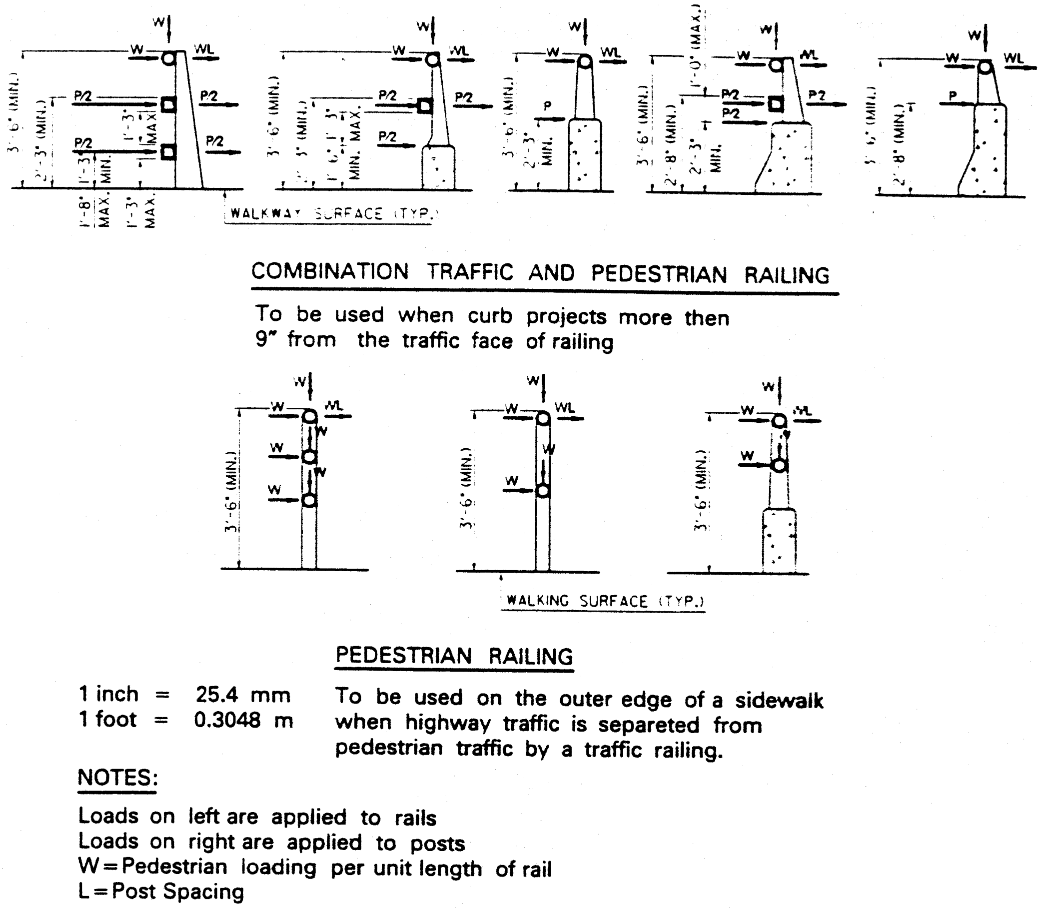
As shown in Figure 62.14, the minimum height of a bicycle railing is 4 ft 6 in. (1372 mm), measured from the top of the riding surface to the top of the top rail.

The Standard Specifications requires that from the bikeway surface to 2 ft 3 in. (686 mm) above it, all railing elements be spaced such that a 6-in. (152-mm) sphere cannot pass through the railing. From 2 ft 3 in. to 4 ft 6 in. (686 to 1372 mm) from the bikeway surface an 8-in. (203 mm) sphere should not be able to pass through the railing. Where the railing is made up of horizontal and vertical elements, the spacing requirements apply to one or the other, but not to both.

The Guide Specifications requires that from the bikeway surface to 4 ft 6 in. (1372 mm) above it, horizontal elements of the railing have a clear spacing of 1 ft 3 in. (381 mm) and vertical elements a clear spacing of 8 in. (203 mm). Where the railing has both horizontal and vertical elements, the spacing requirements will apply to one or the other, but not to both.

62.2.3.2 Loads

As shown on Figure 62.14, the horizontal elements (rails) in a bicycle railing are to be designed for a minimum design loading of $w = 50$ lb/ft (729 N/m) acting laterally and vertically at the same time. The vertical elements (posts) should be designed for wL (where L is the post spacing) acting at the center of the upper rail, but at a height not greater than 4 ft 6 in. (1372 mm). Where a rail is located more than this limit, the design load will be determined by the designer.



COMBINATION TRAFFIC AND PEDESTRIAN RAILING

To be used when curb projects more then 9" from the traffic face of railing

PEDESTRIAN RAILING

To be used on the outer edge of a sidewalk when highway traffic is separeted from pedestrian traffic by a traffic railing.

1 inch = 25.4 mm
1 foot = 0.3048 m

NOTES:

Loads on left are applied to rails
Loads on right are applied to posts
W = Pedestrian loading per unit length of rail
L = Post Spacing

FIGURE 62.15 Pedestrian railings. (*Source*: AASHTO, *Standard Specification for Highway Bridges*, 16th ed., American Association of State Highway and Transportation Officials, Washington, D.C., 1996. With permission).

Where vehicular traffic and bicycles are contained by a single combination railing, the Standard Specifications provides the geometry and loading requirements for five railing options, as reproduced in Figure 62.14.

62.2.4 Pedestrian Railing

62.2.4.1 Geometry

Pedestrian railings are provided along the outer edge of a sidewalk to contain pedestrians. Where the sidewalk is not raised, a traffic railing (a concrete barrier or a guide rail) must separate the pedestrians from highway traffic. In an urban setting, where there is a raised sidewalk, a combination traffic and pedestrian railing, along the outer edge of the sidewalk will be required. Such railings will be designed to provide safety while meeting the aesthetic requirements of the bridge owner. Consideration should also be given to freedom of view from passing vehicles.

As shown in Figure 62.15, the minimum height of a pedestrian or a combination railing is to be 3 ft 6 in. (1067 mm), measured from the top of the walkway to the top of the upper rail.

The Standard Specifications requires that, from the walkway surface to 27 in. (686 mm) above it, all railing elements be spaced such that a 6-in. (152 mm) sphere cannot pass through any opening in the railing. From 2 ft 3 in. to3 ft 6 in. (686 to 1067 mm) from the walkway surface, an 8-in. (203-mm) sphere should not be able to pass through the railing.

The Guide Specifications requires that, within the 3 ft 6-in. (1067 mm) height of the railing, the horizontal elements have a maximum clear spacing of 1 ft 3 in. (381 mm) while the vertical elements have a maximum clear spacing of 8 in. (203 mm). Where the railing has both horizontal and vertical elements, the spacing requirements will apply to one or the other, but not to both.

62.2.4.2 Loads

As shown on Figure 62.15, the horizontal elements (rails) in a pedestrian railing are to be designed for a minimum design loading of $w = 50$ lb/ft (729 N/m), acting laterally and vertically at the same time. Rail members located more than 5 ft (1.524 m) above the walkway are excluded from this requirement. The vertical elements (posts) are to be designed for wL (where L is the post spacing) acting at the center of the upper rail.

Where combination traffic and pedestrian railing is to be provided, the geometry and the loads may be obtained from one of the five options shown in the Standard Specifications and reproduced in Figure 62.15.

62.2.5 Structural Specifications and Guidelines for Bicycle and Pedestrian Railings

Bicycle and pedestrian railings are to be designed by the elastic method to the allowable stresses for the appropriate material. The following requirements are those specified in the AASHTO Standard Specifications, used by permission.

For aluminum alloys the design stresses given in the *Specifications for Aluminum Structures* 5th ed., December 1986, published by the Aluminum Association, Inc., for "Bridge and Similar Type Structures" apply. For alloys 6061-T6 (Table A.6), 6351-T5 (Table A.6), and 6063-T6 (Table A.8) apply, and for cast aluminum alloys the design stresses given for alloys A444.0-T4 (Table A.9), A356.0-T61 (Table A.9), and A356.0-T6 (Table A.9) apply.

For fabrication and welding of aluminum railing see Article 11.5 of the AASHTO *Standard Specifications for Highway Bridges.*

The allowable unit stresses for steel are as given in Article 10.32 of the AASHTO Standard Specifications, except as modified below.

For steels not generally covered by the Standard Specifications but having a guaranteed yield strength, F_y, the allowable unit stress, is derived by applying the general formulas as given in the Standard Specifications under "Unit Stresses" except as indicated below.

The allowable unit stress for shear is $F_v = 0.33\ F_y$.

Round or oval steel tubes may be proportioned using an allowable bending stress, $F_b = 0.66\ F_y$, provided the R/t ratio (radius/thickness) is less than or equal to 40.

Square and rectangular steel tubes and steel W and I sections in bending with tension and compression on extreme fibers of laterally supported compact sections having an axis of symmetry in the plane of loading may be designed for an allowable stress $F_b = 0.60\ F_y$.

The requirements for a compact section are as follows:

In the above formulas b, t, and | are in inches (millimeters) and f_a, F_a, and F_y are in psi (Mpa).

	English Units	S.I Units	
1. The width-to-thickness ratio of projecting elements of the compression flange of W and I sections not to exceed:	$\frac{b}{t} \le \frac{1600}{\sqrt{F_y}}$	$\left(\frac{b}{t} \le \frac{133}{\sqrt{Fy}}\right)$	(62.3)
2. The width-to-thickness ratio of the compression flange of square or rectangular tubes is not to exceed:	$\frac{b}{t} \le \frac{6000}{\sqrt{F_y}}$	$\left(\frac{b}{t} \le \frac{499}{\sqrt{Fy}}\right)$	(62.4)
3. The *D/t* ratio of webs is not to exceed:	$\frac{D}{t} \le \frac{13{,}300}{\sqrt{F_y}}$	$\left(\frac{D}{t} \le \frac{1106}{\sqrt{Fy}}\right)$	(62.5)
4. If subject to combined axial force and bending, the *D/t* ratio of webs is not to exceed:	$\frac{D}{t} < \frac{13{,}300\left[1-1.43\left(\frac{f_a}{F_a}\right)\right]}{\sqrt{F_y}}$	$\left(\frac{1106\left[1-1.43\,\frac{fa}{Fa}\right]}{\sqrt{Fy}}\right)$	(62.6)
but need not be less than:	$\frac{D}{t} < \frac{7000}{\sqrt{F_y}}$	$\left(\frac{D}{t} < \frac{581}{\sqrt{F_y}}\right)$	(62.7)
5. The distance between lateral supports in inches of W or I sections is not to exceed:	$l \le \frac{2400b}{\sqrt{F_y}}$	$\left(\le \frac{199.26}{\sqrt{F_y}}\right)$	(62.8)
or:	$l \le \frac{20{,}000{,}000\,A_f}{dF_y}$	$\left(l \le \frac{137{,}640\,A_f}{dF_y}\right)$	(62.9)

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