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Chapter 7
Bridge Railings and Transitions

7.0 OVERVIEW

A bridge railing is a longitudinal barrier intended to prevent a vehicle from running off the edge of a bridge or culvert. Normally they are constructed of a metal or concrete post and railing system, a concrete safety shape, or a combination of metal and concrete. Most bridge railings differ from roadside barriers in that bridge railings are an integral part of the structure (physically connected) and are usually designed to have virtually no deflection when struck by an errant vehicle.

This chapter summarizes the performance and structural requirements for bridge railings and presents examples of each of the six test levels defined in NCHRP Report 350 (1) for longitudinal barriers. It also addresses selection and placement guidelines for new construction and includes examples of some typical retrofit designs for older bridges having substandard railings. Finally, it addresses bridge railings and roadside barriers as a complete system and provides general information on appropriate transition sections between the two barrier types.

The information presented here is intended only to summarize selected sections of the current AASHTO *Standard Specifications for Highway Bridges* (2) and the *AASHTO LRFD Bridge Design Specifications* (3). Detailed information on analytic design procedures, design loadings, and materials specifications can be found in those documents.

7.1 PERFORMANCE REQUIREMENTS

The AASHTO *Standard Specifications for Highway Bridges* requires that bridge railings meet specific geometric criteria and be capable of resisting applied static loads without exceeding allowable stresses in any of their component members. These specifications do not presently mandate that a bridge railing designed to AASHTO standards be crash tested prior to its use. However, the Federal Highway Administration (FHWA) requires all bridge railings used on the National Highway System to be a crash-tested design.

The *AASHTO LRFD Bridge Design Specifications* provide the most current guidance regarding performance requirements for railings for new bridges and for rehabilitated bridges to the extent that railing replacement is determined to be appropriate. NCHRP Report 350 crash test criteria were used to develop the design criteria contained in the *AASHTO LRFD Bridge Design Specifications*.

Existing bridge railings designed to criteria contained in the AASHTO *Standard Specifications for Highway Bridges* and that may have been crash tested under previous guidelines may be acceptable for use on new or reconstruction projects through evaluation of their in-service performance. For existing bridge rails, individual states should develop a guideline for retention, upgrading, or both retention and upgrading of the in-place rails based on a safe, cost-effective approach. See Section 7.7, Upgrading of Bridge Railings, for additional guidance.

7.2 WARRANTS

Virtually all structures require some type of railing; however, on many small structures on low-speed, low-volume roadways, a railing designed to full AASHTO standards may be neither necessary nor desirable. A rigid railing requires approach guardrail and a transition section between barrier types. This full treatment may not be cost-effective on bridge-length culverts, and alternate treatments should be considered. Such treatments could include extending the structure and leaving the edges unshielded or using a less expensive, semi-rigid type railing.

The owner should 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. Refer to Section 13 of the *AASHTO LRFD Bridge Design Specifications* for guidance in the development of warrants.

When a bridge also serves pedestrians, cyclists, or both, a barrier to shield them from vehicular traffic may be warranted. The need for a pedestrian or cyclist railing should be based on the volume and speed of roadway traffic, the number of pedestrians or cyclists using the bridge, and conditions on either end of the structure.

7.3 TEST LEVEL SELECTION PROCEDURES

As with other traffic barriers, the current design criteria for bridge railings relate primarily to standard size automobiles and pickup trucks and result in the selection of a design meeting NCHRP Report 350, TL-3. Test requirements are the same for a bridge rail as those for a longitudinal barrier as described in Chapter 5.

Several state highway agencies and the FHWA have recognized that it may be desirable in certain situations to design and install railings which can contain and redirect heavy vehicles such as buses and trucks. Although penetration of any railing by a vehicle is potentially hazardous to its occupants, locations where vehicular penetration of a railing system could be particularly hazardous to others as well should be given careful evaluation before deciding on the type of railing to install.

A second concern that must be considered in selecting a high-performance railing is its effective height. A railing may have adequate strength to prevent physical penetration, but unless it also has adequate height, an impacting vehicle or its cargo may roll over the railing or may roll onto its side away from the railing after redirection.

In addition, the shape of the face of the railing will have a significant effect on its performance. Various safety shapes have been successfully tested according to NCHRP Report 350 criteria. However, a safety-shape concrete railing can cause a large vehicle to roll up to 24 degrees before it contacts the upper edge of the railing. Thus, a vertical face may be more desirable whenever heavy vehicle rollover is a primary concern.

At the other extreme, some bridges carry only low traffic volumes at greatly reduced speeds. Bridge railings for these and similar structures may not need to be designed to the same performance level as railings to be used on high-speed, high-volume facilities. Section 5.3 lists the subjective factors most often considered in the selection of an appropriate test level for traffic barriers, including bridge railings, at a specific location.

7.4 CRASH-TESTED RAILINGS

In the past, crash test matrices for bridge railings have differed from those used for other longitudinal barriers. All new tests for bridge railings should be in accordance with the guidelines in NCHRP Report 350. The FHWA maintains a listing of designs that have recently been tested to one of the test levels defined in NCHRP Report 350 and of designs previously tested under earlier guidelines that have been assigned an NCHRP Report 350 equivalent test level.

For illustrative purposes, this section contains photographs and brief descriptions of some of the bridge railings that have been successfully crash tested to one of the six test levels defined in NCHRP Report 350. A complete list of crash-tested bridge railings may be obtained from the FHWA's Office of Highway Safety through its web site: http://safety.fhwa.dot.gov/programs/roadside_hardware.htm.

7.4.1 Test Level 1 Bridge Railings

Since TL-1 designs are tested at impact speeds of only 50 km/h [30 mph], TL-1 bridge railings are not very practical because operating speeds nearly always exceed that level. As a result, there have been almost no bridge railings designed and tested to TL-1. The U.S. Forest Service has done some testing on timber railings for low-speed situations, but most of that effort has been directed towards TL-2 or higher designs.

7.4.2 Test Level 2 Bridge Railings

The side-mounted, thrie-beam bridge railing shown in Figure 7.1 is unique because it is presently the only non-rigid bridge railing that has been successfully crash tested to meet the lower service level performance criteria included in NCHRP Report 230 (4). Intended primarily for use on lower volume secondary roads, the thrie-beam system consists of a thrie-beam rail element, the center of which is mounted 550 mm [22 in.] above the deck on wood or steel posts. Since the thrie-beam railing is designed to deflect on impact, an approach rail transition is not needed be-

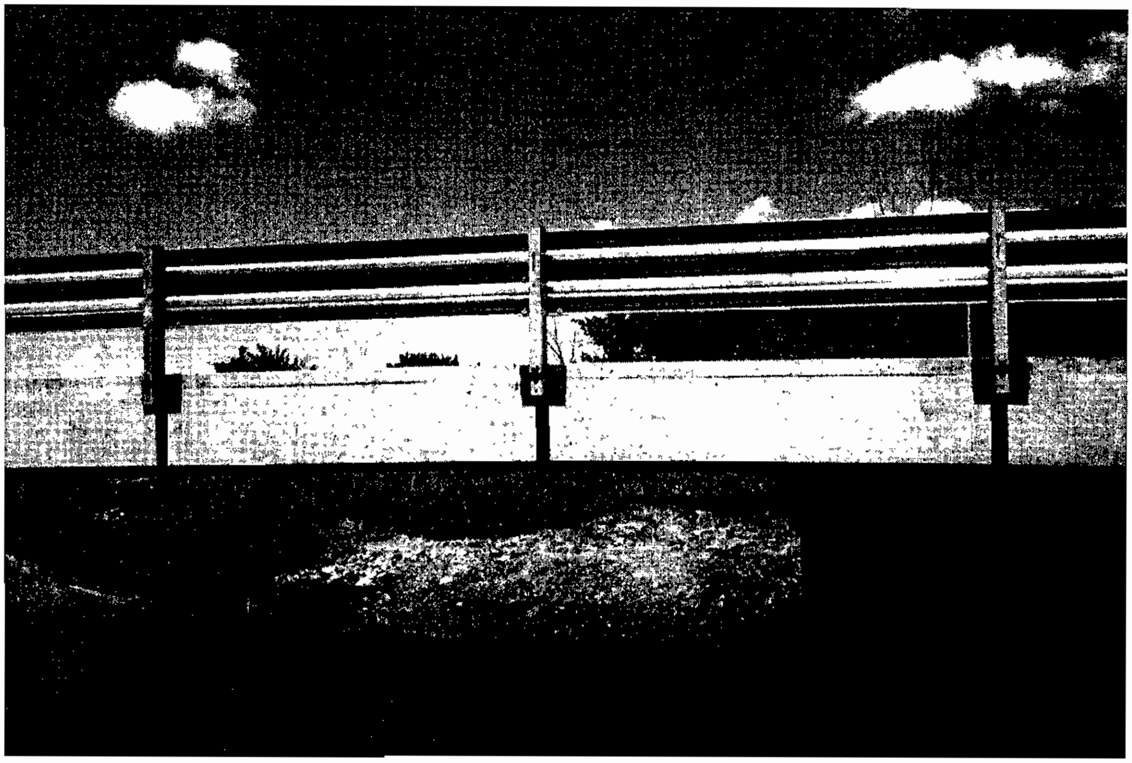


FIGURE 7.1 Side-mounted, thrie-beam bridge railing

cause there is not a hard point in the system. Tests with compact and full-sized automobiles at impact speeds of 100 km/h [60 mph] and impact angles of 15 degrees resulted in smooth redirection and no evidence of snagging. A 9000 kg [20,000 lb] school bus impacting at 70 km/h [45 mph] and at a 7-degree angle resulted in similar performance.

Although not tested to NCHRP Report 350 criteria, the side-mounted, thrie-beam bridge railing is considered equivalent to a TL-2 design. Primary advantages to using this system include its relative simplicity and low cost. The post attachment detail is designed to yield on impact rather than cause damage to the bridge deck. Thus, the thrie-beam railing is significantly more forgiving than a rigid design and is likely to be easier to repair after a hit.

7.4.3 Test Level 3 Bridge Railings

The Wyoming Two-Tube Bridge Railing, shown in Figure 7.2, consists of two horizontal rail elements of TS 152 mm x 51 mm x 6.4 mm [6 in. x 2 in. x $^{1}/_{4}$ in.] structural steel supported by fabricated steel plate posts on 3 m [10 ft] centers. The height to the top of the upper rail is 740 mm [29 in.] and the height to the bottom of the lower rail is 405 mm [16 in.]. The faces of the rail elements are flush with the 150 mm [6 in.] concrete curb on which the posts are mounted. This design was tested to NCHRP Report 350, TL-3. A similar design using larger steel tube rail elements and support posts was successfully tested to TL-4. Transition designs from a standard box beam approach rail to both of these bridge rail designs have been tested to TL-3.

7.4.4 Test Level 4 Bridge Railings

There are several bridge railings that have been tested successfully with a single-unit truck impacting at 80 km/h [50 mph] and at 15-degree angle. Four representative TL-4 designs are described in the next subsections.

7.4.4.1 Solid Concrete Bridge Railings

All of the current solid concrete barriers (New Jersey shape and F-shape, single slope and vertical wall) are considered to be TL-4 bridge railings when adequately reinforced and built to a minimum height of 810 mm [32 in.].

FIGURE 7.2 Wyoming two-tube bridge railing

7.4.4.2 Massachusetts S3 Steel Bridge Railing

The S3 Steel Bridge Railing, shown in Figure 7.3, is a beam and post system consisting of three tubular steel rail elements on W150 x 37 [W6 x 25] posts mounted flush on the outside edge of a sidewalk, as shown, or directly on a 200 mm [8 in.] curb when no sidewalk is present. The top rail element is a TS 127 mm x 102 mm x 6.4 mm [5 in. x 4 in. x $^1/_4$ in.] steel tube, the top of which is 1082 mm [42$^1/_2$ in.] above the deck. The lower two railings are TS 127 mm x 127 mm x 6.4 mm [5 in. x 5 in. x $^1/_4$ in.] steel tubes centered 380 mm [15 in.] and 710 mm [28 in.] above the deck, respectively. The S3 Railing also includes 38 mm x 38 mm x 1.6 mm [1$^1/_2$ in. x 1$^1/_2$ in. x $^1/_{16}$ in.] "pickets" bolted to the back of the rail elements on 150 mm [6 in.] centers. These steel tubes satisfy AASHTO pedestrian rail geometrics and provide an aesthetic look to the bridge rail.

7.4.4.3 Wyoming Two-Tube Bridge Railing

A version of the Wyoming Two-Tube Bridge Railing as described in Section 7.4.3 and shown in Figure 7.2 was tested to TL-4 criteria. This design consists of two horizontal rail elements supported by fabricated steel plate posts on 3 m [10 ft] centers. The top rail element is a TS 152 mm x 102 mm x 6.4 mm [6 in. x 4 in. x $^1/_4$ in.] structural steel tube. The bottom rail element is a TS 152 mm x 76 mm x 6.4 mm [6 in. x 3 in. x $^1/_4$ in.] structural steel tube. The height to the top of the upper rail is 830 mm [33 in.] and the height to the bottom of the lower rail is 480 mm [19 in.]. The face of the rail elements are flush with the 150 mm [6 in.] high concrete curb on which the posts are mounted.

7.4.4.4 BR27C

The BR27C, shown in Figure 7.4, is designed to be either sidewalk mounted on a 1.5 m [5 ft] sidewalk with a 200 mm [8 in.] curb or flush mounted on a bridge deck. The total rail height is 1067 mm [42 in.]. The lower portion of the railing consists of a 610 mm [24 in.] high concrete parapet that is a constant 250 mm [10 in.] thick. The upper portion of the railing consists of TS 102 mm x 102 mm x 4.8 mm [4 in. x 4 in. x $^3/_{16}$ in.] A500,grade B structural tubing used as vertical posts spaced at 2 m [6.5 ft] centers. One TS

FIGURE 7.3 Massachusetts S3 steel bridge railing

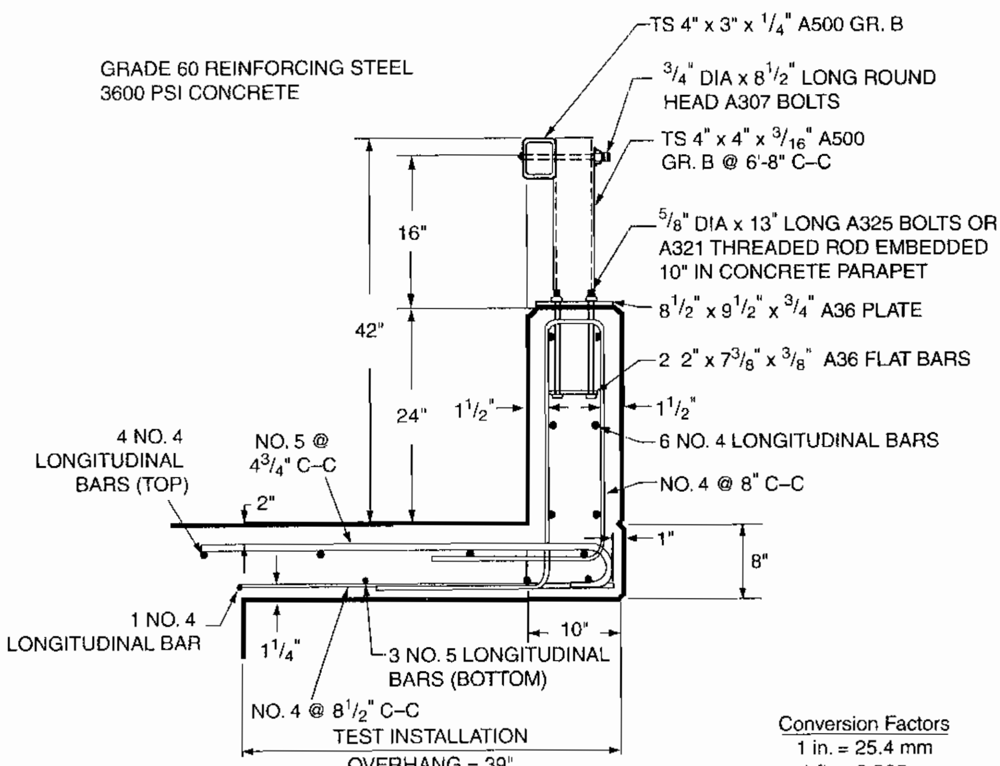


FIGURE 7.4 BR27C on sidewalk

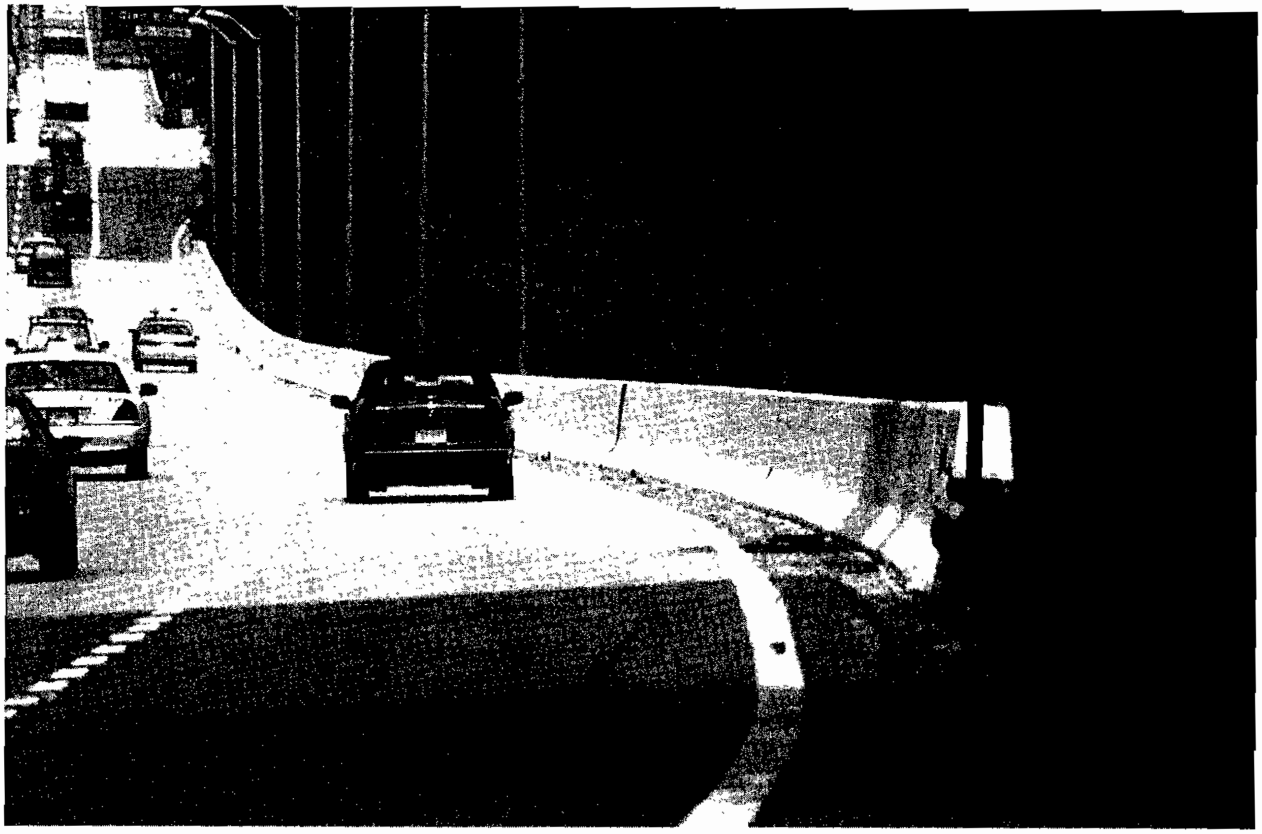


FIGURE 7.5 Tall concrete safety-shape railing

102 mm x 76 mm x 6.4 mm [4 in. x 3 in. x $^1/_4$ in.] structural tube is used as a horizontal rail element mounted to each post with splices at low moment areas.

7.4.5 Test Level 5 Bridge Railings

All of the current solid concrete barriers (New Jersey and F-shapes, single-slope, and vertical wall) are considered to be TL-5 bridge railings when adequately reinforced and built to a minimum height of 1070 mm [42 in.]. The concrete safety shape shown in Figure 7.5 is one of the most common bridge railings used on new construction. Identical to concrete median barrier in the shape of its front face, the architectural treatment of the outside face may vary considerably, depending upon its location. Reinforcing of the shape when it is used as a bridge railing is significant. The concrete barrier requires virtually no maintenance for most hits.

7.4.6 Test Level 6 Bridge Railings

The Texas Type TT (Tank Truck) shown in Figure 7.6 is an extremely strong barrier railing that successfully contained and redirected a 36000 kg [80,000 lb] tractor-tank trailer impacting the barrier at 80 km/h [50 mph] at an angle of 15 degrees. This railing is warranted for use in only the most rare situations. The railing as tested consists of a very heavily reinforced and widened concrete safety shape with a massively reinforced continuous concrete member and post. Total railing height is 2290 mm [90 in.]. Although designed and tested as a bridge railing, this cross-section has also been used as a longitudinal barrier in some locations.

7.5 SELECTION GUIDELINES

There are five factors that should be considered in selecting a bridge railing: performance, compatibility, cost, field experience, and aesthetics. Despite the relative importance placed on these factors, the capability of a railing to contain and redirect the design vehicle should never be compromised.

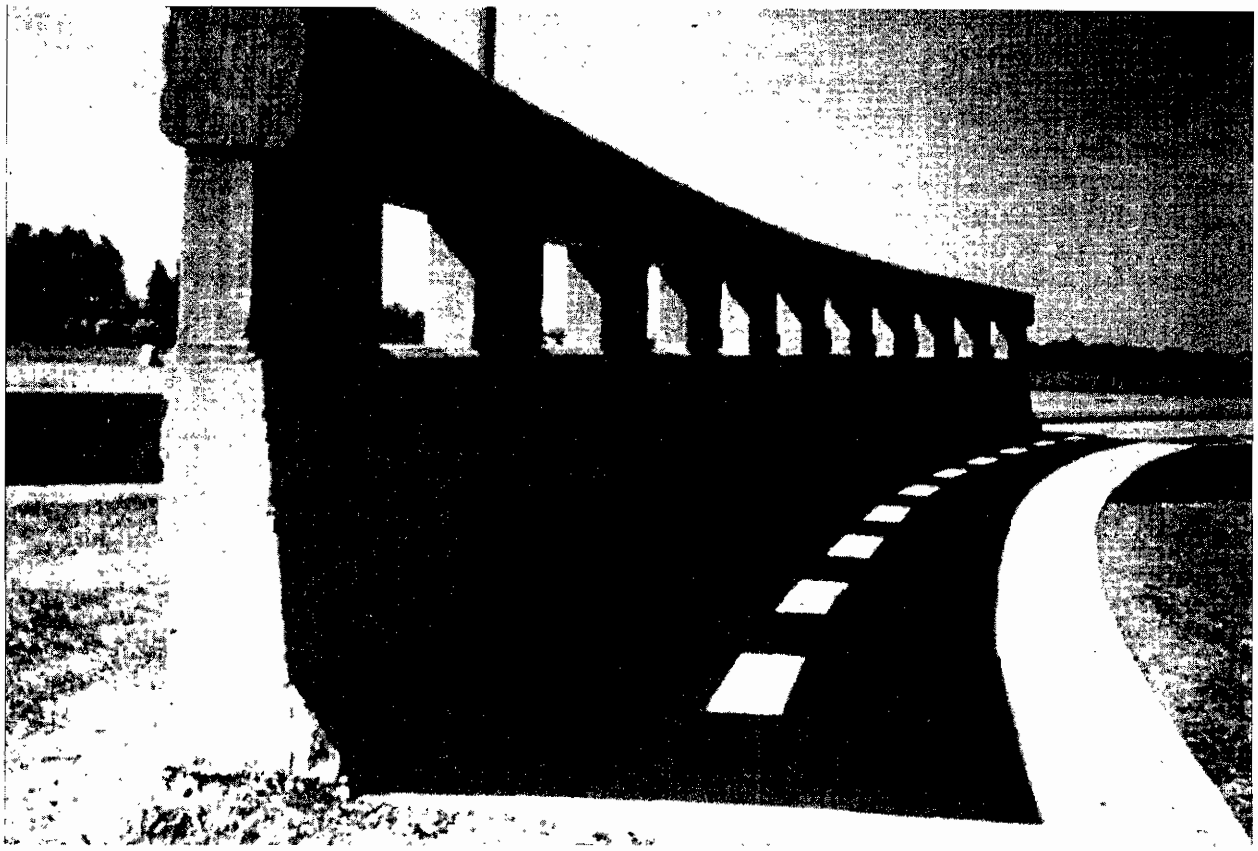


FIGURE 7.6 Texas Type TT (Tank Truck) railing

7.5.1 Railing Performance

Generally, all bridge railings designed in accordance with AASHTO specifications since 1964 have adequate strength to prevent penetration by passenger cars. Many of these railings also provide smooth redirection, although full-scale crash testing has revealed poor performance in some railing designs. Post-crash evaluation of some of the failed systems revealed a lack of design capacity in a detail (such as base plate thickness or a post-to-base plate connection) that adversely affected the capacity of the railing. Bridge railings designed to the current *AASHTO LRFD Bridge Design Specifications* and crash tested to NCHRP Report 350 will provide the best performance.

7.5.2 Compatibility

When the approach roadside barrier significantly differs in strength, height, and deflection characteristics from a bridge railing, a crashworthy transition section, as defined in Section 7.8, is required. It is important to consider the selected bridge railing as a part of the total roadside barrier system that must function effectively as a unit. For urban/suburban roadways with speeds of 70 km/h [45 mph] or less and with continuous raised sidewalks on and off the bridge, bridge rail end treatments and stiffened transitions may not be warranted.

7.5.3 Costs

Costs generally fall into one of three categories: initial construction costs, long-term maintenance costs, and costs resulting from vehicle impacts with the railing. As a general rule, the initial cost of a system increases as its rigidity and strength increases, but it seldom becomes a significant portion of the total bridge construction cost except in the case of extremely long bridges or when a high-performance railing is used. In this case, the railing-to-bridge-deck anchorage requirements may significantly increase the total cost of the structure. This would be particularly true for a high-performance concrete railing that adds considerable dead load to the bridge.

Maintenance costs generally decrease significantly as the strength of railing increases. Some high-performance railings can be essentially maintenance-free unless they are struck by heavy vehicles. Railing designs that are susceptible to impact damage should be standardized to the extent possible so that the availability of replacement parts does not become a major problem. Railings that eliminate or minimize bridge deck damage are very desirable from a maintenance viewpoint.

Crash costs include both damages to vehicles and injury costs to motorists. Generally, more damage is inflicted upon the impacting vehicle and its occupants when the railing is hit if the vehicle is not redirected.

7.5.4 Field Experience

It is important that the in-service performance of any bridge railing that is widely used be evaluated to see if it is working as intended. By reviewing crashes involving bridge railings where available and by documenting damage and repair costs, highway agency personnel can readily determine if a specific design is performing well or if changes could be made to improve railing performance or significantly decrease repair costs.

7.5.5 Aesthetics

While there is no question that an aesthetic bridge railing may be particularly important in scenic areas or along park roads, the safety performance of a railing must not be sacrificed. Some rustic appearing railings have been developed and crash tested to be both effective and acceptable in appearance. Any non-standard bridge railing designed primarily for appearance should be crash tested before being used.

7.6 PLACEMENT RECOMMENDATIONS

A desirable feature of a bridge structure is a full, continuous shoulder so that the uniform clearance to roadside elements is maintained. However, there are many existing bridges that are narrower than the approach roadway and shoulder. When the bridge railing is located within the recommended shy distance (see Table 5.5), the approach railing should have the appropriate flare rate shown in Table 5.7.

Curbs higher than 200 mm [8 in.] in front of bridge railings are to be avoided. In low-speed situations with the bridge railing at the outer edge of the sidewalk, a raised sidewalk may provide some protection for pedestrians; however, a bridge railing between traffic and the sidewalk affords maximum pedestrian protection. A pedestrian railing would then be needed at the outer edge of the sidewalk.

Terminating the bridge railing requires special treatment considerations. Wherever possible, a crash tested transition from the approach guardrail should be attached to the end of the bridge rail. In some restricted, low-speed situations, a tapered end section parallel to the roadway may be used. The taper should be of sufficient length off the end of the bridge so that an impacting vehicle is ramped on and over the sloped end treatment before reaching the outside edge of the structure, yet not extend so far as to intrude on the sight distance of intersecting streets just off the end of the bridge. This method of terminating a railing in low-speed situations is shown in Figure 7.7.

Terminating a bridge railing in rural and high-speed urban areas also requires special treatment considerations. Flaring the end section and the sidewalk away from the roadway is sometimes possible. In instances where this is not practical, a crash cushion or a section of approach guardrail parallel to the roadway with a suitable end terminal may be used. The presence of a curb may adversely affect the performance of this type of end treatment. Termination using parallel approach rail with a suitable end terminal is shown in Figure 7.8.

7.7 UPGRADING OF BRIDGE RAILINGS

This section provides general guidelines for highway agency personnel responsible for identifying and correcting potentially deficient bridge railings.

7.7.1 Identification of Potentially Deficient Systems

Since the primary purpose of a bridge railing is to prevent penetration, it must be strong enough to redirect an impacting vehicle. Bridge railings designed to AASHTO specifications prior to 1964 may not meet current specifications. Most railings properly designed after 1964, if tested, will contain and redirect a 2040 kg [4,500 lb] passenger car impacting at 100 km/h [60 mph] at an angle of 25 degrees. If the capacity of a railing appears questionable, further evaluation should be made to verify critical design details (such as base plate connections, anchor bolts, material brittleness, welding details, and reinforcement development) to ensure that the design meets the intent of the current specifications.

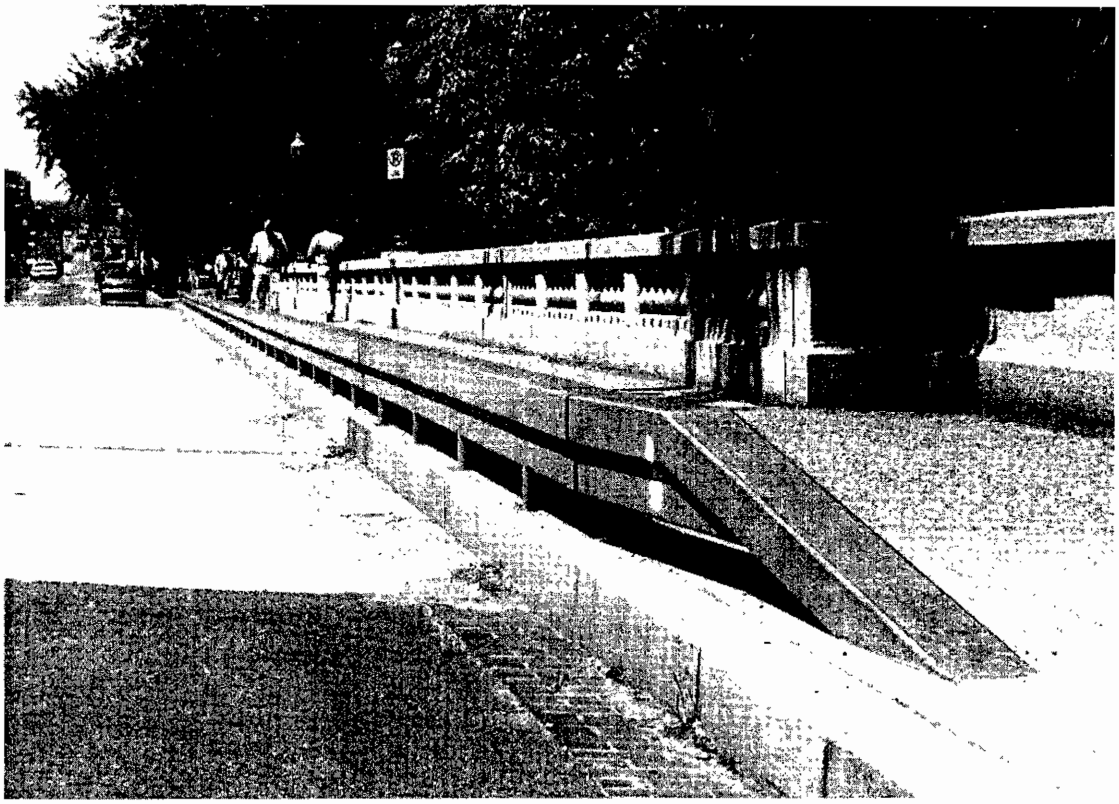


FIGURE 7.7 End treatment for traffic railing on a bridge in low-speed situations

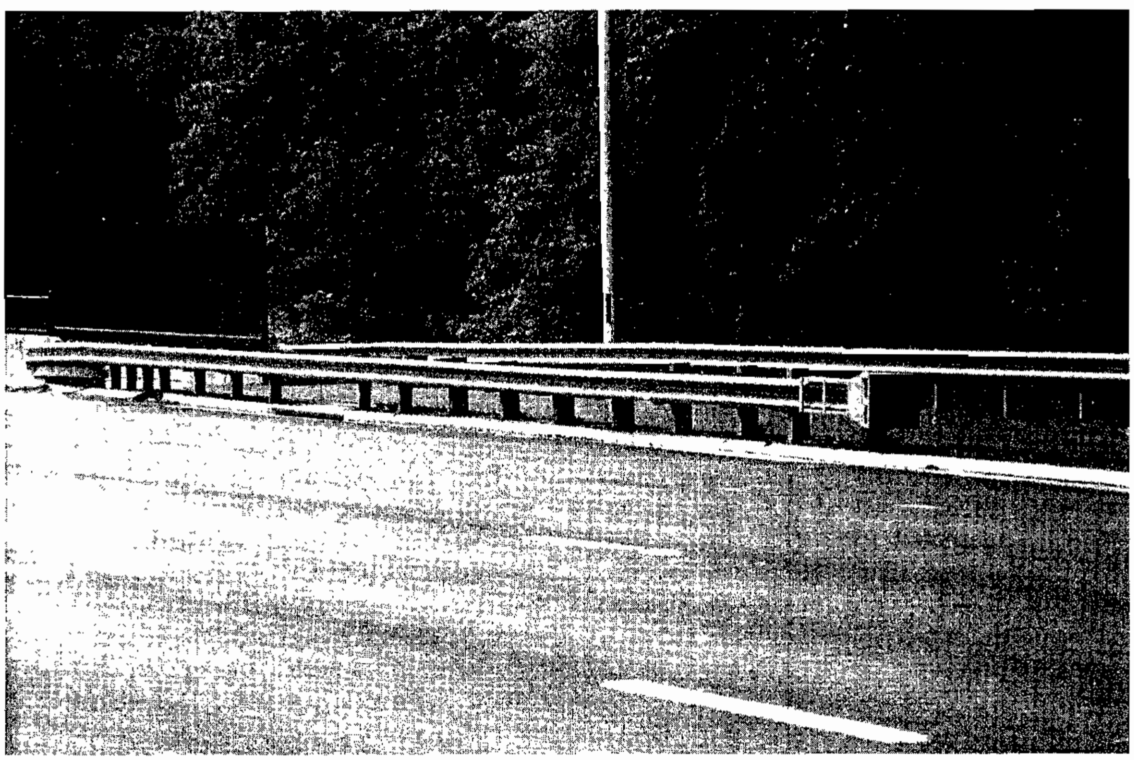


FIGURE 7.8 Terminating traffic barrier on bridge with end terminal

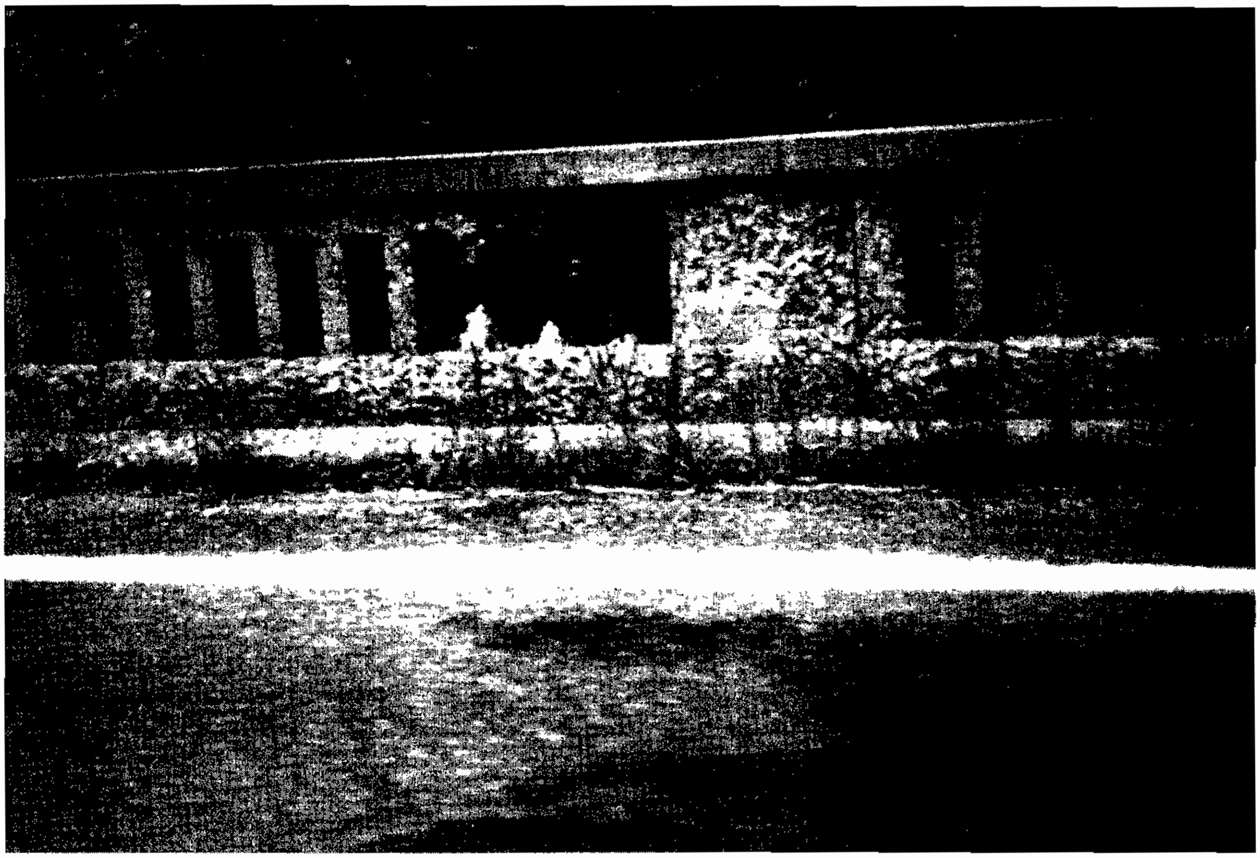


FIGURE 7.9 Inadequate railing strength

Occupant protection is also of considerable importance in a crash. Open-faced railings in particular may cause snagging, which produces high deceleration forces leading to occupant injuries. This type of deficiency can usually be detected best through full-scale crash testing or, in the case of an existing railing, through an analysis of available crash reports.

A third deficiency in many older railing systems is the presence of a curb or walkway between the driving lane and the bridge railing. The curb or the walkway may cause an impacting vehicle to go over the railing or at least strike it from an unstable position and subsequently roll over.

Finally, an adequate approach-rail to bridge-rail transition is essential as discussed in detail in Section 7.8. Figures 7.9 through 7.12 illustrate some of the more common deficiencies found in bridge railings designed before 1964. The next section identifies corrective measures that can be taken to improve the performance of these and similarly deficient systems.

7.7.2 Upgrading Systems

This section discusses only retrofit designs, i.e., changes, modifications, and additions to existing substandard railings that bring these railings up to acceptable performance levels. These retrofit designs may increase the strength of the railing, provide longitudinal continuity to the system, reduce or eliminate undesirable effects of curbs or narrow walkways in front of the bridge rail, and eliminate snagging potential. A retrofit design should also include an acceptable transition from the approach rail to the bridge rail itself.

One of the most common retrofit improvements consists of rebuilding the approach roadside barrier to current standards, including a transition section, and continuing the metal beam rail element across the structure to provide railing continuity. If the existing bridge has a safety curb, the retrofit railing can be blocked out to minimize the possibility of a vehicle ramping over the bridge railing. However, for most high-speed, high-volume roads, retro-

FIGURE 7.10 Lack of continuity in railing

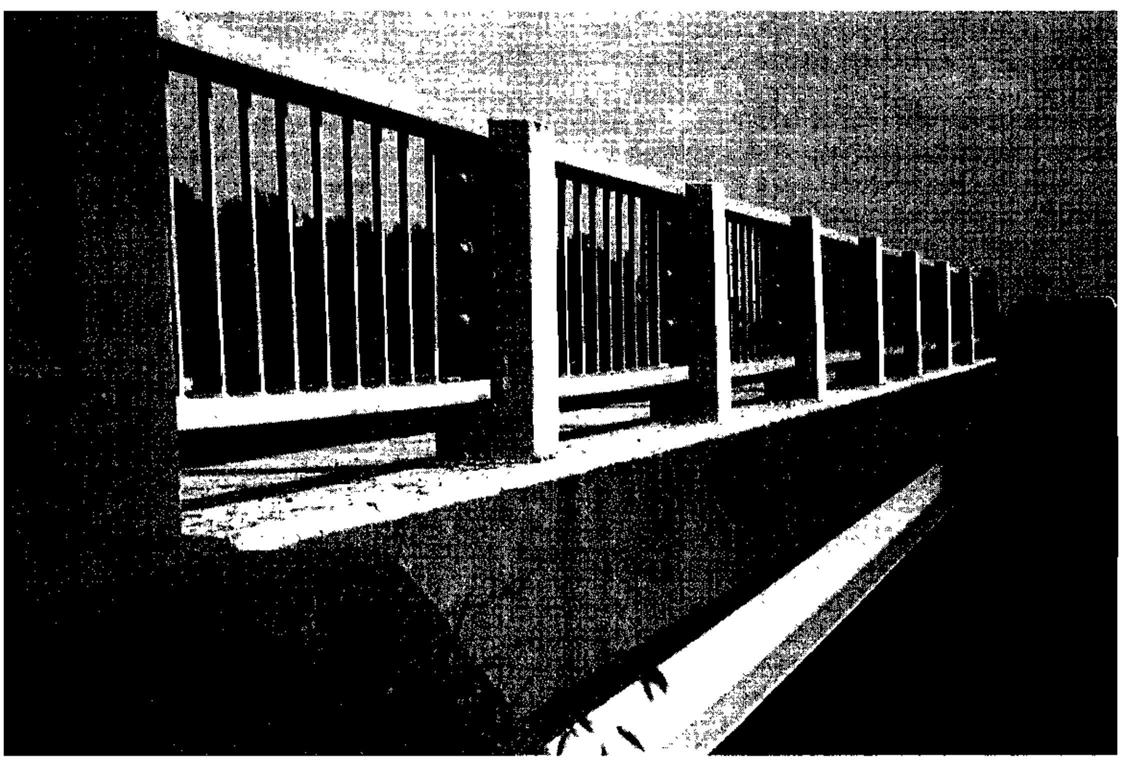


FIGURE 7.11 Snagging potential

FIGURE 7.12 Presence of brush curb

fit designs should be crash tested before they are used. The next sections of this chapter provide information on tested designs that can be used once a determination is made that retrofitting a substandard bridge railing is a cost-effective alternative to leaving an existing railing as is or constructing a new crash-tested railing.

Existing railings that do not meet current standards may sometimes be left in place until the section of highway that includes the bridge is brought to full standards. Until a complete upgrading is done, each existing railing should be evaluated to determine the safest and most cost-effective treatment: retention of the rail, retrofit, or replacement. In general, existing concrete post and open railing systems that predate 1964 must be replaced or retrofitted. However, many existing safety curb and parapet railings are still performing well. Even though they do not meet current full railing strength, they remain functional because they can contain and redirect out-of-control vehicles in all but the most severe impacts.

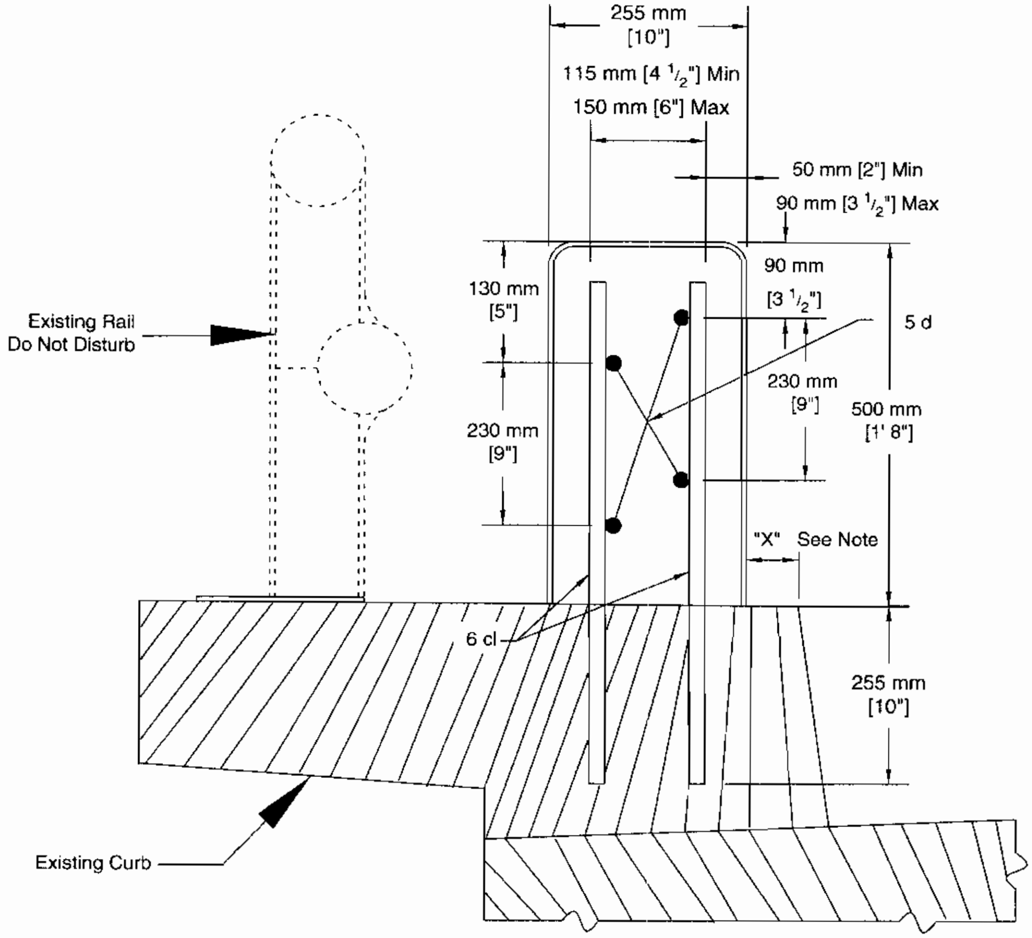
Some specific retrofit concepts that can be adapted to numerous types of deficient designs are:

- Concrete retrofit (safety shape or vertical)
- W-beam/thrie-beam retrofits
- Metal post and beam retrofits

These retrofits are illustrated in Figure 7.13 through Figure 7.15.

7.7.2.1 Concrete Retrofit (Safety Shape or Vertical)

The concrete safety shape that is commonly used for new construction can often be added to an existing substandard bridge railing as an economical retrofit design if the structure can carry the added dead load and if the existing curb and railing configuration can meet the anchorage and impact forces needed for the retrofit barrier. This design is most cost-effective when the existing railing can remain in place and does not require extensive modifica-



Note: On each side of bridge, dimension "X" can be a minimum of 1" and a maximum of 3", but must be constant for full length of bridge. However, approximately 10 linear feet at either end of rail length shall be transitioned to match existing beam guardrail attachment.

FIGURE 7.13 Iowa concrete block retrofit bridge railing

tions. Although a vertically faced retrofit can cause relatively high deceleration forces for sharp angle impacts, its addition to the top of an existing safety curb, as shown in Figure 7.13, creates an effective barrier. Care must be taken to avoid a protruding curb that can cause considerable wheel and suspension system damage and may contribute to vehicular vaulting in shallow angle impacts.

7.7.2.2 W-Beam/Thrie-Beam Retrofits

An inexpensive, short-term solution to the inadequacies of bridge railings designed before 1964 is to carry an approach roadside barrier (W-beam or thrie-beam) across the structure. While this treatment may not bring an existing bridge railing into full compliance with AASHTO design criteria, it can significantly improve the impact performance of a substandard railing. This treatment can be particularly cost-effective on low-volume roadways with structures having timber railings. Testing done in conjunction with the development of the side-mounted thrie-beam bridge railing (see Section 7.4.2) has shown that a bridge railing can be effective even if it deflects several feet upon impact. Continuous metal beam rail across a structure also eliminates one of the major problems of a bridge-rail/approach-rail transition, i.e., adequate anchorage to prevent the approach rail from pulling out on impact. By carrying the approach rail across the bridge, the only transition design elements that remain critical are gradual stiffening and elimination of a snagging potential. These concerns, too, become less critical if the bridge railing is not totally rigid, as is the case on some timber bridges.

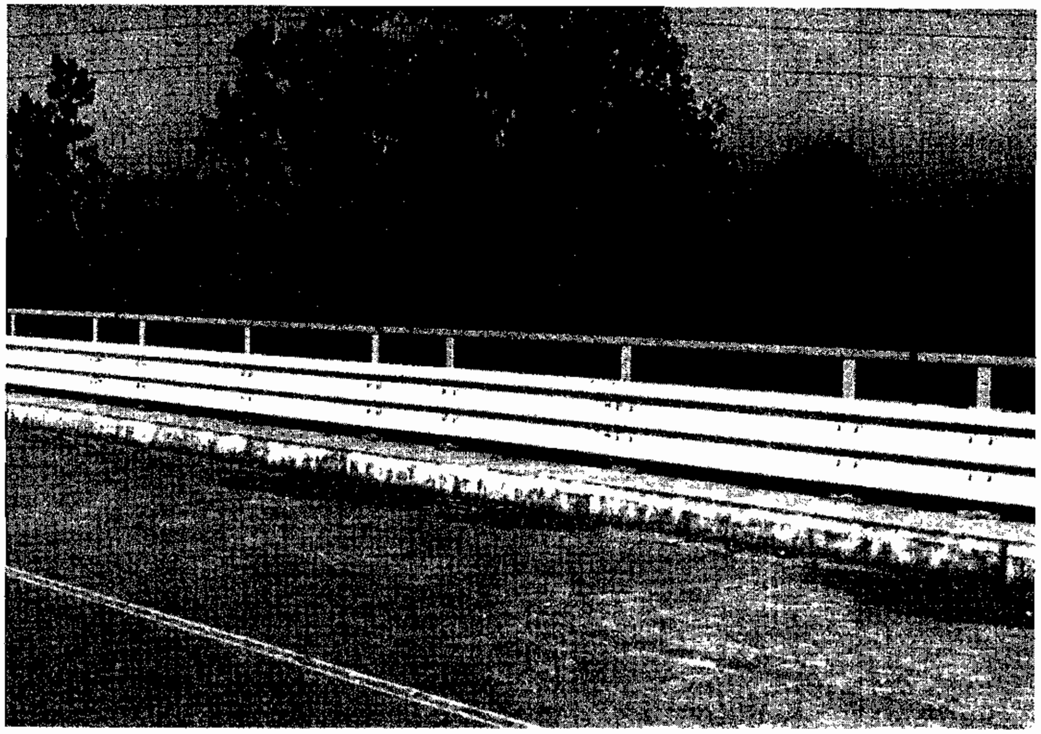


FIGURE 7.14 Thrie-beam retrofit (New York)

Both Washington and New York States have successfully crash tested thrie-beam retrofits of existing substandard railings. The New York design is shown in Figure 7.14.

7.7.2.3 Metal Post and Beam Retrofits

A metal post and beam retrofit railing mounted at the curb edge, such as that shown in Figure 7.15, may be appropriate for use on an existing structure that has a relatively wide raised walkway. This design functions well as a traffic barrier separating motor vehicles from pedestrians using a sidewalk across a bridge. In many cases, the existing bridge railing can be used as, or converted to, a pedestrian railing.

The post attachment to the curb or bridge deck can be designed to withstand the design loads contained in the current *AASHTO LRFD Bridge Design Specifications* or can be a yielding design that eliminates bridge deck damage in high-angle, high-speed impacts. The metal rail elements should be in line with the face of the curb and spaced to minimize the likelihood of vehicle intrusion and subsequent snagging on the posts.

7.8 TRANSITIONS

A transition section is needed where a semi-rigid approach barrier joins a rigid bridge railing. Transitions may not be necessary when bridge railings with some flexibility (such as the TL-2 bridge rail described in Section 7.4.2) are used. The transition design should produce a gradual stiffening of the overall approach protection system so vehicular pocketing, snagging, or penetration can be reduced or avoided at any position along the transition. Details of special importance for transitions are as follows:

- The approach-rail/bridge-rail splice or connection must be as strong as the approach rail itself so it will not fail on impact by pulling out and allowing a vehicle to strike the end of the bridge railing. The use of a cast-in-place anchor or through-bolt connection is recommended. The transition must also be designed to minimize the likelihood of snagging an errant vehicle, as well as one from the opposing lane on a two-way facility.

- Strong post systems (usually blocked out) or combination normal post and strong beam systems can be used on transitions to rigid bridge

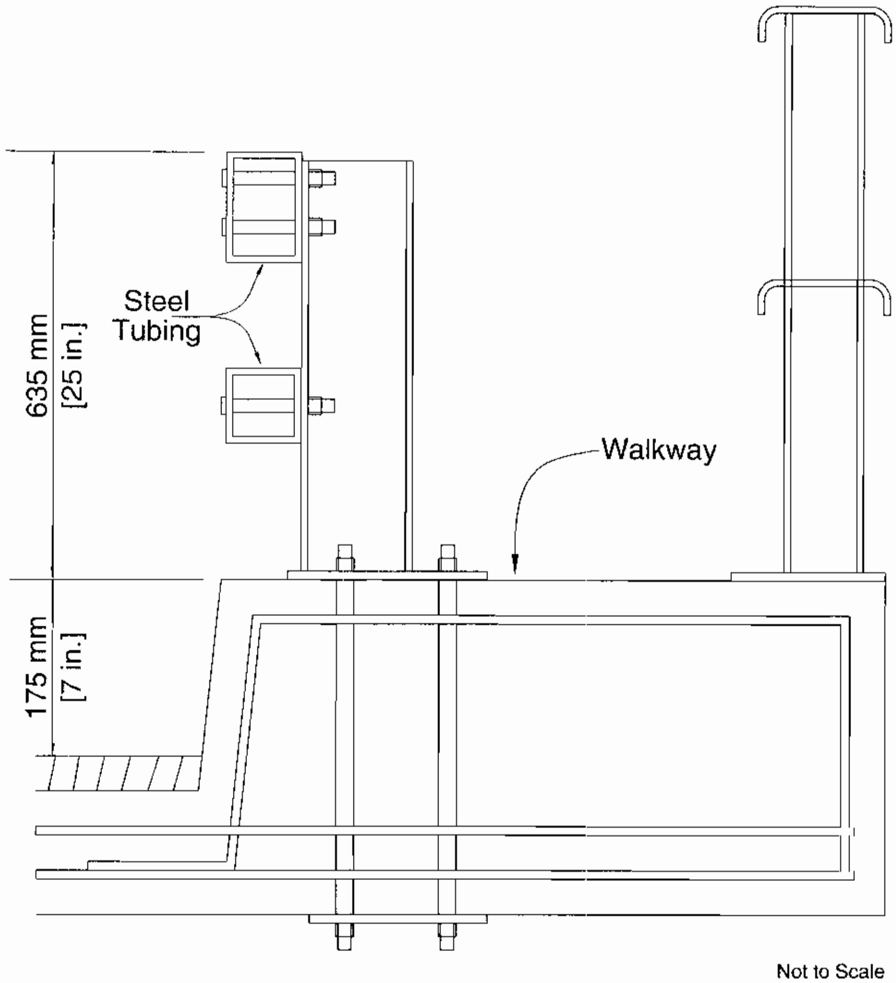


FIGURE 7.15 Metal post and beam retrofit

railings or other rigid objects. These systems should usually be blocked out from their posts unless the railing member is of sufficient width to prevent or reduce snagging to an acceptable level. However, block-outs or railing offsets alone may not be sufficient to prevent potential snagging at the immediate upstream end of the rigid bridge railing. A rubrail may be desirable in some designs using flexible W-beam or box-beam transition members. Tapering of the rigid bridge railing end behind the transition members at their connection point may also be desirable, especially when the approach transition is recessed into the concrete end of the bridge railing or other rigid object.

- The transition section should be long enough so that significant changes in deflection do not occur within a short distance. Generally, the transition length should be 10 to 12 times the difference in the lateral deflection of the two systems in question.

- The stiffness of the transition should increase smoothly and continuously from the less rigid to the more rigid system. This is usually accomplished by decreasing the post spacing, increasing the post size, or doing both, and by strengthening the rail element. W-beam or thrie-beam rail elements are typically strengthened by "nesting" two rails together.

- Drainage features such as curbs, raised inlets, curb inlets, ditches, or drainage swales, when constructed in front of barriers, especially in the transition area, may initiate vehicle instability that

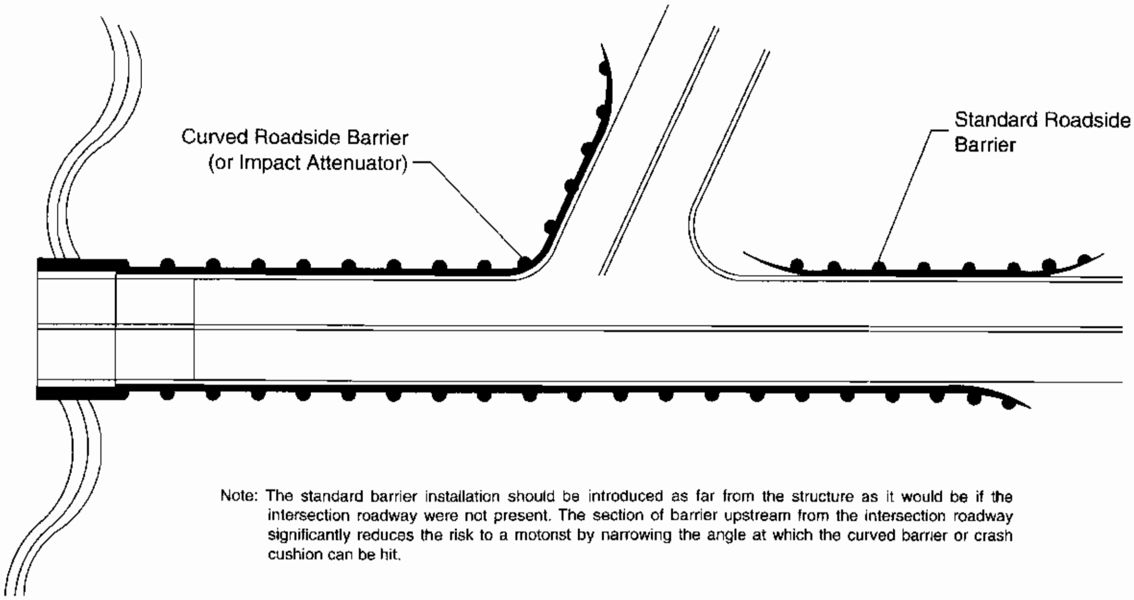


FIGURE 7.16 Possible solution to intersection side road near bridge

can, in some instances, adversely affect the crashworthiness of the transition. However, some transition designs incorporate a curb to reduce the probability of a vehicle snagging on the end of a rigid bridge railing. The slope between the edge of the driving lane and the barrier should be no steeper than 1V:10H.

When a minor road or driveway intersects a main road close to a bridge, it is often difficult to shield the bridge railing end adequately. The preferred solution is to close or relocate the intersecting road and install an approach railing with a standard transition section. If this solution cannot be done, curved guardrails that were crash tested to NCHRP Report 230 (4) can be used. An attempt should be made to ensure that errant vehicles do not go behind, through, or over the barrier. Some sacrifice in the crashworthiness of the barrier may be unavoidable in such circumstances, but the installation should be made as forgiving as possible. The use of appropriate crash cushions or other commercially available appurtenances may provide cost-effective solutions in some cases. Figure 7.16 depicts another possible solution using standard W-beam barrier that minimizes the risk to a motorist by shielding most of the object using a separate guardrail run. Because a motorist may hit the curved section of the rail at a very high angle, some states use weakened wood posts without offset blocks to support the curved section of rail. This design results in the posts breaking without significant leaning in the soil and permits capture of the impacting vehicle by the W-beam rail element. This curved guardrail design has been tested with 820 kg [1,800 lb] and 2040 kg [4,500 lb] passenger cars at 80 km/h [50 mph]. There is no curved guardrail design currently available that has met all NCHRP Report 350 evaluation criteria.

NCHRP Report 350 recommends that transitions be designed and crash tested to the test level appropriate for the intended application. Although the use of W-beam approach rail with neither an adequate blockout connection to the bridge rail nor a rubrail is relatively common, recent crash testing has shown that poor results are produced by allowing an impacting vehicle to snag on the end of the rigid bridge railing or concrete safety shape or parapet. These tests have also demonstrated that a more rigid guardrail transition to the bridge railing is necessary. This can be accomplished through: reduced post spacing; larger, longer, or both larger and longer posts; stronger rail elements (nested rail); and other special features.

Several new transition designs have been tested and proven satisfactory in accordance with NCHRP Report 350. Four of these designs are shown in Figures 7.17 through 7.20. The first two show transition details for a W-beam approach rail to a straight, vertical, concrete rail or end post and to a concrete safety-shape bridge rail, respectively. The third shows a thrie-beam transition to a modified safety-shape bridge railing. The fourth shows a thrie-beam transition to a curb-mounted steel post and beam bridge railing. Key design features of all these designs include:

FIGURE 7.17 W-beam transition to vertical concrete rail

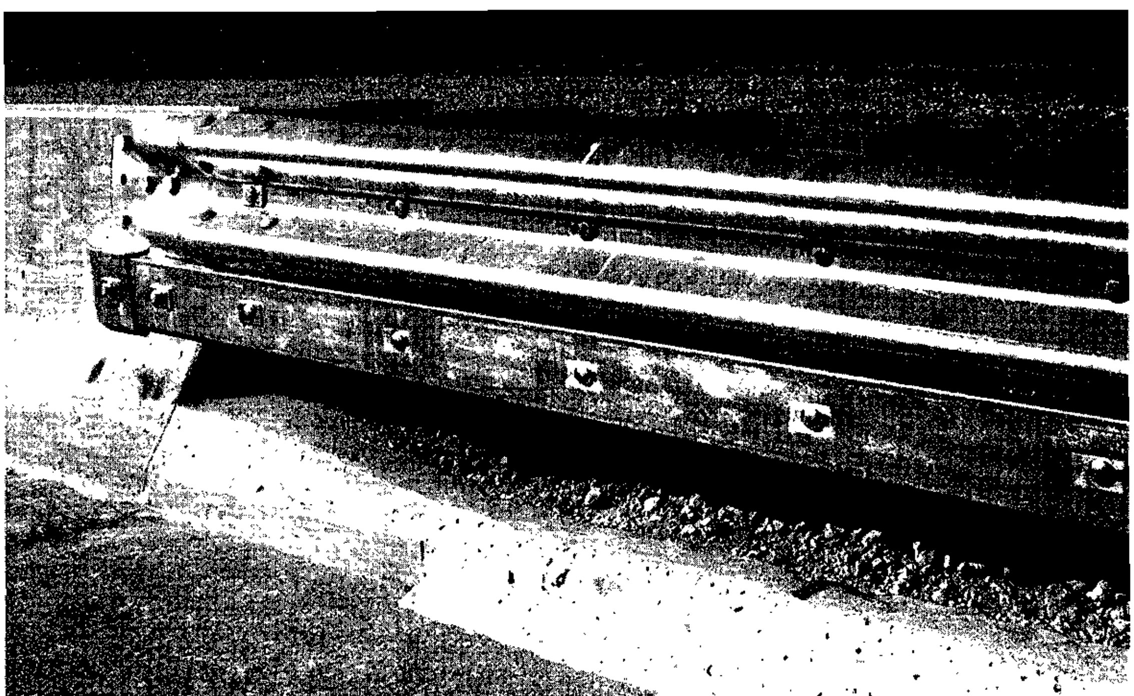


FIGURE 7.18 W-beam transition to modified concrete safety shape

FIGURE 7.19 Thrie-beam transition to modified concrete safety shape

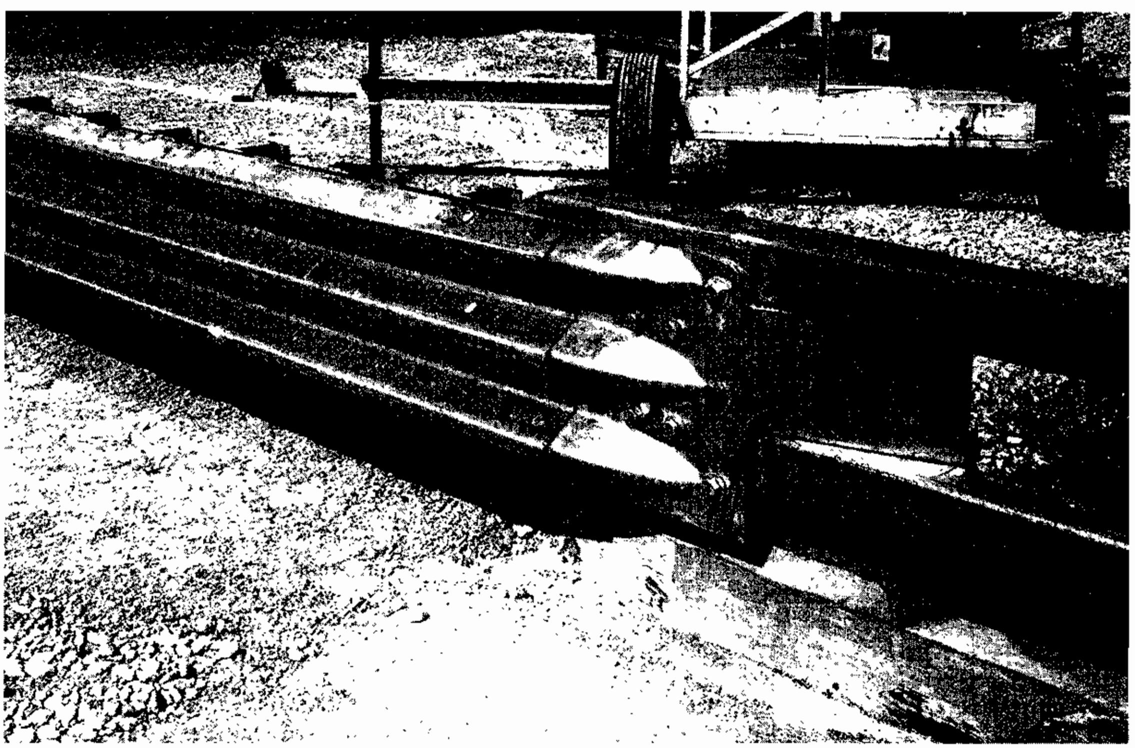


FIGURE 7.20a Thrie-beam transition to curb-mounted steel post and beam bridge railing

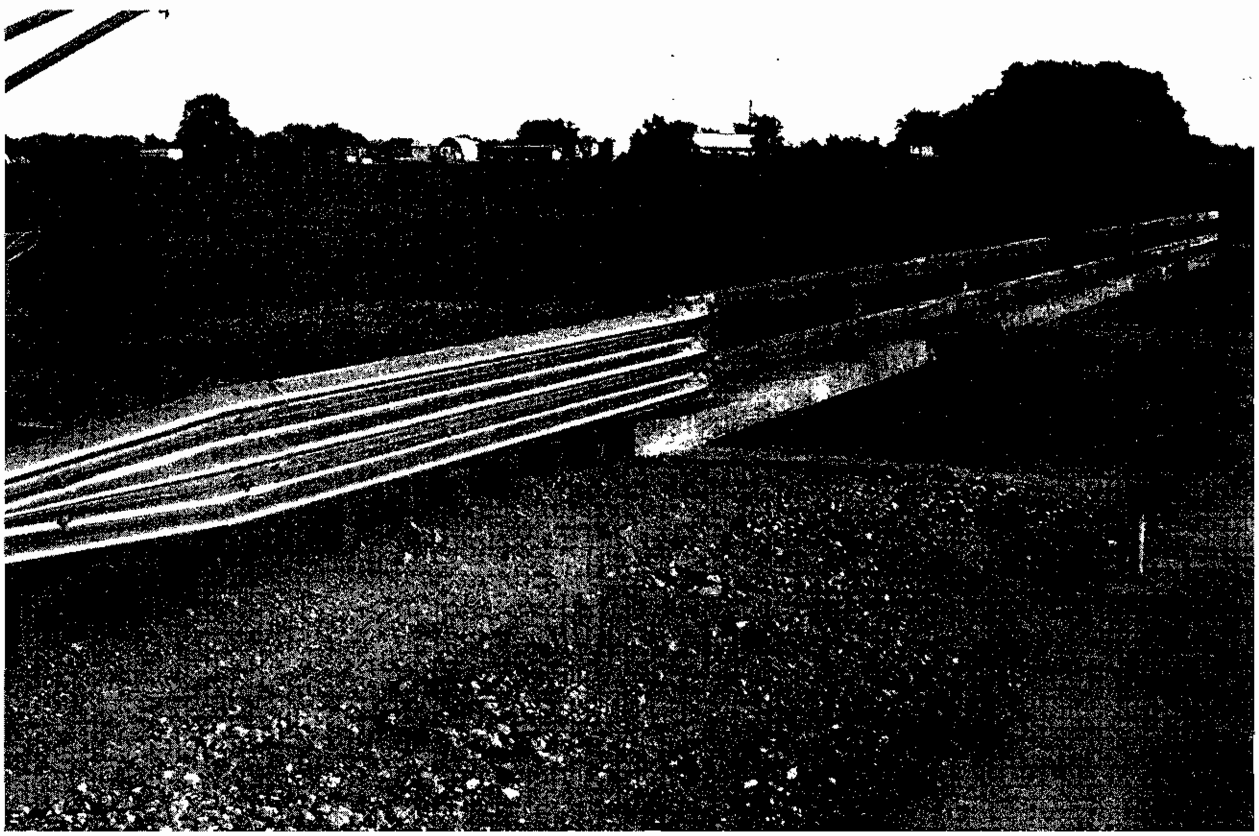


FIGURE 7.20b Thrie-beam transition to curb-mounted steel post and beam bridge railng

- larger, longer posts than were used in comparable NCHRP Report 230 (4) designs immediately adjacent to the parapet;
- nested W-beam or thrie-beam sections (one beam nested inside the other); and
- rubrail or tapered/flared concrete parapet (to minimize snagging at the bridge end).

Because relatively few transition designs have been tested to NCHRP Report 350, FHWA has agreed to the continued use of any transition design that was acceptable under NCHRP Report 230 (4) guidelines until October 2002 on the National Highway System. By then, it is anticipated that several NCHRP Report 350 designs will be available for use.

REFERENCES

1. Ross, H. E., Jr., D. L. Sicking, and R. A. Zimmer. *National Cooperative Highway Research Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Transportation Research Board, Washington DC, 1993.
2. AASHTO. *Standard Specifications for Highway Bridges*. American Association of State Highway and Transportation Officials, Washington, DC, 1996.
3. AASHTO. *AASHTO LRFD Bridge Design Specifications*. American Association of State Highway and Transportation Officials, Washington, DC, 1998.
4. Michie, J. D. *National Cooperative Highway Research Program Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. Transportation Research Board, Washington, DC, 1981.

solid-faced barrier such as a concrete safety shape is least likely to cause traumatic injuries to cyclists upon contact.

5.3 PERFORMANCE LEVEL SELECTION FACTORS

Most roadside barriers were developed, tested, and installed with the intention of containing and redirecting passenger vehicles with masses up to 2000 kg [4,400 lb]. Properly designed and installed barrier systems have proven to be very effective in reducing the amount of damage and lessening the severity of personal injuries when struck by automobiles and similar-sized vehicles at relatively shallow angles (less than 25 degrees) and at reasonable impact speeds (less than 110 km/h [65 mph]). However, it has long been understood that barriers designed for cars should not be expected to perform equally well for larger vehicles, such as buses and trucks. Recognizing this fact, several highway agencies have developed and used barrier systems capable of redirecting vehicles as heavy as 36,000-kg [80,000-lb] tractor-trailer combination trucks. Although objective warrants for the use of higher performance traffic barriers do not presently exist, subjective factors most often considered for new construction or safety upgrading include:

- high percentage of heavy vehicles in traffic stream,
- adverse geometrics, such as sharp curvature, which are often combined with poor sight distance, and
- severe consequences associated with penetration of a barrier by a large vehicle.

These same factors apply on reconstruction or rehabilitation projects but, in these cases, the designer will usually have the added benefit of past crash history, the past performance of the system, and maintenance costs associated with the existing barrier. In addition, a higher performance barrier is likely to lessen the severity of future crashes or reduce maintenance costs significantly. Section 5.4 includes information on the size of vehicle for which each system has been successfully crash tested.

5.4 STRUCTURAL AND SAFETY CHARACTERISTICS OF ROADSIDE BARRIERS

This section includes information on the most commonly used operational roadside barriers as well as data on selected experimental systems. Separate subsections address standard sections of roadside barriers and transition sections. Figure 5.4 graphically depicts each of these elements for typical installations. Information on the structural and safety characteristics of each system is presented in a narrative format, and includes the following information:

- a photograph or sketch of the barrier.
- a barrier description showing the main elements of the barrier and post spacing. Prior to selection of a specific barrier system, the designer should

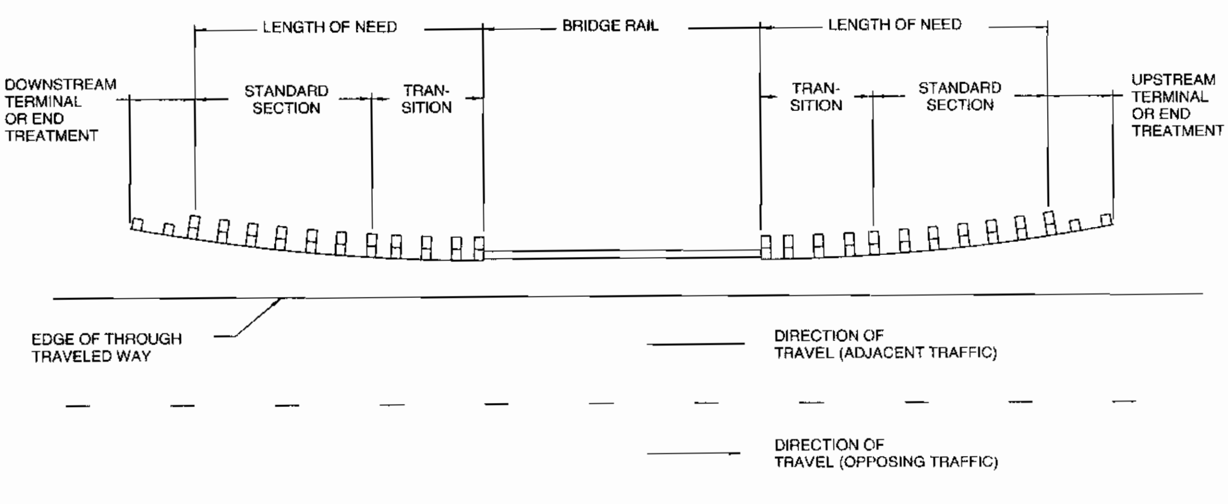


FIGURE 5.4 Definition of roadside barriers