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Memo

Date: 2/3/2020

To: Bridge Design Engineers

From: Arielle Ehrlich
State Bridge Design Engineer

RE: Memo to Designers #2020-01: MASH Implementation and Bridge Railing Design

Introduction

This guidance supersedes the guidance given in Memos to Designers #2016-01 and #2017-01. With the release of this memo, Memos to Designers #2016-01 and #2017-01 are officially rescinded.

This Memo to Designers incorporates all of the recent changes to bridge railings as of the date of publication. AASHTO has plans to rewrite Section 13 of the *AASHTO LRFD Bridge Design Specifications* (LRFD). Section 13 of MnDOT's *LRFD Bridge Design Manual* (BDM) will receive a full update once the LRFD Section 13 rewrite is complete. At that time, the information in this Memo to Designers will be incorporated into the BDM.

MASH Implementation

In order to explain MnDOT's plan for meeting the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) schedule for the implementation of the *Manual for Assessing Safety Hardware* (MASH), MnDOT has developed a *MASH Implementation Plan for Bridges*. That document is available under the "Guidance" section at: http://www.dot.state.mn.us/bridge/design.html. It details the types of bridge railings that are acceptable for both new installations and for retrofits. Note that the MASH Implementation Plan for Bridges will change as bridge railings are crash tested and guardrail connection details and end post details are finalized. Therefore, revisit the link for updates when starting a new bridge project and when finalizing the bridge plan. Standards for bridge railings are found in the Bridge Details Manual Part II, which are available at: https://www.dot.state.mn.us/bridge/bridgedetails2.html.

Detailing Requirements

For bridges where a TL-5 barrier would currently be recommended due to high design speeds, curvature, truck traffic, or other site considerations (see BDM Article 13.2.1), use a TL-4 42” tall Type S barrier or TL-4 54” tall Type S barrier where a glare screen is needed.

For bridges with wingwall orientation parallel to the roadway that have a Type S barrier located on top of the wingwalls, detail the wingwalls to be the same thickness as the barrier (1’-4”) for the top 1’-6” and then transition to the full standard thickness. See Figure 1.

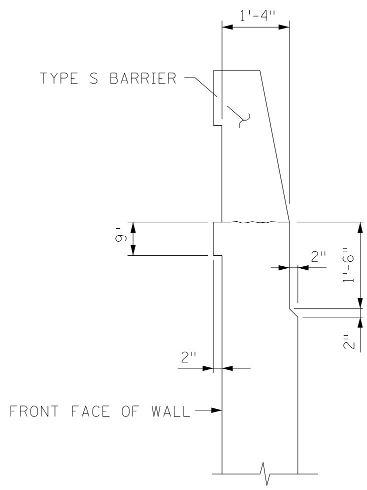

Figure 1

The Midwest Roadside Safety Facility (MwRSF) has provided recommendations for bridge traffic railing placement that are dependent on the cross slope. MwRSF recommends limiting the angle between the roadway surface and the vertical axis of the traffic railing to a maximum of 90 degrees. Use the following guidance to meet these recommendations:

- For driving surfaces with a normal crown section, detail the traffic railing as plumb. See Figure 2 below.

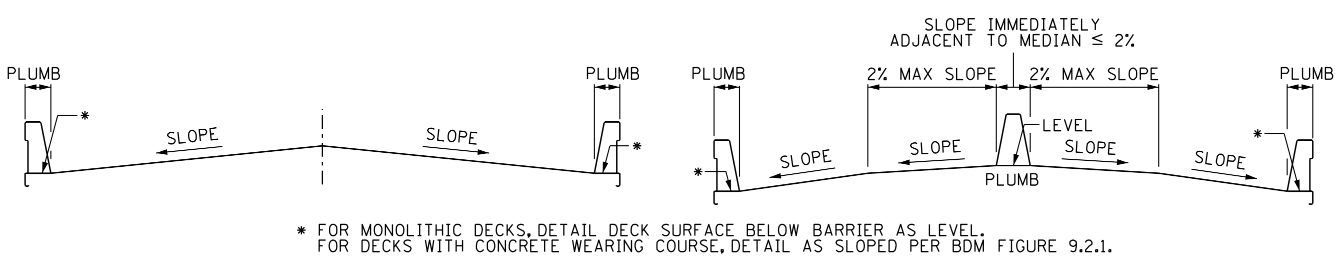

Figure 2 – Crown Section

- For driving surfaces with a <u>constant</u> cross slope (superelevated roadway), detail the angle between the bridge deck/roadway and the vertical axis of the traffic railing so it does not exceed 90 degrees. See Figure 3 below.

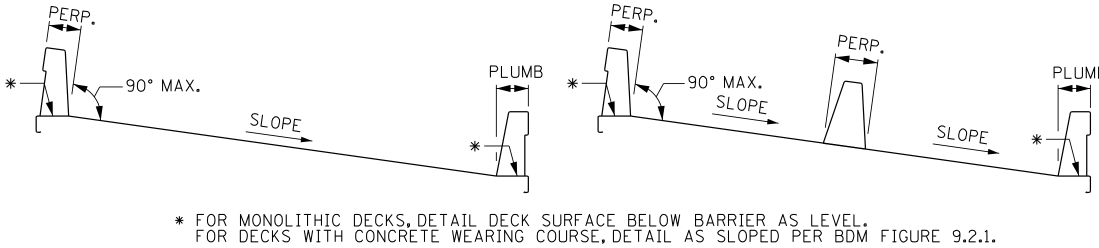

Figure 3 – Constant Cross Slope

- For bridge decks with a variable cross slope or superelevation, detail the angle between the bridge deck/roadway and the vertical axis of the traffic railing to transition from plumb to perpendicular (or vice versa) as shown in Figure 4. In this example, the cross section changes from a crown section to a superelevated cross slope, so the left barrier transitions from plumb at the crown section to perpendicular at 0% slope.

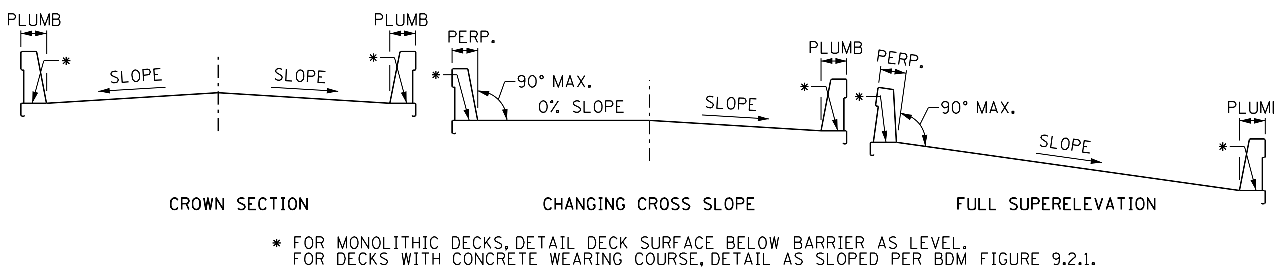

Figure 4 – Variable Cross Slope

- As indicated by the examples above, the vertical position of the traffic railing axis varies depending on the adjacent driving surface slope; therefore, it is imperative that the bridge and roadway designer work together to ensure that design plans are coordinated and that the detailing on the bridge plan matches the roadway plan and vice versa. Consideration of the traffic railing axis must also be taken into account when the barrier/parapet is mounted on top of a wall or approach panel.

- Where fully superelevated cross slopes exceed 2%, include traffic railing height dimensions for both the front <u>and</u> back face of barriers/parapets located at the top of the slope. In addition, revise the R501E, R502E, and R503E bars to provide a minimum front leg projection of 10 inches.

Design of Bridge Deck Overhangs

Currently, the AASHTO LRFD Bridge Design Specifications Appendix A13 contains published minimum bridge railing heights and design forces for NCHRP Report 350 but does not include values for MASH. TTI has published MASH values for TL-4 and TL-3 in the NCHRP Project 20-07/Task 395 report titled *MASH Equivalency of NCHRP Report 350–Approved Bridge Railings* (Silvestri-Dobrovolny et al). Based on the report and discussion with TTI, the MnDOT Bridge Office has adopted the following MASH values:

- MASH Test Level 4 (TL-4): Minimum height of bridge railing (H) is 36 inches. Design transverse force (F_t) is 80 kips applied at a height (H_e) of 30 inches.
- MASH Test Level 3 (TL-3): Minimum height of bridge railing (H) is 29 inches. Design transverse force (F_t) is 71 kips applied at a height (H_e) of 19 inches. TL-3 is not typically used for new MnDOT bridge railings. Only use TL-3 bridge railings on temporary bridges or in circumstances permitted by the Bridge Improvement and Preservation Guidelines (BPIG) on existing bridges.
- MASH Test Level 2 (TL-2): The MASH values for TL-2 are currently unknown. MnDOT requires a minimum bridge railing height (H) equal to 32 inches based on crash testing of the Caltrans Type 732SW combination bridge railing mounted on a sidewalk. TTI has recommended use of a MASH design transverse force (F_t) that is approximately 15% higher than the AASHTO LRFD Table A13.2-1 force given for NCHRP Report 350. TTI also recommended use of the same force application height found in AASHTO LRFD Table A13.2-1. Therefore, use F_t = 31 kips and H_e = 20 inches.

Until AASHTO publishes design values and this guidance is updated, use the values above for deck design. Previously, MnDOT's policy was to design for $4/3 \cdot F_t$ to ensure adequate strength of the deck. For NCHRP 350 TL-4, that value was $4/3 \cdot 54$ kips = 72 kips. With the higher MASH TL-4 design transverse force set at 80 kips, and because existing deck overhangs have performed well and are not showing damage due to barrier/parapet collisions, $4/3 \cdot F_t$ will no longer be considered for deck design. The new MnDOT policy is to design the deck overhang to resist a transverse collision force (F_{coll}) equal to the lesser of:

1) The MASH transverse force (F_{tadj}), which is the value of F_t given above for the appropriate test level that has been adjusted for the height of the bridge railing.
2) The strength of the bridge railing system (R_w). Note that in order to meet the MASH test level, R_w typically must exceed F_{tadj}. However, if there is a case where a bridge railing system was crash tested and passed MASH, but the computed R_w is less than the F_{tadj} given above for the appropriate test level, the deck only needs to be designed for R_w.

Deck overhang reinforcement requirements are dependent on the required MASH test level, bridge railing type, overhang length, and overhang location along the bridge. Use the guidance below to meet MASH for bridges with the following MnDOT standard bridge railings: Type S barriers (includes 36", 42", and 54" heights with or without a concrete wearing course), Type P-1 parapets (with or without a raised sidewalk), Type T-1 structural tubes mounted on P-2 parapets and P-4 parapets (with or without a concrete wearing course). The guidance applies to deck overhangs (measured from centerline of beam to edge of deck) of up to 40% of the beam spacing. Other situations require a special design. For existing bridge decks with bridge railings that meet MASH TL-3 or where bridge railings are being retrofitted to meet MASH TL-3, there is no need to evaluate the in-place deck.

For MASH TL-4:

- In the **interior overhang regions** of decks supported by either **prestressed concrete beams or steel beams**, provide reinforcement per the BDM deck reinforcement Tables 9.2.1.1 and 9.2.1.2 with no modification.
- In the **end overhang regions** (regions where the longitudinal barrier/parapet reinforcement is discontinuous, such as end of bridge joints and expansion joints) of decks supported by **prestressed concrete beams**:
    - For decks where the gutter line is located inside the edge of the fascia beam flange, provide reinforcement per the BDM deck reinforcement Table 9.2.1.1 with no modification.
    - For all other cases, provide #5 bars at 5” spacing or $A_s = 0.74\ in^2/ft$ for the top transverse bars over a distance of 8 feet from the joint or reinforcement discontinuity. Include 180 degree standard hooks on the edge-of-deck ends of these bars. This can be accomplished either by providing hooked overhang bars that splice to the main transverse deck bars or by providing hooked transverse bars that run from edge to edge of the deck.
- In the **end overhang regions** (regions where the longitudinal barrier/parapet reinforcement is discontinuous, such as end of bridge joints and expansion joints) of decks supported by **steel beams**:
    - For decks where the gutter line is located inside the edge of the fascia beam flange, provide reinforcement per the BDM deck reinforcement Table 9.2.1.2 with no modification.
    - For decks not meeting the 1st sub-bullet that have a beam spacing less than 13 feet, provide #5 bars at 5” spacing or $A_s = 0.74\ in^2/ft$ for the top transverse bars over a distance of 8 feet from the joint or reinforcement discontinuity. Include 180 degree standard hooks on the edge-of-deck ends of these bars. This can be accomplished either by providing hooked overhang bars that splice to the main transverse deck bars or by providing hooked transverse bars that run from edge to edge of the deck.
    - For decks not meeting the 1st sub-bullet that have a beam spacing 13 feet or greater, provide #6 bars at 6.5” spacing or $A_s = 0.81\ in^2/ft$ for the top transverse bars over a distance of 8 feet from the joint or reinforcement discontinuity. Include 180 degree standard hooks on the edge-of-deck ends of these bars. This can be accomplished either by providing hooked overhang bars that splice to the main transverse deck bars or by providing hooked transverse bars that run from edge to edge of the deck.

For MASH TL-2:

- In the **interior and end overhang regions** of decks supported by either **prestressed concrete beams or steel beams**, provide reinforcement per the BDM deck reinforcement Tables 9.2.1.1 and 9.2.1.2 with no modification.

For deck overhangs that require a special design, use the following guidance for checking the extreme event limit state:

- Design collision loads F_{cdes} and M_{cdes} will be needed at each section being checked to complete the deck overhang design. There are 2 critical sections to be checked:
  1) At the toe of barrier or parapet.
  2) At the edge of beam flange.

  For each barrier/parapet height H, values for L_c, M_c, and R_w have been determined using the yield line method found in AASHTO LRFD Spec. Article A13.3.1. Values for MnDOT standard bridge railings are shown in Tables 1 through 4 found on pages 7 through 9.

- Since R_w and M_c are based on a load applied at the top of the bridge railing, adjust the transverse force F_t from the point of application to the top of the barrier/parapet to get F_{tadj}:

$$F_{tadj} = \frac{F_t \cdot H_e}{H}$$

  Based on the loading guidance given above, design the deck overhang to resist a transverse collision force (F_{coll}) equal to the smaller of the transverse force adjusted for barrier/parapet height (F_{tadj}) and the strength of the bridge railing system (R_w). The result is that $F_{coll} = F_{tadj}$ for all MnDOT standard bridge railings shown in Tables 1 through 4.

- Determine the resulting adjusted moment about the longitudinal axis M_{cadj} by proportioning M_c:

$$M_{cadj} = \frac{F_{coll} \cdot M_c}{R_w}$$

  Adjust F_{coll} again by distributing the load over L_c + H for end regions and L_c + 2H for interior regions to get F_{cadj}. The results for M_{cadj} and F_{cadj} are shown in Tables 1 through 4 for MnDOT standard bridge railings.

- Translate the moment M_{cadj} at the top of the deck to a moment M_{cdes} located at the center of the deck using the following method (refer to Figure 5 for Type S barriers; parapets will be similar):

$$e = M_{cadj} / F_{cadj}$$

$$F_{cdes} = F_{cadj}$$

  For monolithic decks: $M_{cdes} = F_{cdes} \cdot (e + 0.5 \cdot t_{deck})$

  For decks consisting of structural slab plus wearing course: $M_{cdes} = F_{cdes} \cdot (e + 0.5 \cdot t_{str\ slab})$

  Where t_{deck} = thickness of the deck at the critical section being checked

  $t_{str\ slab}$ = thickness of the structural slab at the critical section being checked

  Use the tension force F_{cdes} and moment M_{cdes} as the collision loads for the deck overhang design.

- Use a load factor of 1.0 for all loads when checking the extreme event limit state.
- Check that the resistance of the deck exceeds the applied axial tension and bending moment using a structural interaction diagram. Use the effective area of reinforcement at the critical section, taking into account any lack of bar development.

Monolithic Deck Without Wearing Course	36" Type S Barrier		42" Type S Barrier		54" Type S Barrier	
	End	Interior	End	Interior	End	Interior
R_w (k)	75.3	119.9	63.9	106.4	47.3	87.5
M_c (k)	22.9	17.0	20.7	14.5	18.8	13.4
L_c (ft)	4.9	10.6	5.4	12.8	5.7	14.7
F_{tadj} (k)	66.7	66.7	57.1	57.1	44.4	44.4
F_{coll} (k)	66.7	66.7	57.1	57.1	44.4	44.4
M_{cadj} (k-ft/ft)	20.3	9.5	18.5	7.8	17.7	6.8
F_{cadj} (k/ft)	8.4	4.0	6.4	2.9	4.4	1.9
Deck With Wearing Course	**36" Type S Barrier**		**42" Type S Barrier**		**54" Type S Barrier**	
	End	Interior	End	Interior	End	Interior
R_w (k)	71.8	117.4	62.6	106.5	46.7	87.7
M_c (k)	22.8	17.1	21.2	15.0	19.0	13.7
L_c (ft)	5.0	10.9	5.4	13.0	5.7	14.9
F_{tadj} (k)	67.4	67.4	58.2	58.2	45.7	45.7
F_{coll} (k)	67.4	67.4	58.2	58.2	45.7	45.7
M_{cadj} (k-ft/ft)	21.4	9.8	19.7	8.2	18.6	7.1
F_{cadj} (k/ft)	8.2	3.9	6.4	2.9	4.4	1.9

Table 1: Type S Barrier Resistance Values and Adjusted Loading for Deck Overhang Design

	32" Type P-1 Parapet With No Sidewalk		32" Type P-1 Parapet With Raised Sidewalk	
	End	Interior	End	Interior
R_w (k)	69.2	135.2	57.3	118.8
M_c (k)	18.1	18.5	19.5	18.6
L_c (ft)	5.0	9.7	5.6	12.2
F_{tadj} (k)	19.4	19.4	22.9	22.9
F_{coll} (k)	19.4	19.4	22.9	22.9
M_{cadj} (k-ft/ft)	5.1	2.7	7.8	3.6
F_{cadj} (k/ft)	2.5	1.3	2.4	1.2

Table 2: Type P-1 Parapet Resistance Values and Adjusted Loading for Deck Overhang Design

	36" Type P-4 Parapet With No Wearing Course		36" Type P-4 Parapet With Wearing Course	
	End	Interior	End	Interior
R_w (k)	96.6	164.6	89.5	158.3
M_c (k)	29.0	24.6	28.0	24.3
L_c (ft)	5.0	10.1	5.1	10.3
F_{tadj} (k)	66.7	66.7	67.4	67.4
F_{coll} (k)	66.7	66.7	67.4	67.4
M_{cadj} (k-ft/ft)	20.0	10.0	21.1	10.3
F_{cadj} (k/ft)	8.3	4.1	8.2	4.1

Table 3: Type P-4 Parapet Resistance Values and Adjusted Loading for Deck Overhang Design

	36" Type T-1 Structural Tube and P-2 Parapet With No Wearing Course		36" Type T-1 Structural Tube and P-2 Parapet With Wearing Course	
	End	Interior	End	Interior
Required Structural Tube R_R (k)	48.0	48.0	48.0	48.0
Required Parapet R_w (k)	32.0	32.0	32.0	32.0
Parapet R_w (k)	117.1	227.5	124.6	210.9
Parapet M_c (k)	20.9	22.9	24.8	22.1
Parapet L_c (ft)	4.9	8.7	4.8	9.1
Parapet F_{tadj} (k)	32.0	32.0	32.0	32.0
Parapet F_{coll} (k)	32.0	32.0	32.0	32.0
Parapet M_{cadj} (k-ft/ft)	5.7	3.2	6.4	3.4
Parapet F_{cadj} (k/ft)	4.8	2.6	4.8	2.5

Table 4: Type T-1 Structural Tube Railing Mounted on P-2 Concrete Parapet - Parapet Resistance Values and Adjusted Loading for Deck Overhang Design.

Notes: Use of AASHTO LRFD Appendix A13.3.3 to determine the collision load distribution to the structural tube rail and concrete parapet results in an inordinately high load applied to the structural tube. The Midwest Roadside Safety Facility (MwRSF) has recommended a different load distribution based on raw data from vertical parapet crash tests. Therefore, the required structural tube resistance (R_R) and required parapet resistance (R_w) given in Table 4 are based on the MwRSF collision load distribution recommendation of 60% to the structural tube and 40% to the parapet. The total MASH TL-4 load applied to the bridge railing for this distribution is assumed to be 80 kips.

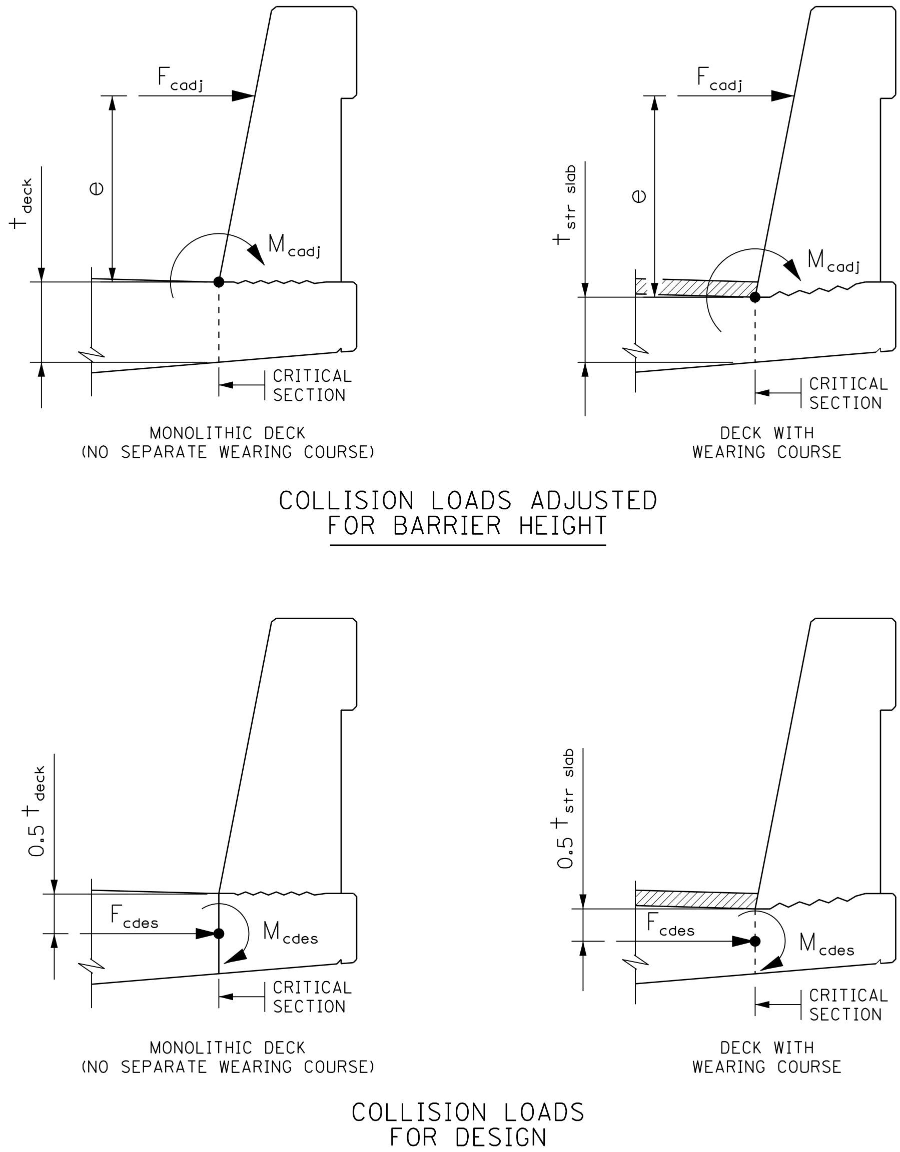

Figure 5

For questions about this policy, please contact Dave Dahlberg (dave.dahlberg@state.mn.us or 651-366-4491) or Arielle Ehrlich (arielle.ehrlich@state.mn.us or 651-366-4506).

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