SECTION 13
RAILINGS

13.1 GENERAL REQUIREMENTS

This section will provide guidance on the selection, design, and construction requirements for bridge railing. For pedestrian, bicycle, and safety railing requirements, refer to Section 2.4 of this BDM and to AASHTO.

Traffic railings provide protection at the edges of traffic and pedestrian structures and in median areas to prevent crossover collisions. In achieving this function, the railing must have the strength to withstand the vehicular impact and safely contain and redirect vehicles without snagging or overturning.

CDOT Bridge Rail Type 9 and Type 10 MASH are provided by CDOT to meet MASH 2016 Test Level 4 (TL-4) and in some cases TL-5 requirements. They are to be used on all new and widened bridges, box culverts, and retaining walls. M-Standard options such as inside mounted MGS rail on CBCs or MGS rail a minimum of 3 feet away from wall faces are acceptable options but only provide TL-3 protection. Other available or retired Colorado railing systems shall be used only with approval from the State Bridge Engineer in coordination with the bridge rail SMEs.

Any other proposed railing system shall be documented to be MASH compliant by meeting the full-scale crash test criteria established in the most current AASHTO *Manual for Assessing Safety Hardware* (MASH), professional evaluation by a crash test facility, comparative analysis to other crash test rails, non-linear time dependent FEM analysis and/or analysis through AASHTO LRFD Appendix A13 with the latest loads from crash testing research and experience. The previous list is in order of preference. Due to the complicated nature of crash and impact mechanics, the best evaluation of a bridge rail system is a physical crash test. Transitions should be evaluated using the same criteria.

AASHTO defines TL-4 as “taken to be generally acceptable for the majority of applications on high speed highways, freeways, expressways and Interstate highways with mixture of trucks and heavy vehicles.” For local agency projects a test level lower than TL-4 may be accepted by CDOT Staff Bridge based on design speed, ADT and other factors but any rail systems and transitions shall still be MASH compliant for the selected test level. A variance/risk recognition letter will be required from the local agency as well as attesting data supporting the bridge rail selected (evaluation factors, test level etc.).

MASH testing involves utilizing vehicles with characteristics similar to, or more critical than, 85% to 95% of vehicles of the type and speeds and angles of incidence similar to, or more critical than, 85% to 95% of road departure incidences. Actual crash conditions are at least partially random and chaotic in behavior so design and testing does not assure benign behavior during all crash incidents. Bridge rail design and evaluation should:

- Use best available methods (MASH criteria, current research, similarity with Crash tested rails, professional evaluations, non-linear time dependent FEM analysis, AASHTO Chapter 13).
- Use redundancy to protect from the unknown or occurrences beyond assumptions. Prevent progressive collapse under realistic but rare loads.
- Promote continuity in rail system
- Avoid obvious snag points or spearing issues
- Avoid transitions with markedly different stiffness

CDOT will monitor in-service behavior of rail types to identify flaws in design or operation. Most fatalities associated with rail are due to rollovers or "bouncing" out into thru traffic for another collision (vehicle interaction). Deflection of a rail system reduces occupant injury potential and the tendency for the vehicle to be thrown back into traffic, if without penetration or "pocketing". Looking at old bridge rails, abutments, and piers that previously lacked motorist protection you will occasionally come across little crosses painted or scratched into them. There is a reason that bridge rail ends were called tombstones. CDOT will make any crash test results and evaluations of current bridge rails available upon request.

13.2 CODE REQUIREMENTS

The design of the railings shall be in accordance with AASHTO and MASH criteria and follow current Staff Bridge Worksheets, when applicable.

13.2.1 AASHTO LRFD

Bridge railing test levels and crash criteria shall be in accordance with AASHTO and MASH. The minimum test level shall be TL-4 for all new bridges, culverts, and retaining walls except as described in Section 13.1.

AASHTO 13.7.2, Table 13.7.2-1

Railing design, including, but not limited to, height of traffic barrier or railing, bicycle railing, pedestrian railing, and design live loads for pedestrian railings, shall adhere to AASHTO and MASH evaluation criteria.

AASHTO Section 13

Railing geometry and anchorages shall be in accordance with AASHTO and MASH.

AASHTO Appendix A13

Traffic railing design forces for concrete railing and post and beam railing shall follow AASHTO and MASH criteria.

AASHTO A13.2, A13.3.1, A13.3.2

Design calculations are not required to be performed for Type 9 and Type 10 MASH bridge railings, provided they are not modified to affect performance from the worksheet details.

13.2.2 AASHTO Manual for Assessing Safety Hardware (MASH)

MASH is the state of practice for crash testing of safety hardware devices for use on the NHS. It updates and replaces NCHRP Report 350 *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

MASH presents uniform guidelines for crash testing permanent and temporary highway safety features and recommends evaluation criteria to assess test results.

- All new testing will follow MASH evaluation techniques.
- Guardrail hardware shall meet MASH requirements for replacement and new installation.
- All new products must be tested using MASH crash test criteria for use on the NHS.

MASH loads and evaluation are based on the most recent research and crash testing and is typically more up to date than the AASHTO Chapter 13 analysis. Below are the loads that should be used in any evaluation or analysis of existing or new rails. New rails designed for TL-2 should have a minimum height of 24". Although there are a few crash tested TL-2 bridge rails with 18" height, 24" minimum is required. These will require a variance.

Design Forces for Traffic Railings

Test Level	Rail Height (in.)	F_t (kip)	F_L (kip)	F_v (kip)	L_t/L_L (ft)	L_v (ft)	H_e (in)	H_{min} (in)
TL-1	18 or above	13.5	4.5	4.5	4.0	18.0	18.0	18.0
TL-2	18 or above	27.0	9.0	4.5	4.0	18.0	20.0	18.0
TL-3	29 or above	71.0	18.0	4.5	4.0	18.0	19.0	29.0
TL-4 (a)	36	68.0	22.0	38.0	4.0	18.0	25.0	36.0
TL-4 (b)	between 36 and 42	80.0	27.0	22.0	5.0	18.0	30.0	36.0
TL-5 (a)	42	160.0	41.0	80.0	10.0	40.0	35.0	42.0
TL-5 (b)	greater than 42	262.0	75.0	160.0	10.0	40.0	43.0	42.0
TL 6		175.0	58.0	80.0	8.0	40.0	56.0	90.0

References:

- TL-1 and TL-2 Design Forces are from AASHTO LRFD Section 13 Table A13.2-1
- TL-3 Design Forces are from research conducted under NCHRP Project 20-07 Task 395
- TL-4 (a), TL-4 (b), TL-5 (a), and TL-5 (b) Design Forces are from research conducted under NCHRP Project 22-20(2)

13.2.3 FHWA Bridge Rail Requirements

FHWA mandated all new bridges carrying traffic on the NHS to have crash tested railing in accordance with MASH 2016

All projects on the NHS after December 31, 2019, shall be at least TL4 MASH compliant bridge rail systems per CDOT requirements.

Existing bridge rails not meeting the above FHWA mandate should be evaluated based on site and traffic conditions and the condition of the existing railing. Rails that are too short or too weak for the appropriate TL level should

be replaced. For additional information about evaluation and rehabilitation of existing bridge rail, refer to Section 2.4.1.1 of this BDM.

13.3 CDOT BRIDGE RAILS

The region typically selects the rail type, which shall be documented in the Structure Selection Report. Corridor requirements, aesthetics, hydraulics, environmental concerns, maintenance, snow removal, and railroad crossings shall be used in the selection. The use of weathering steel is not allowed for bridge railing. Galvanizing of steel portions of a bridge rail is the minimum standard required. In cases where the steel portion of the bridge rail is to be painted for aesthetic or other reasons, it must be done in addition to galvanizing using a duplex coating system. Details for Rail Type 9 and 10MASH can be found in the Staff Bridge Worksheets and Section 2.4 of this BDM. Bridge Rail Types 3, 4, 7, 8 and 10 have been retired but are prevalent on CDOT's roadways and should be used only for rehabilitation of the existing railing. Details can be obtained from Staff Bridge if not on the website. The following railings are available for use.

13.3.1 Type 3 (Retired)

Bridge Rail Type 3 is composed of continuous steel W shape attached to steel posts. The posts can be mounted on a bridge deck, a concrete box culvert top slab or headwall, or the top of a retaining wall. It should be used only for a railing repair of an existing bridge that has Type 3 on it. This railing shall not be used on CDOT structures without prior approval from State Bridge Engineer in coordination with the Bridge Rail SMEs. Due to primarily height issues, Type 3 bridge rail is most likely TL-2 or below and may need to be replaced or modified as safety funding allows.

13.3.2 Type 4 (Retired)

Bridge Rail Type 4 is a reinforced concrete barrier with a sloped front face. This type of barrier is not allowed for use on new bridges or as part of rail replacement rehabilitation projects. This rail, however, remains in service on several existing bridges and may require repair if damaged. Details for Type 4 barrier are not in the Staff Bridge Worksheets but can be obtained from Staff Bridge upon request. Due to primarily height issues, Type 4 bridge rail is most likely TL-3 or below and may need to be replaced or modified as safety funding allows.

13.3.3 Type 7 (Retired)

Bridge Rail Type 7 (F-shape) is a reinforced concrete barrier with a sloped front face. This type of barrier is no longer allowed for use on new bridges or as part of rail replacement rehabilitation projects. This rail, however, remains in service on several existing bridges and may require repair if damaged. Details for Type 7 barrier are not in the Staff Bridge Worksheets but can be obtained from Staff Bridge upon request. Due to primarily height issues, Type 7 bridge rail is TL-3 or below and may need to be replaced or modified as safety funding allows.

13.3.4 Type 8 (Retired)

Bridge Rail Type 8 is composed of a continuous horizontal steel tube attached to steel tube posts. The posts are mounted on a reinforced concrete curb anchored to the bridge deck. Use of this railing originated during the construction of the I-70 corridor through Glenwood Canyon. For aesthetic reasons, use of this rail may be allowed for repairs. This railing shall not be used on new CDOT structures without prior approval from State Bridge Engineer in coordination with the Bridge Rail SMEs. It is classified as a TL-2 railing by NCHRP 350 although a recent crash test article passed a TL-3 crash test. Due to primarily height issues, Type 8 bridge rail is TL-3 or below and may need to be replaced or modified as safety funding allows.

13.3.5 Type 8R MASH

Bridge Rail Type 8R MASH is composed of a continuous horizontal steel tube attached to steel tube posts. The posts are mounted on an existing reinforced concrete curb anchored to the bridge deck. This rail is intended for retrofits or rehabilitation of existing Type 8 rail (primarily in Glenwood Canyon) and is crash tested to a TL-3 level.

13.3.6 Type 10 (Retired)

Bridge Rail Type 10 is composed of two continuous horizontal steel tubes attached to steel W shape posts on top of a concrete curb. This type of barrier is no longer allowed for use on new bridges or as part of rail replacement rehabilitation projects. This rail, however, remains in service on several existing bridges and may require repair if damaged. Details for Type 10 barrier are not in the Staff Bridge Worksheets but can be obtained from Staff Bridge upon request. Due to primarily height issues, Type 10 bridge rail is TL-3 or below and may need to be replaced or modified as safety funding allows. The Type 10 bridge rail with 12’-6” spacing is weaker than the 10’-0” spacing.

13.3.7 Type 9

Bridge Rail Type 9 (Single Slope) is a reinforced concrete barrier with a sloped front face. This bridge rail meets MASH requirements for TL-4 and in some cases TL-5. This bridge rail can be mounted to a bridge deck, to a moment/gravity slab, or on top of cast-in-place retaining walls. CDOT requires the use of Bridge Rail Type 9 or Type 10 MASH on all new and rehabilitated bridges, concrete box culverts, and retaining walls. To maximize splash protection and allow easier installation of protection panels, this is generally the required railing for bridges over railroads.

13.3.8 Type 10 MASH

Bridge Rail Type 10 MASH is composed of two continuous horizontal steel tubes attached to steel W shape posts on top of a concrete curb. Type 10 MASH rails meet AASHTO and MASH TL-4 requirements and in some cases TL-5. CDOT requires the use of Bridge Rail Type 10 MASH or 9 on all new and rehabilitated bridges, concrete box culverts, and retaining walls. Because of splash and railroad requirements, this rail may not be allowed for bridges over railroads without additional features. See Section 13.6 for conduit restriction in the railing.

13.4 COMBINATION VEHICULAR PEDESTRIAN RAILS

Combination vehicular pedestrian railings shall be used at the edge of deck when the sidewalk is not protected from traffic. If the sidewalk is protected from traffic, the edge of deck shall protect the pedestrians with a fence or another combination railing. Combination vehicular and pedestrian railing shall meet AASHTO requirements. Galvanizing of steel portions of rail is the minimum standard required. In cases where the steel portion of the bridge rail is to be painted for aesthetic or other reasons, it must be done in addition to galvanizing using a duplex coating system.

AASHTO 13.10

13.5 PIER AND RETAINING WALL PROTECTION

13.5.1 Pier Protection

Piers or abutments located inside the clear zone, as defined by AASHTO *Roadway Design Guidelines,* and not designed to resist the vehicular collision force (CT) shall be protected with a TL-5 rated barrier, approved by the State Bridge Engineer in coordination with the Bridge Rail SMEs, that meets AASHTO and MASH crash test requirements. Because CDOT does not have an approved TL-5 barrier, the Designer may submit a crash tested TL-5 barrier from another state to State Bridge Engineer and Bridge Rail SMEs for review and possible acceptance. The submittal shall include all documentation showing conformance to current criteria outlined in AASHTO, MASH, this BDM, and FHWA acceptance. If a TL-5 barrier is not used as pier protection, the pier shall be designed to resist the CT load in accordance with AASHTO.

AASHTO 3.6.5.1, Section 13

For piers located inside the clear zone and designed for the CT force, the Designer shall consult the CDOT Project Manager to determine if safety protection is still desired.

Clear zone to the pier shall be determined at the ultimate configuration of the roadway adjacent to the pier. It shall consider all anticipated widenings.

13.5.2 Retaining Wall Protection

When a retaining wall front face is located within the clear zone or when requested by the region, it shall be protected by a barrier. See Section 11.5.11 of this BDM for details.

13.5.3 Sound Barriers

Sound barriers within the clear zone shall meet AASHTO collision requirements. The Designer shall coordinate with the region and roadway engineer to determine the type of protection and setback. If the sound barrier is outside the clear zone, it does not need to be designed for collision.

AASHTO 15.8.4

13.5.4 Rail Anchor Slabs

Bridge rails are often required on retaining walls, culverts, and or other structural systems. Due to the significant loads associated with vehicular impact, railings can be connected to an independent structural foundation called a rail anchor slab. The Designer shall evaluate the cost difference between mounting the barrier directly to the structure or using a rail anchor slab.

To avoid excessive damage from an impact, expansion joint material or other type of separator shall be installed between the nose of the anchor slab and the wall facing below. The Designer shall evaluate vertical and lateral loads that may be transferred from the anchor slab to the wall element below during a vehicular impact.

When a rail anchor slab is required to be designed, the Designer shall use the recommended design procedures from NCHRP Report 663 and outlined in the BDM Example 12, Moment Slab Design. For anchor slab details on MSE walls, the Designer should reference the Staff Bridge Worksheets for MSE walls.

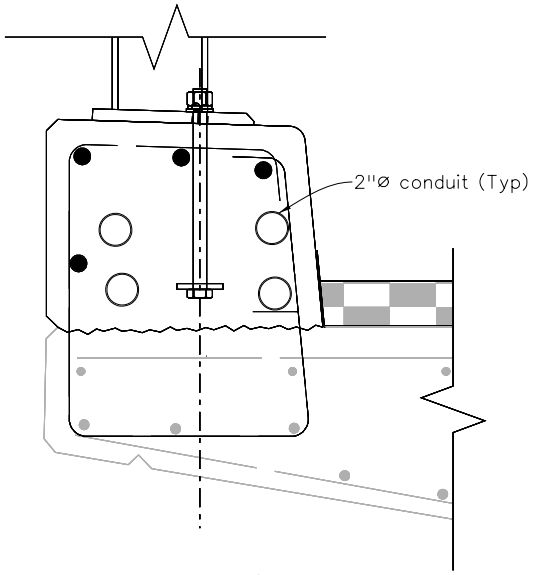
13.6 ATTACHMENTS TO AND CONDUITS IN BRIDGE RAIL SYSTEMS

During collisions with barrier systems, it has been shown that vehicles slide along the top of the barrier and that parts of the vehicle extend over the barrier a considerable distance. This envelope of the vehicle encroaching beyond the barrier is known as the zone of intrusion. Attachments to barrier systems within the zone of intrusion, such as fencing, signs, and light poles, should address safety concerns such as snagging, spearing, and debris falling into traffic below. The amount of intrusion is related to the height and profile of the barrier, as well as the vehicle size, speed, and angle of impact. See NCHRP Research Report 1018: Zone of Intrusion Envelopes Under MASH Impact Conditions for Rigid Barrier Attachments as a reference. The Designer should minimize any attachments to the railing system within this zone whenever possible. Attachments within this zone will affect the safety of the bridge rail. Whenever possible, light poles should be located behind the back face of the barrier.

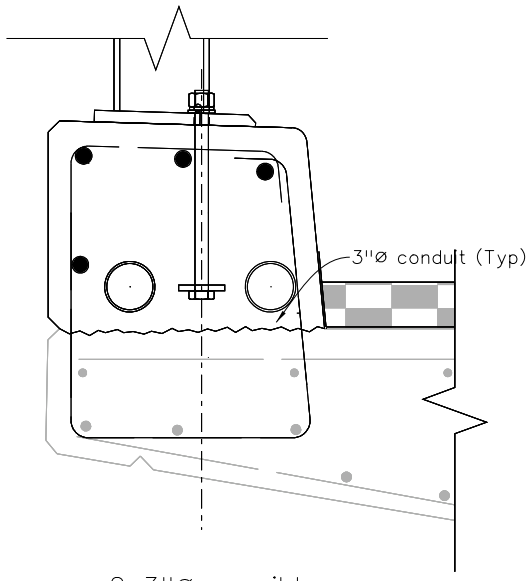
The curb of 10 MASH bridge rails limits the number and size of conduits to assure ease of placement and proper consolidation of concrete. Requirements for location of conduits inside the curb are:

- 1" min. clear from the construction joint between bottom of the curb and the deck
- 1.5" clear spacing between rebar and conduit and between each conduit

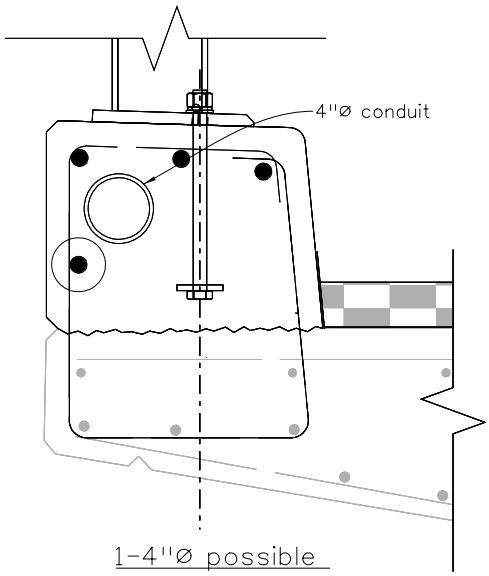
A maximum number of four 2"⌀, two 3"⌀ with 1- 2"⌀ or 1-4"⌀ with 1-3"⌀ conduit are allowed. Conduits placed in excess of this are at a greater risk of damage due to vehicle collisions. Using galvanized rigid conduit will minimize damage as well. See below figure of 10 MASH curb about conduit configuration.



4-2"ø possible conduits configuration



2-3"ø possible conduits configuration



1-4"ø possible conduits configuration

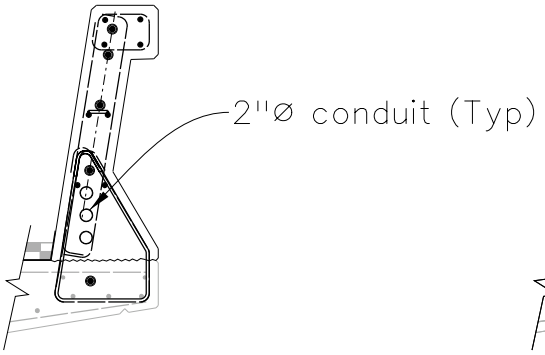
According to the crash test result at the location of the steel post for 10 MASH bridge rails, spalled concrete was observed on the back of the curb as well as cracks on the front face. Based on this observation, placing conduits close to the front face of the curb should have less potential damage risk than on the back. For higher risk systems such as Intelligent Transportation Systems (ITS) locations should be limited to 2-2"⌀ conduit placed close to the front face of the curb with an additional requirement of change to "5.5" minimum from top of curb. When using higher risk systems such as Intelligent Transportation Systems (ITS) conduit, the designer should consider Type 9 bridge rail to reduce damage potential. ITS conduits may still have a certain degree of damage after collision regardless of their locations inside the curb.

The Type 9 bridge rail also limits the number and size of conduits to assure ease of placement and proper consolidation of concrete but provides more flexibility. Requirements for location of conduits inside the rail are:

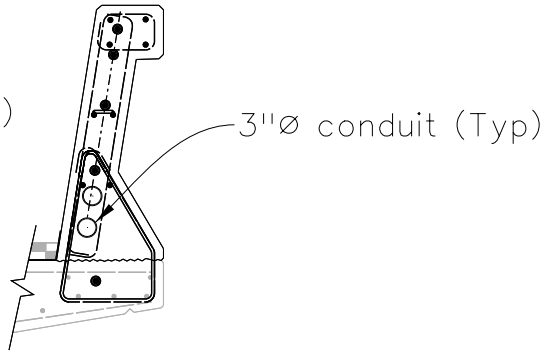
•1" min. clear and 15” max from the construction joint between curb and deck

•1.5" clear spacing between rebar and conduit and between each conduit

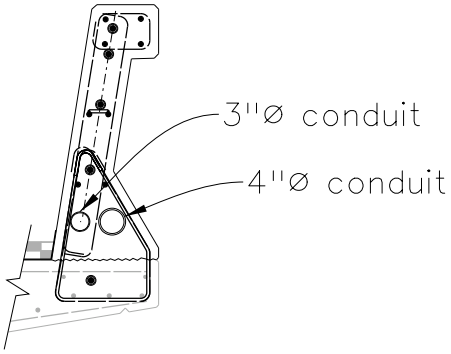
The maximum number of 3-2"⌀, 2-3"⌀ or 1-4"⌀ with 1-3"⌀ conduit are allowed. See below Figure of Bridge Rail Type 9 about conduit configuration. Conduits placed in excess of this are at a greater risk of damage due to vehicle collisions. Using galvanized rigid conduit will minimize damage as well.



3-2"Ø possible conduits configuration



2-3"Ø possible conduits configuration



1-4"Ø and 1-3"Ø possible conduits configuration

13.7 AESTHETIC TREATMENTS TO BRIDGE RAIL SYSTEMS

Except for color treatments, aesthetic enhancements shall not be applied to the traffic face of the barrier systems. Applying aesthetic enhancements to this face increases the likelihood of vehicle snagging and damage caused by snowplows, thereby increasing maintenance costs, and decreasing traveler safety.

13.8 RAILING ATTACHMENT TO HEADWALLS

If a railing is attached to a headwall on a culvert, the Designer shall analyze the structure for collision loading. Headwall mounted barriers are required only if they are within the clear zone and not protected with a roadway barrier.