MASH Implementation for Bridges

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Introduction

A December 21, 2015 agreement between the American Association of State Highway Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) requires that for contracts on the National Highway System (NHS) with a letting date after December 31, 2019, only safety hardware evaluated using the 2016 edition of the *Manual for Assessing Safety Hardware* (MASH) criteria will be allowed for new permanent installations and full replacements for bridge railings.

"Railings" is used as a generic term in the specifications and includes traffic railings, combination railings, bicycle railings, and pedestrian railings. MnDOT further classifies railings as follows:

- Barriers – Concrete railings that have a non-vertical traffic face (e.g. - Type S).
- Parapets – Concrete railings that have a vertical traffic face and a brush curb (e.g. - Type P-4).
- Metal Railings – Steel Railings mounted on curbs, parapets, or the back of barriers (e.g. - Ornamental Metal Railing, Design T-4).

MASH was originally published in 2009, with a second edition issued in 2016. MASH procedures were developed as a replacement for the testing procedures defined by NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, which was originally published in 1993 and implemented in 1998. There were three reasons that the procedures were updated: updates to the vehicle fleet, removal of inconsistencies in impact condition criteria, and improving clarity in evaluation criteria.

The changes in the vehicular fleet have led to changes in the vehicles used for the testing. The test vehicles were updated between NCHRP 350 and MASH to reflect the current 85th percentile of the passenger vehicle fleet in the United States. For example, the loads for the single-unit van truck have changed from 18 kips with a center of gravity at 49 inches in NCHRP 350 to 22 kips with a center of gravity at 63 inches in MASH. The full comparison at all test levels is found in Table 1.

Previously, MnDOT policy for new installation has been to require bridge railings that meet NCHRP Report 350 Test Level 4 (TL-4) on bridges with design speeds greater than 40 mph and TL-2 on bridges with design speeds less than or equal to 40 mph. This document defines policy moving forward.

	Vehicle Characteristics	Small Automobiles		Pickup Truck	Single-Unit Van Truck	Van-Type Tractor-Trailer		Tractor-Tanker Trailer
NCHRP 350	W (kips)	1.55	1.8	4.5	18	50	80	80
	B (ft)	5.5	5.5	6.5	7.5	8	8	8
	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
MASH	W (kips)	2.42	3.3	5	22	N/A	79.3	79.3
	B (ft)	5.5	5.5	6.5	7.5	N/A	8	8
	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

Table 1: Bridge Barrier Test Levels and Crash Criteria for NCHRP 350 and MASH, where W is weight of the vehicle, B is the out-to-out wheel spacing on an axle, and G is the height of the vehicle center of gravity above the bridge deck

Safety Hardware System Components

The safety hardware system on and approaching a bridge consists of three components: the roadway approach system, the bridge railing, and the transition between the two. This document addresses the bridge railing and the bridge/roadway transition, together designated as the bridge railing system in this document. The roadway approach system guidance, including guidance for concrete barriers off bridges, such as median barrier, guardrail, and end terminals are the responsibility of the Design Standards Engineer.

Determination of Adequacy for Use

There are three criteria that must be met for a bridge railing system to be considered adequate for use: stability, geometry, and strength. Stability is met by satisfying minimum height requirements. Geometry is met by satisfying snagging requirements. Snagging can lead to vehicle instability, occupant compartment damage, and excessive acceleration on drivers and passengers, among other undesirable consequences. Finally, strength is determined by evaluating the structural capacity of the elements of the bridge railing system.

MnDOT practice for determination of MASH compliance is to self-certify bridge railing systems for use on Minnesota bridges that meet the stability, geometry, and strength requirements. This process will be done through the Bridge Standards and Research Unit and the Design Standards Unit, with standards approval by the Bridge Office Research and Development (R&D) Committee and the Design Advisory Committee. For a bridge railing system to be used, it will need to meet the requirements of self-certification. This is a long standing MnDOT practice that will be defined more clearly in this document.

MnDOT will use one of the following methods to determine when and where a bridge railing system is appropriate to use.

1. Eligibility letter issued by the Federal Highway Administration (FHWA)

In a May 26, 2017 update to the process for requesting eligibility letters, FHWA changed the requirements for issuance of an eligibility letter. Now, all crash tests in the suite recommended by MASH must be complete for consideration of an eligibility letter.

2. Letter issued by a certified facility

MnDOT will accept a letter from a certified facility, such as the Midwest Roadside Safety Facility (MwRSF) or the Texas Transportation Institute (TTI) stating that a bridge railing system meets MASH. Those facilities can perform simulations and modeling as well as evaluate the results of the testing. An advantage to this process over an FHWA eligibility letter is that not every test in the suite of MASH recommended tests may be required based on the professional experience of the facility experts.

3. Comparable geometry and strength by analysis

A bridge railing system with a structural strength equal to or higher than required by MASH and that also meets MASH geometry and stability requirements can be considered acceptable. For example, a barrier that has the same geometry as one that has an FHWA eligibility letter can be used on the MnDOT system with different rebar size and spacing, provided its strength exceeds the MASH criteria. If the computed strength does not exceed the theoretical static equivalent force based on MASH criteria but analysis demonstrates that it exceeds the computed strength of the original MASH crash-tested barrier, it is also deemed acceptable.

4. Other agency standards

Other agency standards may be used on the MnDOT system, provided the original developer used one of the above methods for determining adequacy. The process of "borrowing" from other agencies is more challenging than it was previously, because many more owners are opting to self-certify rather than getting FHWA approval. For MnDOT to use a system developed by another agency, documentation showing the development process and that it was consistent with MnDOT requirements is imperative.

Process

Any bridge railing system that will be used on Minnesota bridges must follow one of the processes above. Systems that will be used regularly may be developed into standard plans. Bridge railing systems that will be used on a single or very few projects, such as bridge railings with special aesthetic designs or historic features, must be reviewed by the Bridge Standards Engineer and the Design Standards Engineer to confirm that an adequate process was followed.

New Installation

For all projects let after December 31, 2019, all installations of bridge railing systems on new bridges or existing structures where the barrier is replaced must meet MASH 2016 criteria. For speeds 45 mph and lower, TL-2 is acceptable; for speeds over 45 mph, TL-4 is required. When TL-4 railings are required on bridges, the bridge/roadway transition rails on approach panels may be TL-3. Where TL-2 bridge railings are acceptable on the bridge, a TL-2 bridge/approach transition railing is acceptable on the approach panel. Although the FHWA/AASHTO agreement only requires bridge railing systems on bridges on or over the National Highway System (NHS) to meet the MASH requirements, MnDOT requires it for all MnDOT system bridges.

On very low volume roads (ADT<500) with no crash history, the use of a TL-3 bridge railing system on a high speed roadway is acceptable when there are no TL-4 railings that can be used. Additionally, for bridges that are eligible for or are on the National Register of Historic Places, TL-3 bridge railing systems are acceptable when no historically appropriate TL-4 railing is available.

Bridge railing systems on retaining walls are required to follow the same test level requirements as those located on bridge decks based on the speed of the roadway adjacent to the bridge railing. Bridge railing systems on wingwalls can be the same as what is required on the approach panel. However, on very long or tall wingwalls located on high speed roadways, extend the TL-4 bridge railing to within 20 feet of the end of the wingwall.

Protect vehicles when crossing bridge culverts that do not extend far enough to have a recoverable slope in the entire clear zone. Bridge railing systems for culverts are chosen by the roadway designer and can be MASH TL-3.

When a railing system and moment slab are present to prevent vehicles from reaching a drop-off adjacent to a retaining wall, railing systems on moment slabs are required to follow the same test level requirements as those located on bridge decks based on the speed of the roadway adjacent. When the railing system is being used to

protect a pier from a potential impact, use a MASH TL-5 railing system in compliance with the provisions of AASHTO LRFD Article 3.6.5. Other situations may be evaluated on a case by case basis.

Temporary barrier on bridges and temporary bridges may use MASH TL-3 barriers for high speed traffic.

Existing Structures

Existing structures are a much more complex issue with regards to bridge railing system test levels. Most existing bridge railings that would be required to meet MASH TL-4 will not meet that threshold due to having a height less than 36 inches. Requiring these bridge railings to be upgraded to meet a TL-4 level is not a financially viable option, because nearly every project would require upgrading barriers. Therefore, MnDOT has taken a risk based approach to determine how to manage in-service bridge railing performance. Historically, the MnDOT Bridge Preservation and Improvement Guidelines (BPIG) allowed flexibility in allowing barriers designed at a 10 kip load, with no snagging potential, in good condition, and meeting a minimal height to be left in-place. The following guidance shall be followed when the FY 2021-2025 BPIG indicates that evaluation of the barrier is warranted:

- When a bridge railing system does not meet at least MASH TL-3 design load requirements for roads with a posted speed limit of 50 mph or higher, modify the railing to meet at least MASH TL-3 or replace the bridge railing system with one meeting the crash-tested shape and strength requirements for new bridges.
- When a bridge railing system does not meet at least MASH TL-2 design load requirements for roads with a posted speed limit of 45 mph or lower, modify or replace the bridge railing system with one meeting the crash-tested shape and strength requirements for new bridges. From 1971 to 2017, MnDOT used a 28 inch tall parapet. Those can be considered equivalent to MASH TL-2 in the situations defined in the BPIG.

There are cases where a barrier meets the loading requirements of MASH for the speed, but it does not meet the snagging or stability requirements. NCHRP 20-07 Task 395 and the MnDOT research project *Review and Assessment of Past MnDOT Bridge Barrier Types* by William Williams of Texas Transportation Institute (TTI) provide guidance on MASH equivalencies for stability and snagging, in addition to strength, for a variety of barrier types. Using a risk based approach, MnDOT will consider bridge railing systems with no other risk factors that fall in the “marginal” category for geometry or stability as adequate for meeting MASH for rehabilitations. If the bridge railing system is not addressed in the research and it falls into the shaded areas of Table A13.1.1-2 (Potential for Wheel, Bumper, or Hood Impact with Post) or Table A13.1.1-3 (Post Setback Criteria), it can also be considered adequate for meeting MASH for rehabilitations. The criteria for post-and-beam railings are currently being studied in NCHRP 22-35. This guidance will be updated pending the results of the research.

For bridges that are eligible for or are on the National Register of Historic Places, deviations from this policy may be considered on a case by case basis. Complex bridges (such as through-trusses) that would require extensive

reconstruction or significant reduction in roadway width or load carrying capacity to meet this criteria may also be exempted.

In-place conditions indicating an elevated risk, such as deteriorated structural condition, a history of bridge railing system impacts, site-specific roadway geometrics, and critical superstructure members that are susceptible to impact warrant further investigation. See the FY 2021-2025 BPIG for further guidance.

All bridges that are to be let in FY 22 or later are required to meet this policy. Any projects letting between the time of publication and June 30, 2021 are encouraged to meet this policy.

Unresolved Issues

As of the development of this guide, there are a number of issues that are not resolved.

Bridge Standard Plans 5-397.157 and 5-397.158

Bridge Standard Plan 5-397.157 is a combination concrete parapet (Type P-2) and steel (Type T-1) vehicular railing. The current standard meets NCHRP 350 TL-4. There is no MASH compliant crash test on a comparable railing as of December 2019, and the processes developed in NCHRP 20-07 Task 395 do not address this bridge railing system. Likewise, Bridge Standard Plan 5-397.158 which is a metal railing that can be attached to the back face of a Type J, Type F, or Type S concrete barrier to provide bicycle and pedestrian protection has not been proven to be crashworthy under MASH criteria. Both Bridge Standard Plan 5-397.157 and Bridge Standard Plan 5-397.158 have been tested to NCHRP 350. Per the *Clarifications on Implementing the AASHTO Manual for Assessing Safety Hardware, 2016*, owners may continue to use NCHRP 350 tested devices where a MASH 2016-compliant device does not exist to address the situation.

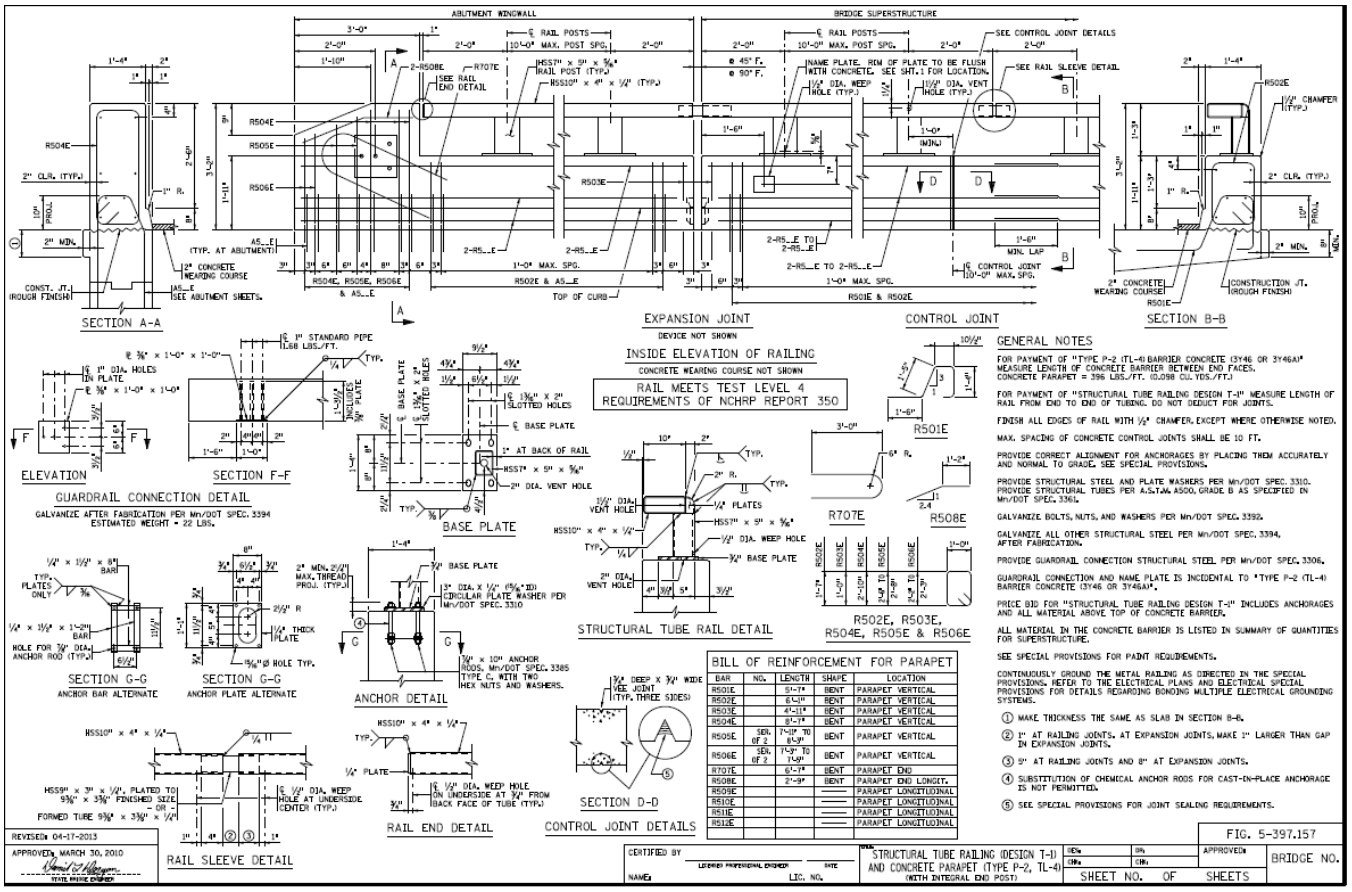

Figure 1: Bridge Standard Figure 5-397.157

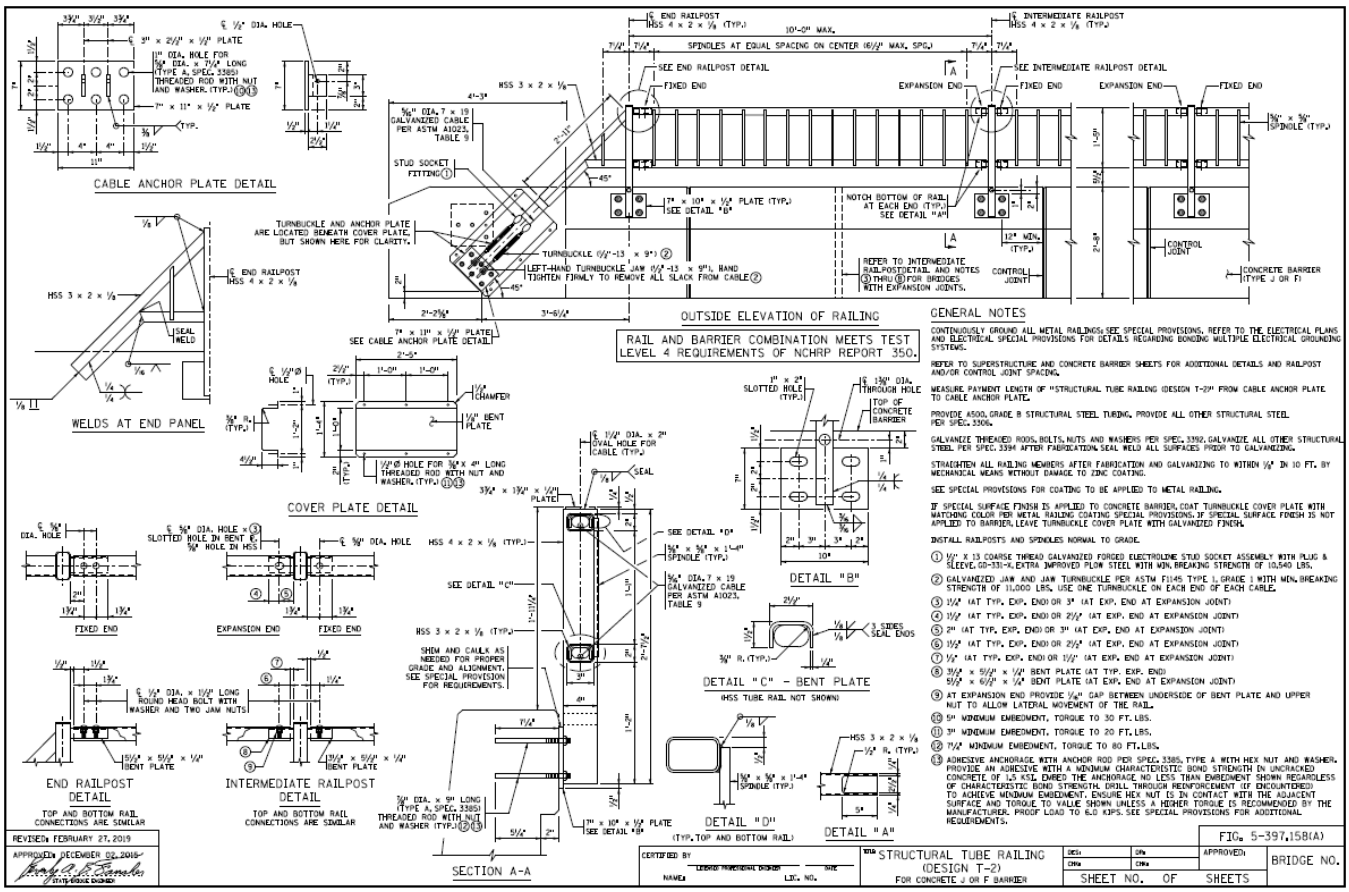

Figure 2: Bridge Standard Figure 5-397.158(A) (For Type J and Type F; similar for Type S)

MnDOT has a contract with the Midwest Roadside Safety Facility (MwRSF) for testing these installations. They have identified some changes to the standard that they believe are necessary for 5-397.157 to meet MASH TL-4 and 5-397.158 to meet MASH TL-3. They will be performing the crash tests from the MASH matrix that they have identified as being critical for determining the crash test level. Those tests are expected to be performed in 2020 with a report to follow. Until the test results are complete, designers may continue using these standards on Minnesota bridges on and off the NHS.

Transitions

Concrete End Post Shape

Single Slope Barriers

In August of 2019, TTI crash tested a connection of a Type 31 thrie beam guardrail to a single slope barrier. Although the report is not yet available, TTI has confirmed that the test was successful. The connection allows for the guardrail to connect directly to the sloped face of the barrier with a 3'-0" long, 1'-1" high vertical taper on the bottom, as shown in Figure 3. This test included a curb that extended under the guardrail past the end of

the single slope barrier. TTI recommended including the curb in the test due to a previous failure without the curb, and based on the results, MwRSF requires a curb for the connection to be considered MASH compliant.

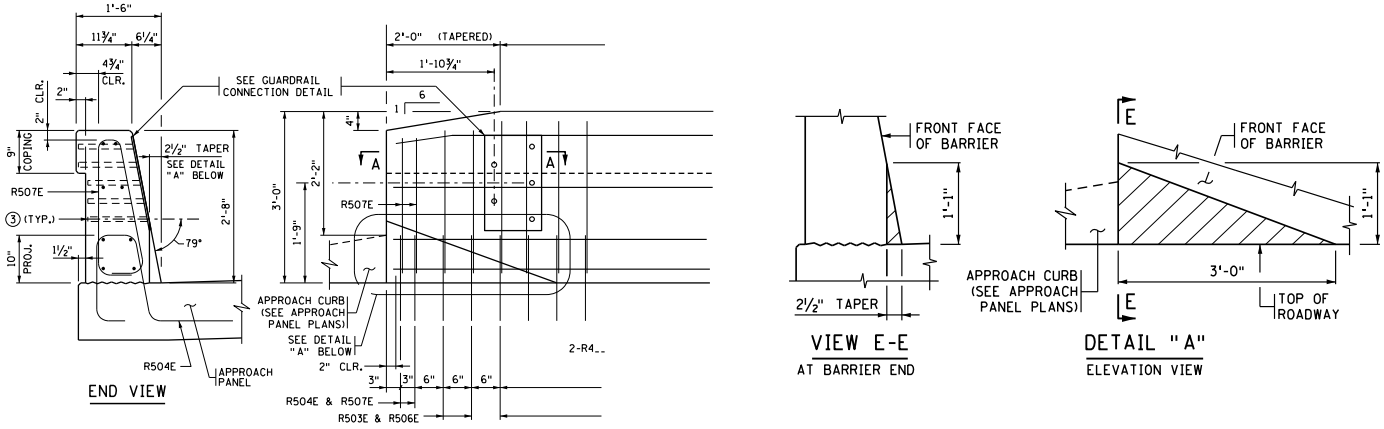

Figure 3: Connection Detail

MwRSF reviewed the component test as well as other relevant test data and concluded that the TTI test was applicable to MnDOT's barrier and guardrail systems. MnDOT will request a written letter confirming the conclusion and then implement an end post style that matches what was tested by TTI. This includes adding curb past the end of the barrier on the approach panel. Details for State Aid projects that have guardrail connected to the end post of a single slope barrier but do not include a curb approaching the bridge still need to be developed, because the curb is a required element of the barrier system.

Vertical Parapets

Based on a crash test run by MwRSF for Hawaii and discussions with MwRSF, MnDOT developed the end post for vertical parapets shown below in Figure 4. Figure 4 shows the end post and curb connection for the Type P-4 parapet (MnDOT Standard Figure 5-397.173), but other vertical face parapets, including the Type P-1 (MnDOT Standard Figure 5-397.166) and Type P-2 with the Type T-1 structural tube rail (MnDOT Standard Figure 5-397.157) would be similar. MnDOT is working with MwRSF to get final written confirmation that these transition details meet MASH TL-3. The curb is a critical portion of the crashworthiness of this detail if guardrail is connected and cannot be removed from the standard. The brush curb cannot extend past the end of the barrier to ensure that the front face of the curb remains far enough behind the face of the guardrail. This will cause the gutterline to vary at the transition from the bridge to the curb. For vertical faces, the variation will be 2 inches, because that is the width of the brush curb. On single slope barriers, this will be 2 ½" due to the size of the cut at the base of the barrier. MnDOT is continuing to determine the best solution for addressing the changes in gutterline.

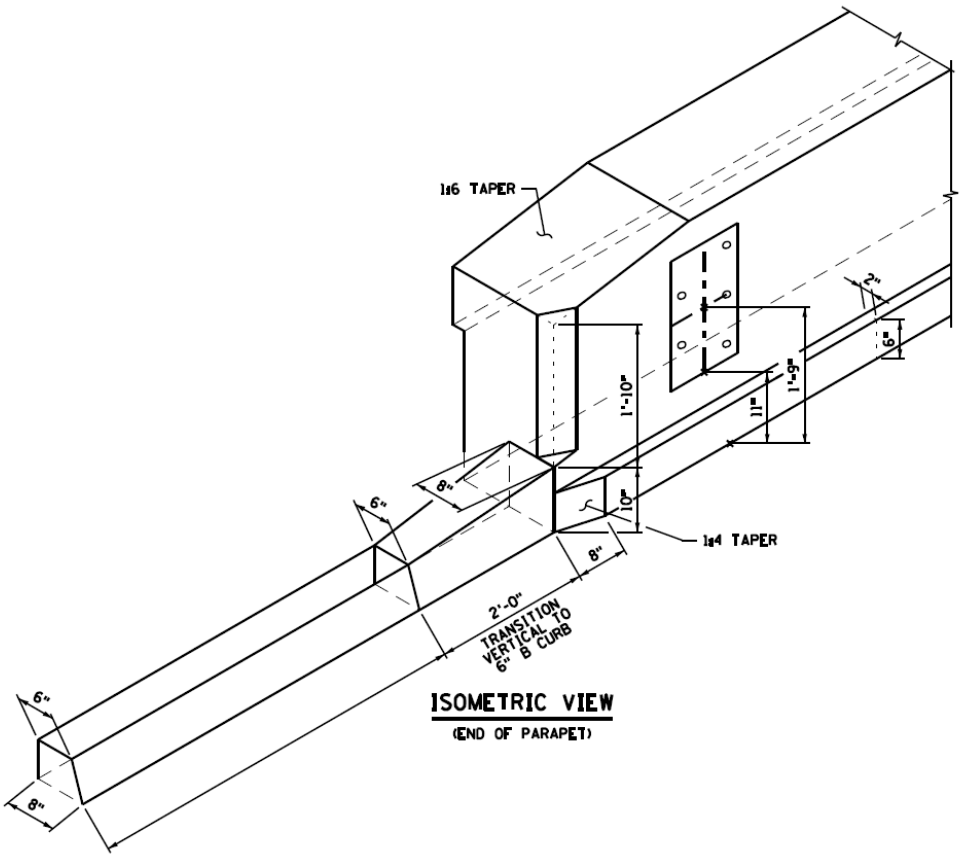

Figure 4: End Post and Guardrail Connection for Vertical Face Parapets

Guardrail Connection to Existing Structures

On preservation projects, Technical Memorandum No. 17-07-TS-02 provides guidance on when and how to upgrade W-beam guardrail to Type 31. Many projects that upgrade guardrail also want to upgrade the connection to the existing end post. If the existing end posts need to be replaced to accommodate the new guardrail, projects become substantially more expensive, traffic disrupting, and time consuming. These upgrades often necessitate a significant amount of replacement of approach panel and barrier to make the transition. Existing bridges with MASH TL-3 compliant Type F and Type J barriers consist of more than half of the length of all barriers on the MnDOT bridge inventory. Although some of those barriers have end posts that are not sufficient for TL-3, many are. Being able to replace the end posts without affecting the approach panel or the barrier on the bridge can be a more economical solution while still accommodating the new Type 31 guardrail.

One potential option to avoid replacing end posts would be to determine what existing end post configurations can be reused simply with drilling new holes for the Type 31 guardrail bolt pattern. This would require confirmation from either MwRSF or TTI on the acceptability of a transition, which may necessitate additional research or crash testing. The goal is to minimize the impact on the bridge while providing an acceptable end

connection that can universally be applied to most bridge railing system ends. There are also potential changes to the guardrail standards that may be necessary. This work is going to be heavily dependent on involvement, coordination, and guidance from the Design Standards Unit.

Until MwRSF or TTI can provide guidance on a transition that does not require the replacement of end posts, the solution to connecting an existing barrier to a Type 31 guardrail includes removing the end of the existing barrier and recasting a transition to a Type S or vertical parapet shape that is compatible with the Type 31 connection.

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