Single Slope Bridge Railing Supplement

1. Overview

The purpose of the single slope bridge railing standard bridge drawings is to provide designer with the necessary information required to detail a MASH compliant bridge railing utilizing GFRP horizontal reinforcing with the single slope barrier shape. The SBR-1-20 and fully reinforced SBR-2-20 are TL-5 compliant railings. The unreinforced SBR-2-20 is a TL-3 compliant railing and the SBR-3-20 is a TL-4 compliant railing.

2. Background

Initially released as an ODOT standard in 1999, the single slope concrete railing shape was introduced to begin phasing out the New Jersey shape concrete barrier because it could accommodate a larger thickness of pavement overlay. The initial release was a 42” tall concrete railing (SBR-1-99). In 2013 sacrificial GFRP bars were introduced to the 42” single slope railing. These GFRP bars were lapped on the horizontal reinforcement at the saw cut joints to help stiffen the rebar cage during construction. The 57” single slope median concrete railing (SBR-2-13) was introduced in 2013. This standard was created to match the single slope roadway median barrier (RM-4.3). The 57” railing was also detailed with the sacrificial GFRP bars.

A 36” single slope concrete railing was added to the Bridge Standard Drawings in 2020 (SBR-3-20). This standard railing is intended to be used on two lane NHS and non-NHS routes making it a single slope railing replacement for the 36” Jersey shape railing (BR-1-13).

In 2020 the horizontal reinforcing steel in all of the single slope concrete railings was replaced with GFRP bars. This change came after numerous requests from the construction community. Using GFRP bars for the horizontal reinforcing reduces the amount of labor spent splicing short GFRP bars. In addition to the continuous horizontal GFRP bars additional diagonal GFRP bars were added to the reinforcement cage. The purpose of these bars is to further stiffen the cage while being slip-formed. It was frequently observed during slip-forming that the vertical steel would begin to sway forward in the direction of the slip-forming and when the bars rebounded it could form voids around the bars.

3. Plan Preparation Requirements

Project plans shall include all details, notes, and pay items needed for construction. If the minimum rebar embedment shown in the standard drawing is not possible, the reinforcement for the barrier will need to be designed for the given situation.

All the single slope bridge railings have been designed to have a standard saw cut joint spacing of 10-ft. The intention is to have 10-ft spacings for all saw cut joints with an odd length on the first and/or last bays on the bridge. The first and last bays on the bridge shall not be smaller than 10-ft and not longer than 15-ft. For example, a railing that is 232-ft long would have the first bay at 11-ft then 22 bays at 10-ft and the last bay would be 11-ft. Similarly, a railing that is 224-ft long would have the first or last bay at 14-ft and 22 bays at 10-ft. The longer span is to be at the beginning or end or the railing because this will fall within a region of positive flexure.

4. Design Example

See attached calculations for the complete design example.
SBR-1-20 Design with Yield Line Analysis
42” Single Slope Barrier
All sections designed as end regions since sawcut spacing is 10-ft. These design calculations are based off of an example calculation provided by ODOT by the Midwest Research Facility. For these calculations it is reasonable to assume tension controlled reinforced concrete.

\[ A_{bh} = 0.44 \text{ in}^2 \quad A_{hh} = 0.2 \text{ in}^2 \]

Bar area, vertical and horizontal

\[ f'_c := 4.5 \text{ ksi} \]

Concrete strength, QC2

\[ f_y := 60 \text{ ksi} \]

Yield strength of steel rebar

\[ b := 12 \text{ in} \]

Assuming for per foot design

\[ H_F := 42 \text{ in} \]

Height of barrier

\[ \beta_j := 0.85 - 0.05 \cdot \left( \frac{f' c - 4 \text{ ksi}}{\text{ksi}} \right) = 0.825 \]

Factor used to simplify the compressive stress block

\[ \varepsilon_{cu} := 0.003 \]

Compressive strain limit for concrete

\[ C_E := 0.7 \]

AASHTO GFRP Table 2.4.2.1-1

\[ E_G := 8700 \text{ ksi} \]

GFRP Modulus of elasticity, C&MS 705.28

\[ f_{fu} := 118 \text{ ksi} \quad \varepsilon_{fu} := \frac{f_{fu}}{E_G} = 0.0136 \]

C&MS 705.28

\[ f_{fd} := C_E \cdot f_{fu} = 82.6 \text{ ksi} \quad \varepsilon_{fd} := C_E \cdot \varepsilon_{fu} = 0.0095 \]

AASHTO Eqn. 2.4.2.1-1

Overturning Moment Resistance
The overturning moment resistance is provided by the vertical reinforcement in the railing

\[ s = 12 \text{ in} \]

Vertical bar spacing

\[ l_e = 9 \text{ in} \]

Length of embedment

\[ l_{hb} := \frac{38.0 \cdot 0.75 \text{ in}}{60} \cdot \left( \frac{f_y}{\sqrt{f'_c \cdot \text{ksi}}} \right) = 13.44 \text{ in} \]

AASHTO 5.10.8.2.4a-2

\[ \lambda_{rc} := 1.0 \quad \lambda_{cw} := 1.2 \quad \lambda_{er} := 1.0 \quad \lambda := 1.0 \]

AASHTO 5.10.8.2.4b

\[ l_{dh} := l_{hb} \cdot \left( \frac{\lambda_{rc} \cdot \lambda_{cw} \cdot \lambda_{er}}{\lambda} \right) = 16.12 \text{ in} \]

AASHTO 5.10.8.2.4a-1
Since the vertical bar is not sufficiently developed into the deck overhang along the entire yield line, a weighed average of the undeveloped portion of the bar is used to calculate the area of steel that is partially developed

\[
A_{s1} := \min \left( \frac{A_{b v} \cdot \left( \frac{12 \text{ in}}{s} \right) \cdot \left( 1 + \frac{l_c}{l_{db}} \right)}{2}, A_{b v} \cdot \left( \frac{12 \text{ in}}{s} \right) \right) = 0.34 \text{ in}^2
\]

Area of steel per foot, reinforcement partially developed across yield line

\[
A_{s2} := A_{b v} \cdot \left( \frac{12 \text{ in}}{s} \right) = 0.44 \text{ in}^2
\]

Area of steel per foot, reinforcement fully developed across yield line

\[
d_{cF1} := \frac{14.875 \text{ in} + 13.5 \text{ in}}{2} = 14.19 \text{ in}
\]

Distance to centroid of tension rein. from extreme comp. fiber, partially developed

\[
d_{cF2} := \frac{13.5 \text{ in} + 7.75 \text{ in}}{2} = 10.63 \text{ in}
\]

Distance to centroid of tension rein. from extreme comp. fiber, fully developed

See Figure 1 for a sketch showing how these distances where measured

\[
a_1 := \frac{A_{s1} \cdot f_y}{0.85 \cdot f'_c \cdot b} = 0.45 \text{ in}
\]

Simplified thickness of compression block, partially developed

\[
a_2 := \frac{A_{s2} \cdot f_y}{0.85 \cdot f'_c \cdot b} = 0.58 \text{ in}
\]

Simplified thickness of compression block, fully developed

\[
M_{cF1} := \frac{1}{\text{ ft}} \cdot A_{s1} \cdot f_y \cdot \left( \bar{d}_{cF1} - \frac{a_1}{2} \right) = 23.93 \frac{\text{kip} \cdot \text{ft}}{\text{ft}}
\]

Overturning moment resistance, partially developed

\[
M_{cF2} := \frac{1}{\text{ ft}} \cdot A_{s2} \cdot f_y \cdot \left( \bar{d}_{cF2} - \frac{a_2}{2} \right) = 22.74 \frac{\text{kip} \cdot \text{ft}}{\text{ft}}
\]

Overturning moment resistance, fully developed

\[
M_c := \frac{M_{cF1} + M_{cF2}}{2} = 23.34 \frac{\text{kip} \cdot \text{ft}}{\text{ft}}
\]

Average overturning moment resistance for the section
Wall Moment Resistance

Resistance I - Moment resistance when the front face of the barrier is in tension

\[ d_{ai} := 8.125 \text{ in} \quad d_{ci} := 10.875 \text{ in} \quad d_{ei} := 13.75 \text{ in} \]

\[ d_{bi} := 9.5 \text{ in} \quad d_{di} := 12.25 \text{ in} \quad d_{fi} := 10.375 \text{ in} \]

See Figure 2 for a sketch showing how these distances were measured. Only one of the diagonal GFRP bars is considered effective for the yield line wall moment resistance because one of the bars will be approximately parallel to the yield line. For this reason that bar is considered ineffective. To be conservative the inside bar was used for the wall moment resistance. Because it is positioned close to the neutral axis, the uppermost horizontal bar is ignored.

\[ A_T := n_b \cdot A_{bh} = 1.2 \text{ in}^2 \quad A_F := \frac{A_T}{H_F} = 0.34 \frac{\text{in}^2}{\text{ft}} \]

\[ d_{FI} := \frac{A_{bh} \cdot (d_{ai} + d_{bi} + d_{ci} + d_{di} + d_{ei} + d_{fi})}{A_T} = 10.81 \text{ in} \]

\[ c_{FI} := d_{FI} \cdot \left( \frac{\epsilon_{cu}}{\epsilon_{cu} + \epsilon_{fd}} \right) = 2.6 \text{ in} \quad a_{FI} := \beta_1 \cdot c_{FI} = 2.14 \text{ in} \]

\[ M_{WFII} := A_F \cdot f_{fd} \cdot \left( d_{FI} - \frac{a_{FI}}{2} \right) = 22.99 \frac{\text{kip} \cdot \text{ft}}{\text{ft}} \]

Resistance II - Moment resistance when the rear face of the barrier is in tension

\[ d_{aII} := 8.25 \text{ in} \quad d_{cII} := 10.875 \text{ in} \quad d_{eII} := 13.5 \text{ in} \]

\[ d_{bII} := 9.5 \text{ in} \quad d_{dII} := 12.25 \text{ in} \quad d_{fII} := 10.5 \text{ in} \]

See Figure 3 for a sketch showing how these distances were measured

\[ d_{FI} := \frac{A_{bh} \cdot (d_{aII} + d_{bII} + d_{cII} + d_{dII} + d_{eII} + d_{fII})}{A_T} = 10.81 \text{ in} \]

\[ c_{FI} := \epsilon_{cu} \cdot \left( \frac{d_{FI}}{\epsilon_{fd} + \epsilon_{cu}} \right) = 2.6 \text{ in} \quad a_{FI} := \beta_1 \cdot c_{FI} = 2.14 \text{ in} \]

\[ M_{WFII} := A_F \cdot f_{fd} \cdot \left( d_{FI} - \frac{a_{FI}}{2} \right) = 22.99 \frac{\text{kip} \cdot \text{ft}}{\text{ft}} \]

\[ M_W := \frac{M_{WFI} + M_{WFII}}{2} = 22.99 \frac{\text{kip} \cdot \text{ft}}{\text{ft}} \]
Yield Line Calculations

\[ M_b := 0 \cdot kip \cdot ft \quad L_t := 8 \text{ ft} \]

\[ L_{cr} := \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + H_F \cdot \left(\frac{M_{WF} \cdot H_F}{M_{cF}}\right)} = 9.3 \text{ ft} \]

must be 10-ft or less due to Deflection Joint sawcuts

AASHTO LRFD A13.3.1-4

\[ R_w := \left(\frac{2}{2 \cdot L_{cr} - L_t}\right) \left(M_{WF} \cdot H_F + \frac{M_{cF} \cdot L_{cr}^2}{H_F}\right) = 124 \text{ kip} \]

AASHTO LRFD A13.3.1-3

\[ F_t := 124 \text{ kip} \]

AASHTO LRFD Table A13.2-1

GFRP Lap Splice Length

\[ d_b := 0.5 \text{ in} \quad s_b := 7.125 \text{ in} \]

\[ \alpha := 1.5 \]

AASHTO GFRP 2.9.7.4.1

\[ f_c' = 4.5 \text{ ksi} \]

AASHTO GFRP 2.9.7.6

\[ f_{fs} := 0.25 \cdot f_{fu} = 29.5 \text{ ksi} \]

AASHTO GFRP 2.9.7.4.1

\[ C := \min (2 \text{ in } + 0.75 \text{ in } + 1.5 \cdot d_b, 0.5 \cdot s_b) = 3.5 \text{ in} \]

AASHTO GFRP 2.9.7.6

\[ l_d := \max \left(31.6 \cdot \alpha \cdot \frac{f_{fs}}{f_c'} - 340 \right) \]

\[ \sqrt{\frac{f_c'}{ksi}} \cdot ksi \]

\[ 13.6 + \frac{C}{d_b} \cdot d_h, 20 \cdot d_b \] = 10 in

AASHTO GFRP 2.9.7.4.1-1

\[ l_{splice} := \max (12 \text{ in }, 1.3 \cdot l_d) = 13 \text{ in} \]

AASHTO GFRP 2.9.7.6

Bar Length into the Barrier

\[ l_{hb} := \frac{38.0 \cdot 0.75 \text{ in}}{60} \cdot \frac{f_{fs}}{\sqrt{\frac{f_c'}{ksi}}} = 13.44 \text{ in} \]

AASHTO 5.10.8.2.4a-2

\[ \lambda_{rc} := 1.0 \quad \lambda_{cw} := 1.2 \quad \lambda_{er} := \frac{F_t}{R_w} = 1 \quad \lambda := 1.0 \]

AASHTO 5.10.8.2.4b

\[ l_{dh} := l_{hb} \cdot \left(\frac{\lambda_{rc} \cdot \lambda_{cw} \cdot \lambda_{er}}{\lambda}\right) = 16.12 \text{ in} \]

AASHTO 5.10.8.2.4a-1