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SECTION 13

RAILINGS

13.1—SCOPE

This Section applies to railings for new bridges and for rehabilitated bridges to the extent that railing replacement is determined to be appropriate.

This Section provides six bridge railing test levels and their associated crash test requirements. Guidance for determining the level to meet the warrants for the more common types of bridge sites and guidance for structural and geometric design of railings are provided.

A process for the design of crash test specimens to determine their crashworthiness is described in Appendix A13. This methodology is based on an application of the yield line theory. For use beyond the design of test specimens with expected failure modes similar to those shown in Figures CA13.3.1-1 and CA13.3.1-2, a rigorous yield line solution or a finite element solution should be developed. The procedures of Appendix A13 are not applicable to traffic railings mounted on rigid structures, such as retaining walls or spread footings, when the cracking pattern is expected to extend to the supporting components.

C13.1

All bridge traffic barrier systems will be referred to as railings herein.

The bridge railing performance need not be identical over the whole highway network. New railing designs should match site needs leading to a multiple test level concept, as described in NCHRP Report 350 or AASHTO's *Manual for Assessing Safety Hardware* (MASH).

All highway safety hardware accepted prior to the adoption of MASH, using criteria contained in NCHRP Report 350, may remain in place and may continue to be manufactured and installed. Highway safety hardware accepted using NCHRP Report 350 criteria is not required to be retested using MASH criteria. New highway safety hardware not previously evaluated must utilize MASH for testing and evaluation.

With the finite resources available to bridge owners, it is not reasonable to expect all existing rails to be updated any more than to expect every existing building to be immediately updated with the passing of a new building code. Many existing bridge rails have proven functional and need only be replaced when removed for bridge widenings.

13.2—DEFINITIONS

Agency—A responsible business or service authorized to act on behalf of others, e.g., a governmental department, consulting engineering firm, or owner of the facility or feature.

Barrier Curb—A platform or block used to separate a raised sidewalk for pedestrians, bicycles, or both above the roadway level; see Figure 13.7.1.1-1.

Bicycle Railing—A railing or fencing system, as illustrated in Figure 13.9.3-1, that provides a physical guide for bicyclists crossing bridges to minimize the likelihood of a bicyclist falling over the system.

Bridge Approach Railing—A roadside guardrail system preceding the structure and attached to the bridge rail system that is intended to prevent a vehicle from impacting the end of the bridge railing or parapet.

Combination Railing—A bicycle or pedestrian railing system, as illustrated in Figures 13.8.2-1 and 13.9.3-1, added to a crashworthy bridge vehicular railing or barrier system.

Concrete Barrier—A railing system of reinforced concrete having a traffic face that usually but not always adopts some form of a safety shape.

Concrete Parapet—A railing system of reinforced concrete, usually considered an adequately reinforced concrete wall.

Crash Testing of Bridge Railings—Conducting a series of full-scale impact tests of a bridge railing in accordance with the recommended guidelines in NCHRP Report 350 or AASHTO's *Manual for Assessing Safety Hardware* in order to evaluate the railing's strength and safety performance.

Crashworthy—A 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.

Design Force—An equivalent static force that represents the dynamic force imparted to a railing system by a specified vehicle impacting a railing at a designated speed and angle.

Encroachment—An intrusion into prescribed, restrictive, or limited areas of a highway system, such as crossing a traffic lane or impacting a barrier system. Also, the occupancy of highway right-of-way by nonhighway structures or objects of any kind or character.

End Zone—The area adjacent to any open joint in a concrete railing system that requires added reinforcement.

Expressway—A controlled access arterial highway that may or may not be divided or have grade separations at intersections.

Face of the Curb—The vertical or sloping surface on the roadway side of the curb.

Freeway—A controlled access divided arterial highway with grade separations at intersections.

Longitudinal Loads—Horizontal design forces that are applied parallel to the railing or barrier system and that result from friction on the transverse loads.

Multiple-Use Railing—Railing that may be used either with or without a raised sidewalk.

Owner—An authority or governmental department representing investors and/or taxpayers that is responsible for all the safety design features and functions of a bridge.

Pedestrian Railing—A railing or fencing system, as illustrated in Figure 13.8.2-1, providing physical guidance for pedestrians across a bridge so as to minimize the likelihood of a pedestrian falling over the system.

Post—A vertical or sloping support member of a rail system that anchors a railing element to the deck.

Rail Element—Any component that makes up a railing system. It usually pertains to a longitudinal member of the railing.

Severity—A characterization of the degree of an event. It is usually associated with characterizing accidents as fatal, injury, or property damage only so that a dollar value can be assessed for economic study. It may also pertain to indexing the intensity of an accident so that a railing system can be assessed as a preventive or safety measure.

Speeds—Low/High—Vehicle velocities in mph. Low speeds are usually associated with city or rural travel where posted speeds do not exceed 45 mph. High speeds are usually associated with expressways or freeways where posted speeds are in excess of 45 mph.

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.

Transverse Loads—Horizontal design forces that are applied perpendicular to a railing or barrier system.

Vehicle Rollover—A term used to describe an accident in which a vehicle rotates at least 90° about its longitudinal axis after contacting a railing. This term is used if the vehicle rolls over as a result of contacting a barrier and not another vehicle.

Warrants—A document that provides guidance to the Designer in evaluating the potential safety and operational benefits of traffic control devices or features. Warrants are not absolute requirements; rather, they are a means of conveying concern over a potential traffic hazard.

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13.3—NOTATION

A_f	=	area of post compression flange (in.^{2}) (A13.4.3.2)
B	=	out-to-out wheel spacing on an axle (ft); distance between centroids of tensile and compressive stress resultants in post (in.) (A13.2) (A13.4.3.2)
b	=	length of deck resisting post strength or shear load (ft) (A13.4.3.1)
C	=	vertical post capacity or compression flange resistance of post in bending (kip-ft) (CA13.4.3.2)
d_b	=	distance from the outer edge of the base plate to the innermost row of bolts (in.) (A13.4.3.1)
E	=	distance from edge of slab to centroid of compressive stress resultant in post (in.) (A13.4.3.2)
F_L	=	longitudinal friction force along rail = 0.33 F_t (kips) (A13.2)
F_t	=	transverse vehicle impact force distributed over a length L_t at a height H_e above bridge deck (kips) (A13.2)
F_v	=	vertical force of vehicle laying on top of rail (kips) (A13.2)
F_y	=	yield strength of post-compression flange (ksi) (A13.4.3.2)
f'_c	=	28-day compressive strength of concrete (ksi) (A13.4.3.2)
G	=	height of vehicle center of gravity above bridge deck (in.) (A13.2)
H	=	height of wall (ft) (A13.3.1)
H_R	=	height of rail (ft) (A13.3.3)
H_w	=	height of wall (ft) (A13.3.3)
h	=	depth of slab (in.) (A13.4.3.2)
L	=	post spacing of single span (ft) (A13.3.2)
L_c	=	critical length of wall failure (ft) (A13.3.1)
L_L	=	longitudinal length of distribution of friction force F_L, $L_L = L_t$ (ft) (A13.2)
L_t	=	longitudinal length of distribution of impact force F_t along the railing located a height of the H_e above the deck (ft) (A13.2)
L_v	=	longitudinal distribution of vertical force F_v on top of railing (ft) (A13.2)
ℓ	=	length of vehicle impact load on railing or barrier taken as L_t, L_v, or L_L, as appropriate (ft) (A13.3.1)
M_b	=	ultimate moment capacity of beam at top of wall (kip-ft) (A13.3.1)
M_c	=	ultimate flexural resistance of wall about horizontal axis (kip-ft/ft) (A13.3.1)
M_d	=	deck overhang moment (kip-ft/ft) (A13.4.3.1)
M_p	=	plastic or yield line resistance of rail (kip-ft) (A13.3.2)
M_{post}	=	plastic moment resistance of a single post (kip-ft) (A13.3.2)
M_w	=	ultimate flexural resistance of wall about vertical axis (kip-ft) (A13.3.1)
P_p	=	shear force on a single post which corresponds to M_{post} and is located $\bar{Y}$ above the deck (kips) (A13.3.2)
R	=	total ultimate resistance, i.e., nominal resistance, of the railing (kips) (A13.3.2)
R_R	=	ultimate capacity of rail over one span (kips) (A13.3.3)
R'_R	=	ultimate transverse resistance of rail over two spans (kips) (A13.3.3)
R_w	=	total transverse resistance of the railing (kips); ultimate capacity of wall as specified in Article A13.3.1 (kips) (A13.3.1) (A13.3.3)
R'_w	=	capacity of wall, reduced to resist post load (kips) (A13.3.3)
$\bar{R}$	=	sum of horizontal components of rail strengths (kips) (A13.2)
T	=	tensile force per unit of deck length (kip/ft) (A13.4.2)
v_c	=	nominal shear resistance provided by tensile stresses in the concrete (ksi) (A13.4.3.2)
V_n	=	nominal shear resistance of the section considered (kips) (A13.4.3.2)
V_r	=	factored shear resistance (kips) (A13.4.3.2)
V_u	=	factored shear force at section (kips) (A13.4.3.2)
W	=	weight of vehicle corresponding to the required test level, from Table 13.7.2-1 (kips) (13.7.2)
W_b	=	width of base plate (in.) (A13.4.3.1)
X	=	length of overhang from face of support to exterior girder or web (ft) (A13.4.3.1)
$\bar{Y}$	=	height of $\bar{R}$ above bridge deck (in.) (A13.2)
β_c	=	ratio of the long side to the short side of the concentrated load or reaction area (A13.4.3.2)
ϕ	=	resistance factor = 1.0 (A13.4.3.2)

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13.4—GENERAL

The owner shall develop the warrants for the bridge site. A bridge railing should be chosen to satisfy the concerns of the warrants as completely as possible and practical.

Railings shall be provided along the edges of structures for protection of traffic and pedestrians. Other applications may be warranted on bridge-length culverts.

A pedestrian walkway may be separated from an adjacent roadway by a barrier curb, traffic railing, or combination railing, as indicated in Figure 13.4-1. On high-speed urban expressways where a pedestrian walkway is provided, the walkway area shall be separated from the adjacent roadway by a traffic railing or combination railing.

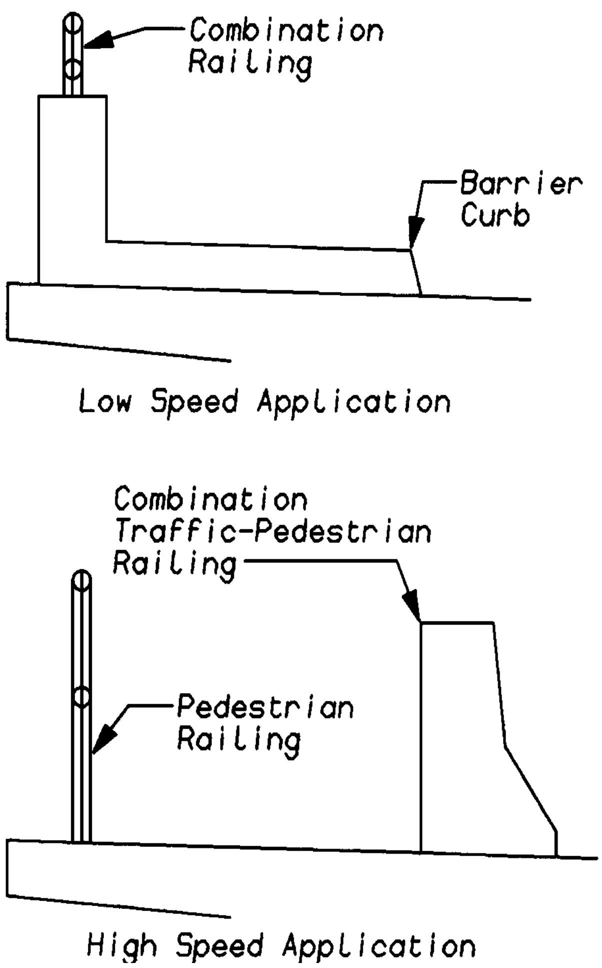

Figure 13.4-1—Pedestrian Walkway

New bridge railings and the attachment to the deck overhang shall satisfy crash testing requirements to confirm that they meet the structural and geometric requirements of a specified railing test level using the test criteria specified in Article 13.7.2.

C13.4

Additional guidance applicable to bridge-length culverts may be found in the AASHTO *Roadside Design Guide*.

The following guidelines indicate the application of various types of rails:

- Traffic railing is used when a bridge is for the exclusive use of highway traffic;
- A combination barrier in conjunction with a raised curb and sidewalk is used only on low-speed highways;
- On high-speed highways, the pedestrian or bicycle path should have both an outboard pedestrian or bicycle railing and an inboard combination railing; and
- Separate pedestrian bridges should be considered where the amount of pedestrian traffic or other risk factors so indicate.

For the purpose of this Article, low speed may be taken as speeds up to and including 45 mph. High speed may be taken as speeds in excess of 45 mph.

The walkway faces of combination railings separating walkways from adjacent roadways serve as pedestrian or bicycle railings. When the height of such railings above the walkway surface is less than the minimum height required for pedestrian or bicycle railings, as appropriate, the Designer may consider providing additional components, such as metal rails, on top of the combination railing. The additional components need to be designed for the appropriate pedestrian or bicycle railing design forces.

Warning devices for pedestrians are beyond the scope of these Specifications, but they should be considered.

Procedures for testing railings are given in MASH.

13.5—MATERIALS

The requirements of Sections 5, 6, 7, and 8 shall apply to the materials employed in a railing system, unless otherwise modified herein.

C13.5

Factors to be considered in choosing the material for use in any railing system include ultimate strength, durability, ductility, maintenance, ease of replacement, and long-term behavior.

13.6—LIMIT STATES AND RESISTANCE FACTORS

13.6.1—Strength Limit State

The strength limit states shall apply using the applicable load combinations in Table 3.4.1-1 and the loads specified herein. The resistance factors for post and railing components shall be as specified in Articles 5.5.4, 6.5.4, 7.5.4, and 8.5.2.

Design loads for pedestrian railings shall be as specified in Article 13.8.2. Design loads for bicycle railings shall be as specified in Article 13.9.3. Pedestrian or bicycle loadings shall be applied to combination railings as specified in Article 13.10.3. Deck overhangs shall be designed for applicable strength load combinations specified in Table 3.4.1-1.

13.6.2—Extreme Event Limit State

The forces to be transmitted from the bridge railing to the bridge deck may be determined from an ultimate strength analysis of the railing system using the loads given in Appendix A13. Those forces shall be considered to be the factored loads at the extreme event limit state.

13.7—TRAFFIC RAILINGS

13.7.1—Railing System

13.7.1.1—General

The primary purpose of traffic railings shall be to contain and redirect vehicles using the structure. All new vehicle traffic barrier systems, traffic railings, and combination railings shall be shown to be structurally and geometrically crashworthy.

Consideration should be given to:

- Protection of the occupants of a vehicle in collision with the railing,
- Protection of other vehicles near the collision,
- Protection of persons and property on roadways and other areas underneath the structure,
- Possible future rail upgrading,
- Railing cost-effectiveness, and
- Appearance and freedom of view from passing vehicles.

A combination railing, conforming to the dimensions given in Figures 13.8.2-1 and 13.9.3-1, and crash tested

C13.7.1.1

Variations in traffic volume, speed, vehicle mix, roadway alignment, activities, and conditions beneath a structure, and other factors combine to produce a vast variation in traffic railing performance requirements.

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with a sidewalk may be considered acceptable for use with sidewalks having widths 3.5 ft or greater and curb heights up to the height used in the crash test installation.

A railing designed for multiple use shall be shown to be crashworthy with or without the sidewalk. Use of the combination vehicle–pedestrian railing shown in Figure 13.7.1.1-1 shall be restricted to roads designated for 45 mph or less and need to be tested to Test Level 1 or 2.

Because of more recent tests on sidewalks, an 8.0-in. maximum height for sidewalk curbs has generally been accepted.

AASHTO's *A Policy on Geometric Design of Highways and Streets* recommends that a barrier curb be used only for speeds of 45 mph or less. For speeds of 50 mph or greater, pedestrians should be protected by a separation traffic barrier.

A railing intended for use only on a sidewalk need not be tested without the sidewalk.

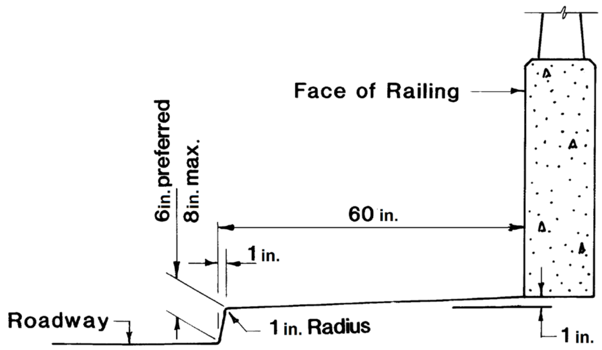

Figure 13.7.1.1-1—Typical Raised Sidewalk

13.7.1.2—Approach Railings

An approach guardrail system should be provided at the beginning of all bridge railings in high-speed rural areas.

A bridge approach railing system should include a transition from the guardrail system to the rigid bridge railing system that is capable of providing lateral resistance to an errant vehicle. The approach guardrail system shall have a crashworthy end terminal at its nosing.

C13.7.1.2

In urban areas or where city streets and/or sidewalks prevent installation of approach guardrail transitions or crashworthy terminals, consideration should be given to:

- Extending the bridge rail or guard rail in a manner that prevents encroachment of a vehicle onto any highway system below the bridge,
- Providing a barrier curb,
- Restricting speed,
- Adding signing of intersections, and
- Providing recovery areas.

A bridge end drainage facility should be an integral part of the barrier transition design.

13.7.1.3—End Treatment

In high-speed rural areas, the approach end of a parapet or railing shall have a crashworthy configuration or be shielded by a crashworthy traffic barrier.

C13.7.1.3

If the approach railing is connected to a side-of-road railing system, it can be continuous with the bridge approach system, and only a transition from a flexible to a rigid railing system is required.

13.7.2—Test Level Selection Criteria

One of the following test levels should be specified:

- TL-1—Test Level One—taken to be generally acceptable for work zones with low posted speeds and very low-volume, low-speed local streets;
- TL-2—Test Level Two—taken to be generally acceptable for work zones and most local and collector roads with favorable site conditions as well as where a small number of heavy vehicles is expected and posted speeds are reduced;
- TL-3—Test Level Three—taken to be generally acceptable for a wide range of high-speed arterial highways with very low mixtures of heavy vehicles and with favorable site conditions;
- TL-4—Test Level Four—taken to be generally acceptable for the majority of applications on high-speed highways, freeways, expressways, and Interstate highways with a mixture of trucks and heavy vehicles;
- TL-5—Test Level Five—taken to be generally acceptable for the same applications as TL-4 and where large trucks make up a significant portion of the average daily traffic or when unfavorable site conditions justify a higher level of rail resistance; and
- TL-6—Test Level Six—taken to be generally acceptable for applications where tanker-type trucks or similar high center of gravity vehicles are anticipated, particularly along with unfavorable site conditions.

It shall be the responsibility of the user agency to determine which of the test levels is most appropriate for the bridge site.

The testing criteria for the chosen test level shall correspond to vehicle weights and speeds and angles of impact outlined in Table 13.7.2-1.

C13.7.2

The six test levels mentioned herein are intended to correspond with the six test levels contained in AASHTO's *Manual for Assessing Safety Hardware* and NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." AASHTO's *A Policy on Geometric Design of Highways and Streets* and its *Roadside Design Guide* are referred to as aides in the bridge railing selection process.

The individual tests are designed to evaluate one or more of the principal performance factors of the bridge railing, which include structural adequacy, occupant risk, and postimpact behavior of the test vehicle. In general, the lower test levels are applicable for evaluating and selecting bridge railings to be used on segments of lower service level roadways and certain types of work zones. The higher test levels are applicable for evaluating and selecting bridge railings to be used on higher service level roadways or at locations that demand a special, high-performance bridge railing. In this regard, TL-4 railings are expected to satisfy the majority of interstate design requirements.

TL-5 provides for a van-type tractor–trailer that will satisfy design requirements where TL-4 railings are deemed to be inadequate due to the high number of this type of vehicle anticipated, or due to unfavorable site conditions where rollover or penetration beyond the railing could result in severe consequences.

TL-6 provides for a tanker-type truck that will satisfy design requirements where this type vehicle with a higher center of gravity has shown a history of rollover or penetration, or unfavorable site conditions may indicate the need for this level of rail resistance.

Unfavorable site conditions include but are not limited to reduced radius of curvature, steep downgrades on curvature, variable cross slopes, and adverse weather conditions.

Agencies should develop objective guidelines for use of bridge railings. These guidelines should take into account factors such as traffic conditions, traffic volume and mix, cost and in-service performance, and life-cycle cost of existing railings.

These criteria, including other vehicle characteristics and tolerances, are described in detail in MASH and NCHRP Report 350.

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Table 13.7.2-1—Bridge Railing Test Levels and Crash Test Criteria

	Vehicle Characteristics	Small Automobiles		Pickup Truck	Single-Unit Van Truck	Van-Type Tractor–Trailer		Tractor–Tanker Trailer
NCHRP Report 350	*W* (kips)	1.55	1.8	4.5	18.0	50.0	80.0	80.0
	B (ft)	5.5	5.5	6.5	7.5	8.0	8.0	8.0
	G (in.)	22	22	27	49	64	73	81
	Crash angle, θ	20°	20°	25°	15°	15°	15°	15°
	Test Level	Test Speeds (mph)						
	TL-1	30	30	30	N/A	N/A	N/A	N/A
	TL-2	45	45	45	N/A	N/A	N/A	N/A
	TL-3	60	60	60	N/A	N/A	N/A	N/A
	TL-4	60	60	60	50	N/A	N/A	N/A
	TL-5	60	60	60	N/A	N/A	50	N/A
	TL-6	60	60	60	N/A	N/A	N/A	50
AASHTO MASH	*W* (kips)	2.42	3.3	5.0	22.0	N/A	79.3	79.3
	B (ft.)	5.5	5.5	6.5	7.5	N/A	8.0	8.0
	G (in.)	N/A	N/A	28	63	N/A	73	81
	Crash angle, θ	25°	N/A	25°	15°	N/A	15°	15°
	Test Level	Test Speeds (mph)						
	TL-1	30	N/A	30	N/A	N/A	N/A	N/A
	TL-2	45	N/A	45	N/A	N/A	N/A	N/A
	TL-3	60	N/A	60	N/A	N/A	N/A	N/A
	TL-4	60	N/A	60	55	N/A	N/A	N/A
	TL-5	60	N/A	60	N/A	N/A	50	N/A
	TL-6	60	N/A	60	N/A	N/A	N/A	50

13.7.3—Railing Design

13.7.3.1—General

A traffic railing should normally provide a smooth, continuous face of rail on the traffic side. Steel posts with rail elements should be set back from the face of the rail. Structural continuity in the rail members and anchorages of ends should be considered.

A railing system and its connection to the deck shall be approved only after they have been shown through crash testing to be satisfactory for the desired test level.

C13.7.3.1

Protrusions or depressions at rail openings may be acceptable, provided that their thickness, depth, or geometry does not prevent the railing from meeting the crash test evaluation criteria.

Test specimens should include a representative length of the overhang to account for the effect of deck flexibility on the distance over which the railing engages the deck.

13.7.3.1.1—Application of Previously Tested Systems

A crashworthy railing system may be used without further analysis and/or testing, provided that the proposed installation does not have features that are absent in the tested configuration and that might detract from the performance of the tested railing system.

C13.7.3.1.1

When a minor detail is changed on or an improvement is made to a railing system that has already been tested and approved, engineering judgment and analysis should be used when determining the need for additional crash testing.

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13.7.3.1.2—New Systems

New railing systems may be used, provided that acceptable performance is demonstrated through full-scale crash tests.

The crash test specimen for a railing system may be designed to resist the applied loads in accordance with Appendix A13.

Provision shall be made to transfer loads from the railing system to the deck. Railing loads may be taken from Appendix A13.

Unless a lesser thickness can be proven satisfactory during the crash testing procedure, the minimum edge thickness for concrete deck overhangs shall be taken as:

- For concrete deck overhangs supporting a deck-mounted post system: 8.0 in.
- For a side-mounted post system: 12.0 in.
- For concrete deck overhangs supporting concrete parapets or barriers: 8.0 in.

C13.7.3.1.2

Preliminary design for bridge decks should comply with Article A13.1.2. A determination of the adequacy of deck reinforcement for the distribution of post anchorage loads to the deck should be made during the rail testing program. If the rail testing program satisfactorily models the bridge deck, damage to the deck edge can be assessed at this time.

In adequately designed bridge deck overhangs, the major crash-related damage presently occurs in short sections of slab areas where the barrier is hit.

13.7.3.2—Height of Traffic Parapet or Railing

Traffic railings shall be at least 27.0 in. for TL-3, 32.0 in. for TL-4, 42.0 in. for TL-5, and 90.0 in. in height for TL-6.

The bottom 3.0-in. lip of the safety shape shall not be increased for future overlay considerations.

The minimum height for a concrete parapet with a vertical face shall be 27.0 in. The height of other combined concrete and metal rails shall not be less than 27.0 in. and shall be determined to be satisfactory through crash testing for the desired test level.

The minimum height of a pedestrian or bicycle railing should be measured above the surface of the sidewalk or bikeway.

The minimum geometric requirements for combination railings beyond those required to meet crash test requirements shall be taken as specified in Articles 13.8, 13.9, and 13.10.

C13.7.3.2

These heights have been determined as satisfactory through crash tests performed in accordance with NCHRP Report 350 and experience.

For future deck overlays, an encroachment of 2.0 in., leaving a 1.0-in. lip, has been satisfactorily tested for safety shapes.

13.8—PEDESTRIAN RAILINGS

13.8.1—Geometry

The minimum height of a pedestrian railing shall be 42.0 in., measured from the top of the walkway.

A pedestrian railing may be composed of horizontal and/or vertical elements. The clear opening between elements shall be such that a 6.0-in. diameter sphere shall not pass through.

When both horizontal and vertical elements are used, the 6.0-in. clear opening shall apply to the lower 27.0 in. of the railing, and the spacing in the upper portion shall be such that an 8.0-in. diameter sphere shall not pass through. A safety toe rail or curb should be provided. Rails should

C13.8.1

project beyond the face of posts, pickets, or both as shown in Figure A13.1.1-2.

The rail spacing requirements given above should not apply to chain link or metal fabric fence support rails and posts. Mesh size in chain link or metal fabric fence should have openings no larger than 2.0 in.

The size of openings should be capable of retaining an average size beverage container.

13.8.2—Design Loads

The design live load for pedestrian railings shall be taken as w = 0.050 klf, both transversely and vertically, acting simultaneously. In addition, each longitudinal element will be designed for a concentrated load of 0.20 kips, which shall act simultaneously with the above loads at any point and in any direction at the top of the longitudinal element.

The posts of pedestrian railings shall be designed for a concentrated design live load applied transversely at the center of gravity of the upper longitudinal element or, for railings with a total height greater than 5.0 ft, at a point 5.0 ft above the top surface of the sidewalk. The value of the concentrated design live load for posts, P_{LL}, in kips, shall be taken as:

$$P_{LL} = 0.20 + 0.050L \quad (13.8.2\text{-}1)$$

where:

L = post spacing (ft)

The application of loads shall be as indicated in Figure 13.8.2-1, in which the shapes of rail members are illustrative only. Any material or combination of materials specified in Article 13.5 may be used.

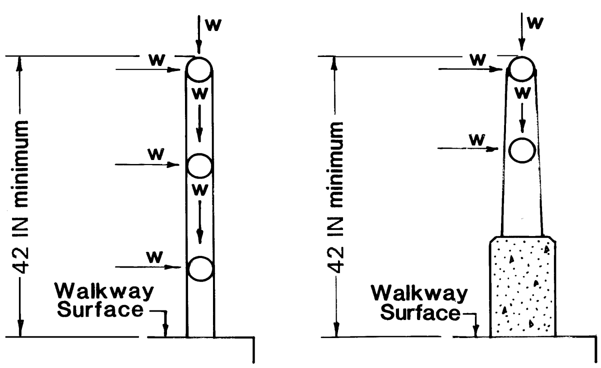

Figure 13.8.2-1—Pedestrian Railing Loads—To be used on the outer edge of a sidewalk when highway traffic is separated from pedestrian traffic by a traffic railing. Railing shape illustrative only.

The design wind load for chain link or metal fabric fence shall be taken as 0.015 ksf acting normal to the entire surface. The wind load need not be applied simultaneously with live load.

C13.8.2

These live loads apply to the railing. The pedestrian live load, specified in Article 3.6.1.6, applies to the sidewalk.

13.9—BICYCLE RAILINGS

13.9.1—General

Bicycle railings shall be used on bridges specifically designed to carry bicycle traffic and on bridges where specific protection of bicyclists is deemed necessary.

13.9.2—Geometry

The height of a bicycle railing shall not be less than 42.0 in., measured from the top of the riding surface.

Bicycle railings shall have rail spacing satisfying the respective provisions of Article 13.8.1.

If deemed necessary, rubrails attached to the rail or fence to prevent snagging should be deep enough to protect a wide range of bicycle handlebar heights.

If screening, fencing, or a solid face is utilized, the number of rails may be reduced.

C13.9.2

Railings, fences, or barriers on either side of a shared use path on a structure, or along bicycle lane, shared use path or signed shared roadway located on a highway bridge should be a minimum of 42.0 in. high. The 42.0-in. minimum height is in accordance with the *AASHTO Guide for the Development of Bicycle Facilities*.

On a bridge or bridge approach where high-speed, high-angle impacts with a railing, fence, or barrier are more likely to occur (such as short-radius curves with restricted sight distance, or at the end of a long descending grade) or in locations with site-specific safety concerns, a railing, fence, or barrier height above the minimum should be considered.

The need for rubrails attached to a rail or fence is controversial among many bicyclists.

13.9.3—Design Live Loads

If the rail height exceeds 54.0 in. above the riding surface, design loads shall be determined by the Designer. The design loads for the lower 54.0 in. of the bicycle railing shall not be less than those specified in Article 13.8.2, except that for railings with total height greater than 54.0 in., the design live load for posts shall be applied at a point 54.0 in. above the riding surface.

The application of loads shall be as indicated in Figure 13.9.3-1. Any material or combination of materials specified in Article 13.5 may be used.

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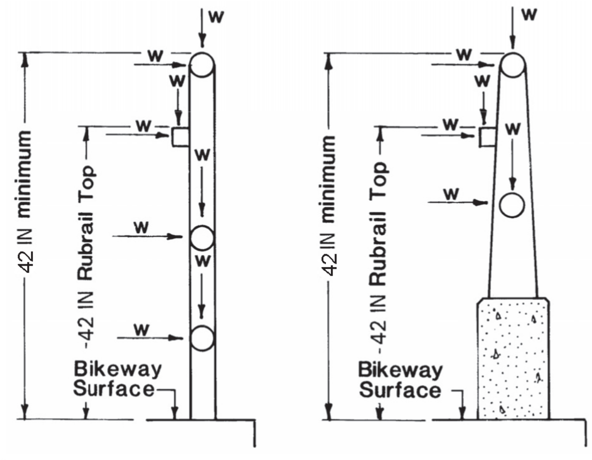

Figure 13.9.3-1—Bicycle Railing Loads—To be used on the outer edge of a bikeway when highway traffic is separated from bicycle traffic by a traffic railing. Railing shape illustrative only.

13.10—COMBINATION RAILINGS

13.10.1—General

The combination railing shall conform to the requirements of either the pedestrian or bicycle railings, as specified in Articles 13.8 and 13.9, whichever is applicable. The traffic railing portion of the combination railing shall conform to Article 13.7.

13.10.2—Geometry

The geometric provisions of Articles 13.7, 13.8, and 13.9 shall apply to their respective portions of a combination railing.

13.10.3—Design Live Loads

Design loads, specified in Articles 13.8 and 13.9, shall not be applied simultaneously with the vehicular impact loads.

13.11—CURBS AND SIDEWALKS

13.11.1—General

Horizontal measurements of roadway width shall be taken from the bottom of the face of the curb. A sidewalk curb located on the highway traffic side of a bridge railing shall be considered an integral part of the railing and shall be subject to the crash test requirements specified in Article 13.7.

13.11.2—Sidewalks

When curb and gutter sections with sidewalks are used on roadway approaches, the curb height for raised sidewalks on the bridge should be no more than 8.0 in. If a barrier curb is required, the curb height should not be less than 6.0 in. If the height of the curb on the bridge differs from that off the bridge, it should be uniformly transitioned over a distance greater than or equal to 20 times the change in height.

C13.11.2

Raised sidewalks on bridges are not usually provided where the approach roadway is not curbed for pedestrians or the structure is not planned for pedestrian occupancy.

For recommendations on sidewalk width, see Figure 13.7.1.1-1 and AASHTO's *A Policy on Geometric Design of Highways and Streets*.

During stage construction, the same transition considerations will be given to the provision of ramps from the bridge sidewalk to the approach surface.

13.11.3—End Treatment of Separation Railing

The end treatment of any traffic railing or barrier shall meet the requirements specified in Articles 13.7.1.2 and 13.7.1.3.

13.12—REFERENCES

AASHTO. *A Policy on Geometric Design of Highways and Streets*, Seventh Edition, GDHS-7. American Association of State Highway and Transportation Officials, Washington, DC, 2018.

AASHTO. *Roadside Design Guide*, Fourth Edition, RSDG-4. American Association of State Highway and Transportation Officials, Washington, DC, 2011.

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Ross, H. E., D. L. Sicking, R. A. Zimmer, and J. D. Michie. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1993.

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APPENDIX A13

A13.1—GEOMETRY AND ANCHORAGES

A13.1.1—Separation of Rail Elements

For traffic railings, the criteria for maximum clear opening below the bottom rail, c_b, the setback distance, S, and maximum opening between rails, c, shall be as follows:

- The rail contact widths for typical railings may be taken as illustrated in Figure A13.1.1-1;
- The total width of the rail(s) in contact with the vehicle, ΣA, shall not be less than 25 percent of the height of the railing;
- For post railings, the vertical clear opening, c, and the post setback, S, shall be within or below the shaded area shown in Figure A13.1.1-2; and
- For post railings, the combination of ($\Sigma A/H$) and the post setback, S shall be within or above the shaded area shown in Figure A13.1.1-3.

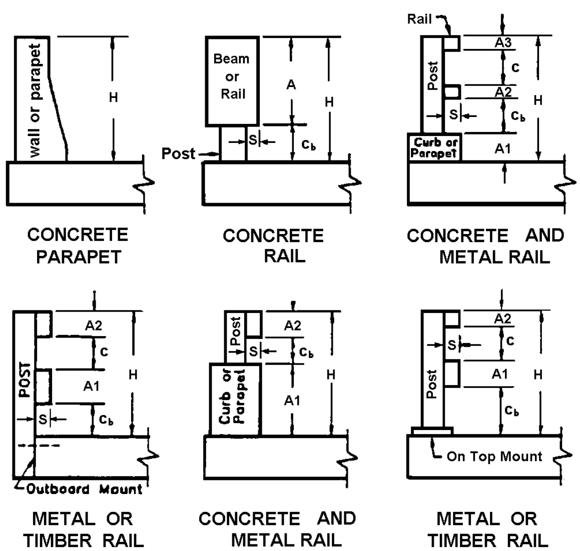

Figure A13.1.1-1—Typical Traffic Railings

CA13.1.1

The post setback shown from face of rail for various post shapes is based on a limited amount of crash test data. The potential for wheel snagging involved with a given design should be evaluated as part of the crash test program.

The post setback, S, shown for various shape posts in Figure A13.1.1-2, recognizes the tendency for various shape posts to snag wheels. The implication of the various definitions of setback, S, is that all other factors being equal, the space between a rail and the face of a rectangular post will be greater than the distance between a rail and the face of a circular post.

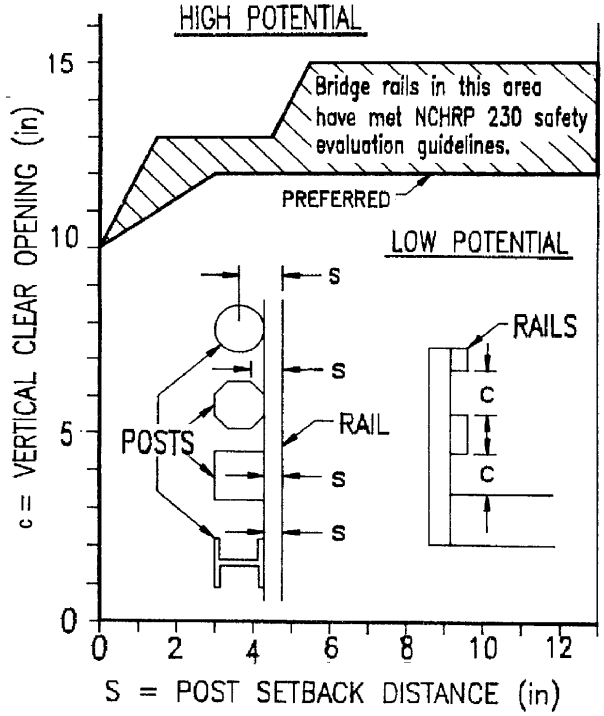

Figure A13.1.1-2—Potential for Wheel, Bumper, or Hood Impact with Post

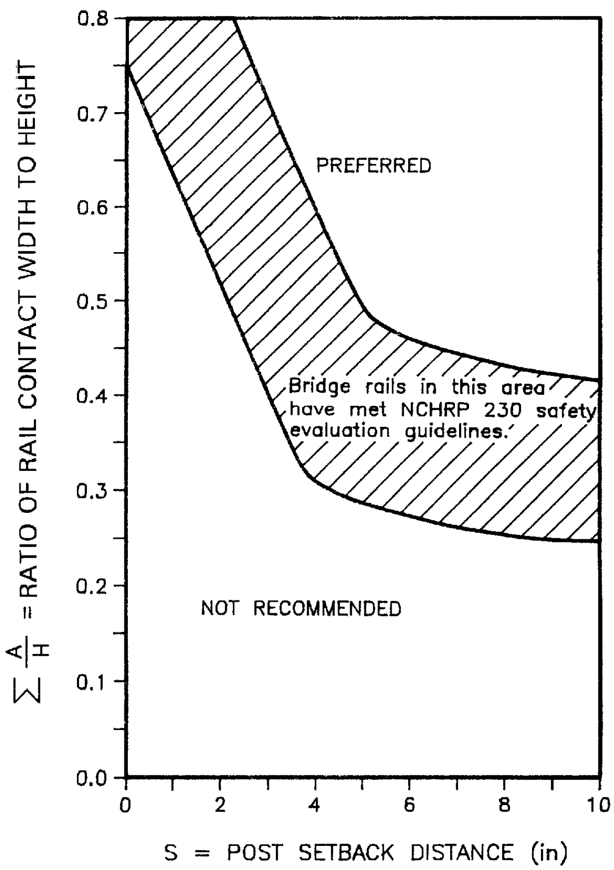

Figure A13.1.1-3—Post Setback Criteria

The maximum clear vertical opening between succeeding rails or posts shall be as specified in Articles 13.8, 13.9, and 13.10.

A13.1.2—Anchorages

The yield strength of anchor bolts for steel railings shall be fully developed by bond, hooks, attachment to embedded plates, or any combination thereof.

Reinforcing steel for concrete barriers shall have embedment length sufficient to develop the yield strength.

CA13.1.2

Noncorrosive bonding agents for anchor dowels may be cement grout, epoxy, or a magnesium phosphate compound. Sulfur or expansive-type grouts should not be used.

Some bonding agents on the market have corrosive characteristics; these should be avoided.

Development length for reinforcing bars is specified in Section 5.

A13.2—TRAFFIC RAILING DESIGN FORCES

Unless modified herein, the extreme event limit state and the corresponding load combinations in Table 3.4.1-1 shall apply.

Railing design forces and geometric criteria to be used in developing test specimens for a crash test program should be taken as specified in Table A13.2-1 and illustrated in Figure A13.2-1. The transverse and longitudinal loads given in Table A13.2-1 need not be applied in conjunction with vertical loads.

The effective height of the vehicle rollover force is taken as:

$$H_e = G - \frac{12WB}{2F_t} \tag{A13.2-1}$$

where:

G = height of vehicle center of gravity above bridge deck, as specified in Table 13.7.2-1 (in.)

W = weight of vehicle corresponding to the required test level, as specified in Table 13.7.2-1 (kips)

B = out-to-out wheel spacing on an axle, as specified in Table 13.7.2-1 (ft)

F_t = transverse force corresponding to the required test level, as specified in Table A13.2-1 (kips)

Railings shall be proportioned such that:

$$\overline{R} \geq F_t \tag{A13.2-2}$$

$$\overline{Y} \geq \frac{H_e}{12} \tag{A13.2-3}$$

in which:

$$\overline{R} = \sum R_i \tag{A13.2-4}$$

$$\overline{Y} = \frac{\Sigma(R_i Y_i)}{\overline{R}} \tag{A13.2-5}$$

CA13.2

Nomenclature for Eqs. A13.2-1 and A13.2-2 is illustrated in Figure CA13.2-1.

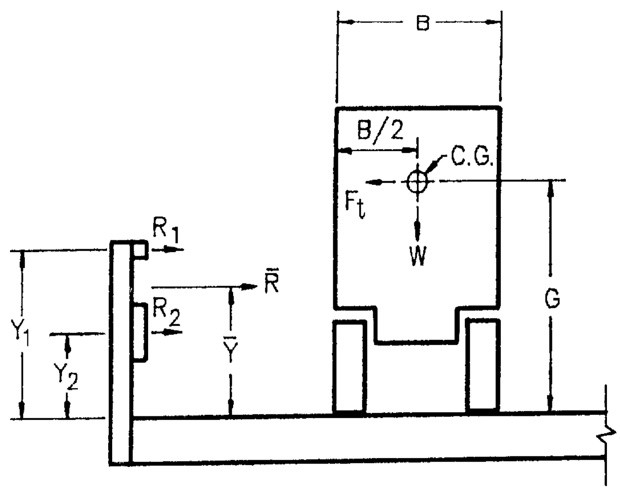

Figure CA13.2-1—Traffic Railing

If the total resistance, $\overline{R}$, of a post-and-beam railing system with multiple rail elements is significantly greater than the applied load, F_t, then the resistance, R_i, for the lower rail element(s) used in calculations may be reduced.

The reduced value of $\overline{R}$ will result in an increase in the computed value of $\overline{Y}$. The reduced notional total rail resistance and its effective height must satisfy Eqs. A13.2-2 and A13.2-3.

where:

R_i = resistance of the rail (kips)

Y_i = distance from bridge deck to the ith rail (ft)

All forces shall be applied to the longitudinal rail elements. The distribution of longitudinal loads to posts shall be consistent with the continuity of rail elements. Distribution of transverse loads shall be consistent with the assumed failure mechanism of the railing system.

Eq. A13.2-1 has been found to give reasonable predictions of effective railing height requirements to prevent rollover.

If the design load located at H_e falls between rail elements, it should be distributed proportionally to rail elements above and below such that $Y \geq H_e$.

As an example of the significance of the data in Table A13.2-1, the length of 4.0 ft for L_t and L_L is the length of significant contact between the vehicle and railing that has been observed in films of crash tests. The length of 3.5 ft for TL-4 is the rear-axle tire diameter of the truck. The length of 8.0 ft for TL-5 and TL-6 is the length of the tractor rear tandem axles: two 3.5-ft diameter tires, plus 1.0 ft between them.

F_v, the weight of the vehicle lying on top of the bridge rail, is distributed over the length of the vehicle in contact with the rail, L_v.

For concrete railings, Eq. A13.2-1 results in a theoretically-required height, H, of 34.0 in. for TL-4. However, a height of 32.0 in., shown in Table A13.2-1, was considered to be acceptable because many railings of that height have been built and appear to be performing acceptably.

The minimum height, H, listed for TL-1, TL-2, and TL-3 is based on the minimum railings height used in the past. The minimum effective height, H_e, for TL-1 is an estimate based on the limited information available for this test level.

The minimum height, H, of 42.0 in., shown in Table A13.2-1, for TL-5 is based on the height used for successfully crash-tested concrete barrier engaging only the tires of the truck. For post-and-beam metal bridge railings, it may be prudent to increase the height by 12.0 in. so as to engage the bed of the truck.

The minimum height, H, shown in Table A13.2-1, for TL-6 is the height required to engage the side of the tank as determined by crash test.

Table A13.2-1—Design Forces for Traffic Railings

Design Forces and Designations	Railing Test Levels					
	TL-1	TL-2	TL-3	TL-4	TL-5	TL-6
F_t Transverse (kips)	13.5	27.0	54.0	54.0	124.0	175.0
F_L Longitudinal (kips)	4.5	9.0	18.0	18.0	41.0	58.0
F_v Vertical (kips) Down	4.5	4.5	4.5	18.0	80.0	80.0
L_t and L_L (ft)	4.0	4.0	4.0	3.5	8.0	8.0
L_v (ft)	18.0	18.0	18.0	18.0	40.0	40.0
H_e (min) (in.)	18.0	20.0	24.0	32.0	42.0	56.0
Minimum H Height of Rail (in.)	27.0	27.0	27.0	32.0	42.0	90.0

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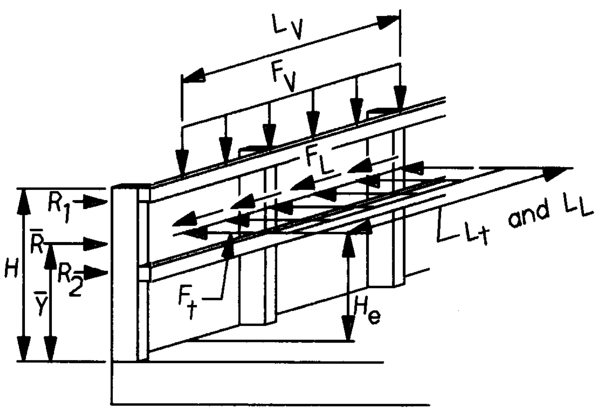

Figure A13.2-1—Metal Bridge Railing Design Forces, Vertical Location, and Horizontal Distribution Length

Figure A13.2-1 shows the design forces from Table A13.2-1 applied to a beam and post railing. This is for illustrative purposes only. The forces and distribution lengths shown apply to any type of railing.

A13.3—DESIGN PROCEDURE FOR RAILING TEST SPECIMENS

A13.3.1—Concrete Railings

Yield line analysis and strength design for reinforced concrete and prestressed concrete barriers or parapets may be used.

The nominal railing resistance to transverse load, R_w, may be determined using a yield line approach as:

- For impacts within a wall segment:

$$R_w = \left(\frac{2}{2L_c - L_t}\right)\left(8M_b + 8M_w + \frac{M_c L_c^{\,2}}{H}\right) \tag{A13.3.1-1}$$

The critical wall length over which the yield line mechanism occurs, L_c, shall be taken as:

$$L_c = \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + \frac{8H(M_b + M_w)}{M_c}} \tag{A13.3.1-2}$$

- For impacts at end of wall or at joint:

$$R_w = \left(\frac{2}{2L_c - L_t}\right)\left(M_b + M_w + \frac{M_c L_c^{\,2}}{H}\right) \tag{A13.3.1-3}$$

$$L_c = \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + H\left(\frac{M_b + M_w}{M_c}\right)} \tag{A13.3.1-4}$$

where:

F_t = transverse force specified in Table A13.2-1 assumed to be acting at top of a concrete wall (kips)
H = height of wall (ft)
L_c = critical length of yield line failure pattern (ft)

CA13.3.1

The yield line analysis shown in Figures CA13.3.1-1 and CA13.3.1-2 includes only the ultimate flexural capacity of the concrete component. Stirrups or ties should be provided to resist the shear and/or diagonal tension forces.

The ultimate flexural resistance, M_s, of the bridge deck or slab should be determined in recognition that the deck is also resisting a tensile force, caused by the component of the impact forces, F_t.

In this analysis, it is assumed that the yield line failure pattern occurs within the parapet only and does not extend into the deck. This means that the deck must have sufficient resistance to force the yield line failure pattern to remain within the parapet. If the failure pattern extends into the deck, the equations for resistance of the parapet are not valid.

The analysis is also based on the assumption that sufficient longitudinal length of parapet exists to result in the yield line failure pattern shown. For short lengths of parapet, a single yield line may form along the juncture of the parapet and deck. Such a failure pattern is permissible, and the resistance of the parapet should be computed using an appropriate analysis.

This analysis is based on the assumption that the negative and positive wall resisting moments are equal and that the negative and positive beam resisting moments are equal.

The measurement of system resistance of a concrete railing is R_w, which is compared to the loads in Table A13.2-1 to determine structural adequacy. The flexure resistances, M_b, M_w, and M_c, are related to the system resistance, R_w, through the yield line analysis embodied in Eqs. A13.3.1-1 and A13.3.1-2. In the terminology of these Specifications, R_w is the nominal resistance because it is compared to the nominal load given in Table A13.2-1.

Where the width of the concrete railing varies along the height, M_c used in Eqs. A13.3.1-1 through A13.3.1-4 for wall resistance should be taken as the average of its value along the height of the railing.

L_t = longitudinal length of distribution of impact force F_t (ft)
R_w = total transverse resistance of the railing (kips)
M_b = additional flexural resistance of beam in addition to M_w, if any, at top of wall (kip-ft)
M_c = flexural resistance of cantilevered walls about an axis parallel to the longitudinal axis of the bridge (kip-ft/ft)
M_w = flexural resistance of the wall about its vertical axis (kip-ft)

For use in the above equations, M_c and M_w should not vary significantly over the height of the wall. For other cases, a rigorous yield line analysis should be used.

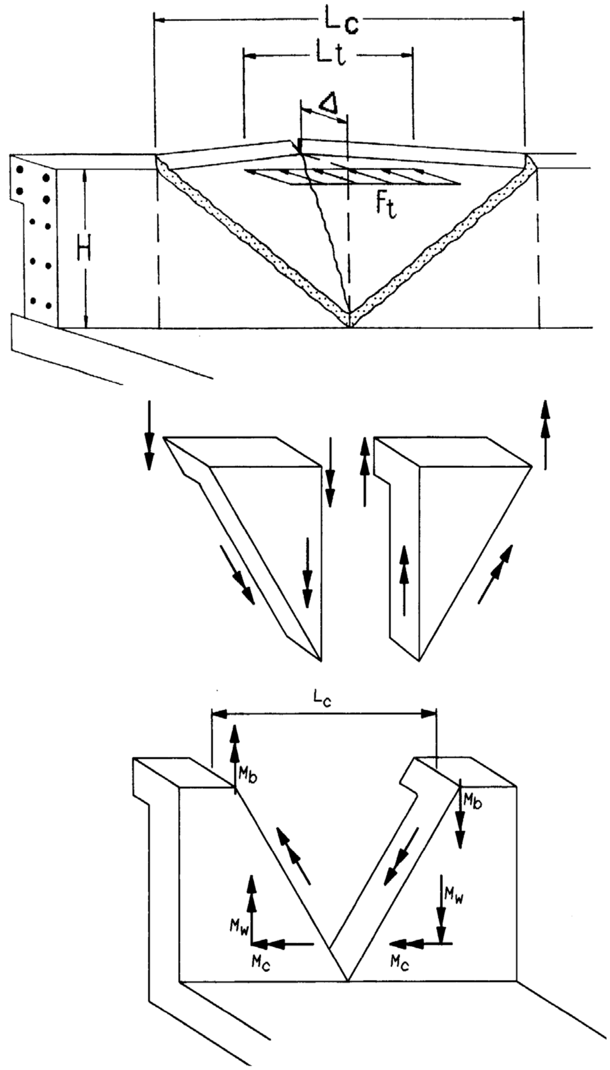

Figure CA13.3.1-1—Yield Line Analysis of Concrete Parapet Walls for Impact within Wall Segment

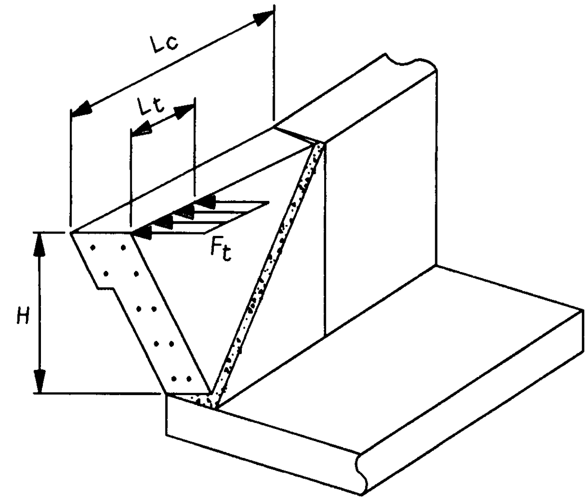

Figure CA13.3.1-2—Yield Line Analysis of Concrete Parapet Walls for Impact near End of Wall Segment

A13.3.2—Post-and-Beam Railings

Inelastic analysis shall be used for design of post-and-beam railings under failure conditions. The critical rail nominal resistance, R, when the failure does not involve the end post of a segment, shall be taken as the least value determined from Eqs. A13.3.2-1 and A13.3.2-2 for various numbers of railing spans, N.

CA13.3.2

A basis for applying inelastic analysis is shown in Figure CA13.3.2-1.

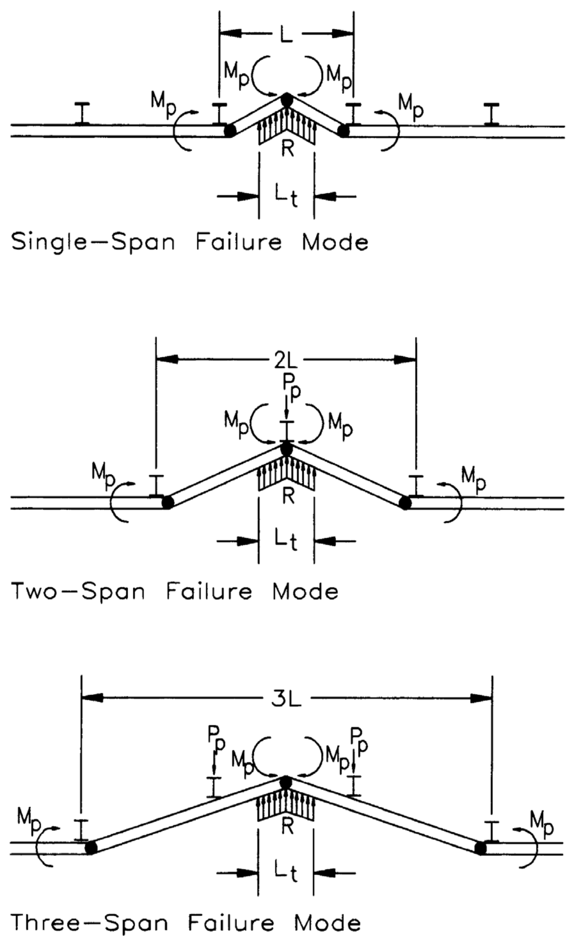

Figure CA13.3.2-1—Possible Failure Modes for Post-and-Beam Railings

- For failure modes involving an odd number of railing spans, N:

$$R = \frac{16M_p + (N-1)(N+1)P_p L}{2NL - L_t} \qquad \text{(A13.3.2-1)}$$

- For failure modes involving an even number of railing spans, N:

$$R = \frac{16\,M_p + N^2 P_p L}{2NL - L_t} \qquad \text{(A13.3.2-2)}$$

where:

L	=	post spacing or single-span (ft)
M_p	=	inelastic or yield line resistance of all of the rails contributing to a plastic hinge (kip-ft)
M_{post}	=	plastic moment resistance of a single post (kip-ft)
P_p	=	shear force on a single post which corresponds to M_{post} and is located $\overline{Y}$ above the deck (kips)
R	=	total ultimate resistance, i.e., nominal resistance, of the railing (kips)
L_t, L_L	=	transverse length of distributed vehicle impact loads, F_t and F_L (ft)

For impact at the end of rail segments that causes the end post to fail, the critical rail nominal resistance, R, shall be calculated using Eq. A13.3.2-3.

- For any number of railing spans, N.

$$R = \frac{2M_p + 2P_p L\left(\sum_{i=1}^{N} i\right)}{2NL - L_t} \qquad \text{(A13.3.2-3)}$$

This design procedure is applicable to concrete and metal post-and-beam railings.

The post on each end of the plastic mechanism must be able to resist the rail or beam shear.

For multiple-rail systems, each of the rails may contribute to the yield mechanism shown schematically in Figure CA13.3.2-1, depending on the rotation corresponding to its vertical position.

A13.3.3—Concrete Parapet and Metal Rail

The resistance of each component of a combination bridge rail shall be determined as specified in Articles A13.3.1 and A13.3.2. The flexural strength of the rail shall be determined over one span, R_R, and over two spans, R'_R. The resistance of the post on top of the wall, P_p, including the resistance of the anchor bolts or post, shall be determined.

The resistance of the combination parapet and rail shall be taken as the lesser of the resistances determined for the two failure modes shown in Figures A13.3.3-1 and A13.3.3-2.

CA13.3.3

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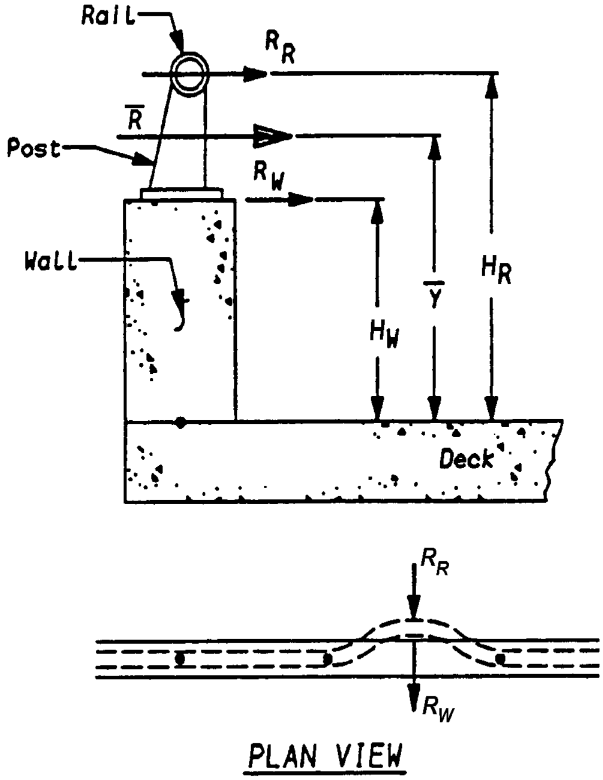

Figure A13.3.3-1—Concrete Wall and Metal Rail Evaluation—Impact at Midspan of Rail

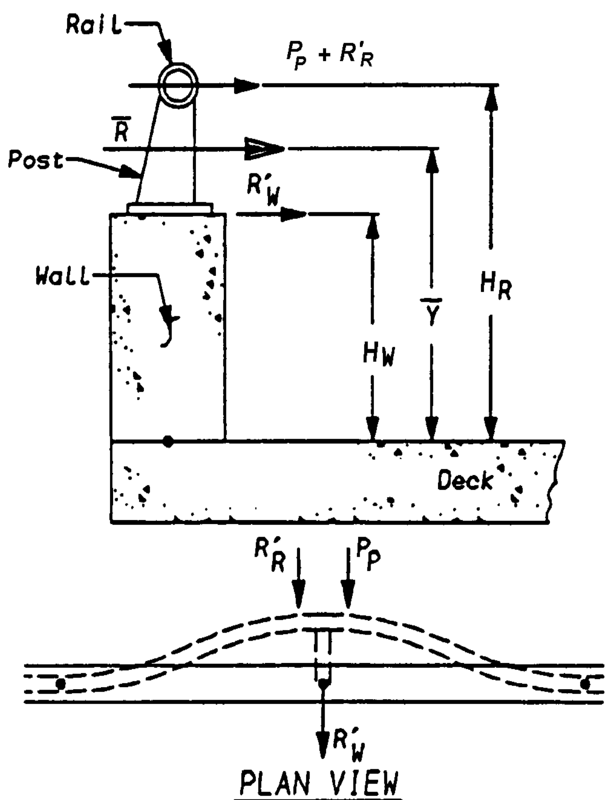

Figure A13.3.3-2—Concrete Wall and Metal Rail Evaluation—Impact at Post

Where the vehicle impact is at midspan of the metal rail, as illustrated in Figure A13.3.3-1, the flexural resistance of the rail, R_R, and the maximum strength of the concrete wall, R_w, shall be added together to determine the combined resultant strength, $\overline{R}$, and the effective height, $\overline{Y}$, taken as:

$$\overline{R} = R_R + R_w \quad \text{(A13.3.3-1)}$$

$$\overline{Y} = \frac{R_R H_R + R_w H_w}{\overline{R}} \quad \text{(A13.3.3-2)}$$

where:

R_R = ultimate capacity of rail over one span (kips)
R_w = ultimate capacity of wall as specified in Article A13.3.1 (kips)
H_w = height of wall (ft)
H_R = height of rail (ft)

The commentary to Article CA13.2 applies.

Where the vehicle impact is at a post, as illustrated in Figure A13.3.3-2, the maximum resultant strength, $\overline{R}$, shall be taken as the sum of the post capacity, P_p, the rail strength, R'_R, and a reduced wall strength, R'_w, located at a height $\overline{Y}$.

$$\overline{R} = P_p + R'_R + R'_w \quad \text{(A13.3.3-3)}$$

$$\overline{Y} = \frac{P_p H_R + R'_R H_R + R'_w H_w}{\overline{R}} \quad \text{(A13.3.3-4)}$$

in which:

$$R'_w = \frac{R_w H_w - P_p H_R}{H_w} \quad \text{(A13.3.3-5)}$$

where:

P_p = ultimate transverse resistance of post (kips)
R'_R = ultimate transverse resistance of rail over two spans (kips)
R'_w = capacity of wall, reduced to resist post load (kips)
R_w = ultimate transverse resistance of wall as specified in Article A13.3.1 (kips)

It should also be recognized that a maximum effective height, $\overline{Y}$, equal to the centroid rail height, H_R, could be obtained, but at a reduced resultant strength, $\overline{R}$, equal to the post capacity, P_p, and rail capacity, R'_R, only.

The analysis herein does not consider impacts near open joints in the concrete wall or parapet. The metal rail will help distribute load across such joints. Improved rail resistance will be obtained if the use of expansion and contraction joints is minimized.

For impact near the end of railing segments, the nominal resistance may be calculated as the sum of the wall resistance, calculated using Eq. A13.3.1-3, and the metal rail resistance over one span, calculated using Eq. A13.3.2-3.

A13.3.4—Wood Barriers

Wood barriers shall be designed by elastic linear analysis with member sections proportioned on the basis of their resistances, specified in Section 8, using the strength limit states and the applicable load combinations specified in Table 3.4.1-1.

CA13.3.4

A limit or failure mechanism is not recommended for wood railings.

A13.4—DECK OVERHANG DESIGN

A13.4.1—Design Cases

Bridge deck overhangs shall be designed for the following design cases considered separately:

Design Case 1: the transverse and longitudinal forces specified in Table A13.2-1—Extreme Event Load Combination II limit state

Design Case 2: the vertical forces specified in Table A13.2-1—Extreme Event Load Combination II limit state

Design Case 3: the loads, specified in Article 3.6.1, that occupy the overhang—Load Combination Strength I limit state

For Design Cases 1 and 2, the load factor for dead load, γ_p, shall be taken as 1.0.

The total factored force effect shall be taken as:

$$Q = \sum \eta_i \gamma_i Q_i \tag{A13.4.1-1}$$

where:

η_i = load modifier specified in Article 1.3.2
γ_i = load factors specified in Tables 3.4.1-1 and 3.4.1-2, unless specified elsewhere
Q_i = force effects from loads specified herein

A13.4.2—Decks Supporting Concrete Parapet Railings

For Design Case 1, the deck overhang may be designed to provide a flexural resistance, M_s, in kip-ft/ft which, acting coincident with the tensile force, T, in kip/ft, specified herein, exceeds M_c of the parapet at its base. The axial tensile force, T, may be taken as:

$$T = \frac{R_w}{L_c + 2H} \tag{A13.4.2-1}$$

where:

R_w = parapet resistance specified in Article A13.3.1 (kips)
L_c = critical length of yield line failure pattern (ft)
H = height of wall (ft)
T = tensile force per unit of deck length (kip/ft)

Design of the deck overhang for the vertical forces specified in Design Case 2 shall be based on the overhanging portion of the deck.

CA13.4.2

If the deck overhang capacity is less than that specified, the yield line failure mechanism for the parapet may not develop as shown in Figure CA13.3.1-1, and Eqs. A13.3.1-1 and A13.3.1-2 will not be correct.

The crash testing program is oriented toward survival, not necessarily the identification of the ultimate strength of the railing system. This could produce a railing system that is significantly overdesigned, leading to the possibility that the deck overhang is also overdesigned.

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A13.4.3—Decks Supporting Post-and-Beam Railings

A13.4.3.1—Overhang Design

For Design Case 1, the moment in kip-ft/ft, M_d, and tensile force, in kip/ft of deck, T, may be taken as:

$$M_d = \frac{12M_{post}}{W_b + d_b} \quad \text{(A13.4.3.1-1)}$$

$$T = \frac{12P_p}{W_b + d_b} \quad \text{(A13.4.3.1-2)}$$

For Design Case 2, the punching shear force and overhang moment may be taken as:

$$P_v = \frac{F_v L}{L_v} \quad \text{(A13.4.3.1-3)}$$

$$M_d = \frac{P_v X}{b} \quad \text{(A13.4.3.1-4)}$$

in which:

$$b = 2X + \frac{W_b}{12} \leq L \quad \text{(A13.4.3.1-5)}$$

where:

M_{post} = plastic moment resistance of a single post (kip-ft)
P_p = shear force on a single post which corresponds to M_{post} and is located $\overline{Y}$ above the deck (kips)
X = distance from the outside edge of the post base plate to the section under investigation, as specified in Figure A13.4.3.1-1 (ft)
W_b = width of base plate (in.)
T = tensile force in deck (kip/ft)
d_b = distance from the outer edge of the base plate to the innermost row of bolts, as shown in Figure A13.4.3.1-1 (in.)
L = post spacing (ft)
L_v = longitudinal distribution of vertical force F_v on top of railing (ft)
F_v = vertical force of vehicle laying on top of rail after impact forces F_t and F_L are over (kips)
b = length of deck resisting post strength or shear load

CA13.4.3.1

Vehicle collision on beam-and-post railing systems, such as a metal system with wide flange or tubular posts, imposes large concentrated forces and moments on the deck at the point where the post is attached to the deck.

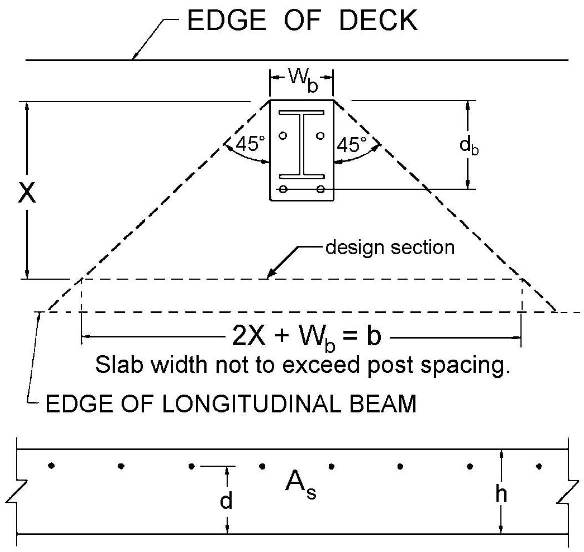

Figure A13.4.3.1-1—Effective Length of Cantilever for Carrying Concentrated Post Loads, Transverse or Vertical

Previous editions of the AASHTO *Standard Specifications for Highway Bridges* distributed railing or post loads to the slab using similar simplified analysis, e.g., "The effective length of slab resisting post loadings shall be equal to $E = 0.8x + 3.75$ ft where no parapet is used and equal to $E = 0.8x + 5.0$ ft where a parapet is used, where x is the distance in ft from the center of the post to the point under investigation."

A13.4.3.2—Resistance to Punching Shear

For Design Case 1, the factored shear may be taken as:

$$V_u = A_f F_y \tag{A13.4.3.2-1}$$

The factored resistance of deck overhangs to punching shear may be taken as:

$$V_r = \phi V_n \tag{A13.4.3.2-2}$$

$$V_n = v_c \left[W_b + h + 2\left(E + \frac{B}{2} + \frac{h}{2} \right) \right] h \tag{A13.4.3.2-3}$$

$$v_c = \left(0.0633 + \frac{0.1265}{\beta_c} \right) \sqrt{f'_c} \leq 0.1265\sqrt{f'_c} \tag{A13.4.3.2-4}$$

$$\frac{B}{2} + \frac{h}{2} \leq B \tag{A13.4.3.2-5}$$

in which:

$$\beta_c = W_b / d_b \tag{A13.4.3.2-6}$$

where:

V_u = factored shear force at section (kips)
A_f = area of post compression flange (in.^{2})
F_y = yield strength of post compression flange (ksi)
V_r = factored shear resistance (kips)
V_n = nominal shear resistance of the section considered (kips)
v_c = nominal shear resistance provided by tensile stresses in the concrete (ksi)
W_b = width of base plate (in.)

CA13.4.3.2

Concrete slabs or decks frequently fail in punching shear resulting from the force in the compression flange of the post, C. Adequate thickness, h, edge distance, E, or base plate size (W_b or B or thickness) should be provided to resist this type of failure.

h = depth of slab (in.)
E = distance from edge of slab to centroid of compressive stress resultant in post (in.)
B = distance between centroids of tensile and compressive stress resultants in post (in.)
β_c = ratio of the long side to the short side of the concentrated load or reaction area
f'_c = 28-day compressive strength of concrete (ksi)
ϕ = resistance factor = 1.0
d_b = distance from the outer edge of the base plate to the innermost row of bolts (in.)

The assumed distribution of forces for punching shear shall be as shown in Figure A13.4.3.2-1.

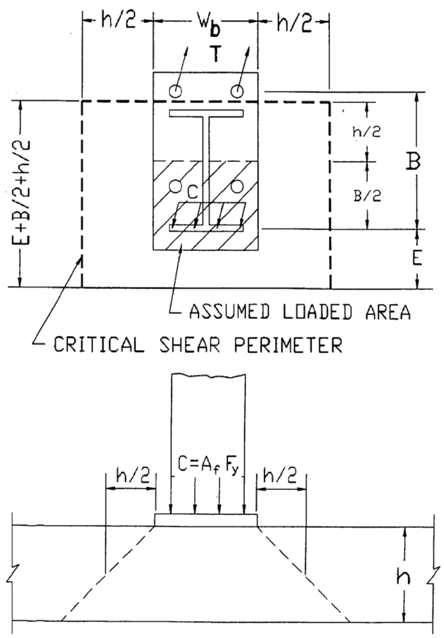

Figure A13.4.3.2-1—Punching Shear Failure Mode

Test results and in-service experience have shown that where deck failures have occurred, the failure mode has been a punching shear-type failure with loss of structural integrity between the concrete and reinforcing steel. Use of various types of shear reinforcement may increase the ultimate strength of the postdeck connection but is ineffective in reducing shear, diagonal tension, or cracking in the deck. Shear resistance can be increased by increasing the slab thickness, base plate width and depth, or edge distance.

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