MDOT RC-1563

High Skew Link Slab Bridge System with Deck Sliding over Backwall or Backwall Sliding over Abutments

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APPENDICES

Western Michigan University
Department of Civil & Construction Engineering
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Research

High Skew Link Slab Bridge System with Deck Sliding over Backwall or Backwall Sliding over Abutments

(Appendices)

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APPENDIX A - ACRONYMS AND ABBREVIATIONS

AASHTO - American Association of State Highway and Transportation Officials

AASHTO LRFD - American Association of State Highway and Transportation Officials Load and Resistant Factor Design

CDP – Cotton duck pads

DOT – Department of Transportation

EPS - Expanded polystyrene

EVA - Ethylene vinyl acetate (commonly known as expanded rubber or foam rubber)

FE – Finite element

FHWA – Federal Highway Administration

FRP - Fiberglass-reinforced pad

MDOT – Michigan Department of Transportation

NCDOT – North Carolina Department of Transportation

NTG – Negative Temperature Gradient

OMOT – Ontario Ministry of Transportation

PC – Prestressed Concrete PCI

PEP - Plain elastomeric pad

PTFE – Polytetrafluorethylene

PTG – Positive Temperature Gradient

ROFP – Random oriented fiber pads

SHA – State Highway Agencies

SREB – Steel-reinforced elastomeric bearings

SREP – Steel-reinforced elastomeric pads

VDOT – Virginia Department of Transportation

APPENDIX B

Table B-1. Longitudinal Bearing Translation over South Abutment (in.) – Loading Scenario I

Girder Label	FE Analysis	Tracker
A	-0.044	0.041
B	-0.042	-
C	-0.034	0.027
D	-0.025	-
E	-0.020	0.018
F	-0.018	-
G	-0.016	0.018

Table B-2. Girder Translations – Loading Scenario I

Measurement Point	FE Analysis (in.)$^{+}$			Tracker Measurement (in.)$^{++}$		
	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
R1	-0.016	0.024	-0.004	0.008	-0.007	0.001
R2	-0.019	0.047	-0.091	0.012	-0.031	0.060
R3	-0.026	0.062	-0.306	0.023	-0.040	0.194
R4	-0.015	0.026	-0.018	0.009	-0.010	0
R5	-0.015	0.034	-0.070	0.009	-0.020	0.036
R6	-0.010	0.058	-0.186	0.003	-0.041	0.115
R7	-0.003	0.067	-0.372	0.001	-0.044	0.242
R8	-0.013	0.016	-0.032	0.007	-0.007	0
R9	-0.010	0.020	-0.066	0.005	-0.012	0.025
R10	-0.003	0.031	-0.141	-0.004	-0.022	0.082
R11	0.012	0.043	-0.277	-0.016	-0.036	0.188
R12	-0.009	0.002	-0.032	0.006	-0.002	-0.003
R13	-0.003	0.003	-0.049	0	-0.003	0.016
R14	0.013	0.006	-0.110	-0.021	-0.009	0.084

+ Refer FE model coordinates (Figure 3-14)
++ Refer Tracker measurement coordinates (Figure 3-32)

Table B-3. Longitudinal Bearing Translation over South Abutment (in.) – Loading Scenario II

Girder Label	FE Analysis	Tracker
A	-0.086	0.088
B	-0.083	-
C	-0.071	0.065
D	-0.056	-
E	-0.047	0.045
F	-0.041	-
G	-0.036	0.040

Table B-4. Girder Translations – Loading Scenario II

Measurement Point	FE Analysis (in.)+			Tracker Measurement (in.)++		
	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
R1	-0.037	0.062	-0.007	0.032	-0.029	0.014
R2	-0.046	0.103	-0.199	0.038	-0.071	0.163
R3	-0.062	0.122	-0.571	0.060	-0.080	0.406
R4	-0.035	0.068	-0.037	0.029	-0.033	0.021
R5	-0.035	0.085	-0.161	0.027	-0.053	0.105
R6	-0.029	0.135	-0.414	0.021	-0.096	0.298
R7	-0.023	0.142	-0.762	0.021	-0.090	0.528
R8	-0.030	0.042	-0.070	0.026	-0.023	0.011
R9	-0.025	0.053	-0.154	0.017	-0.035	0.074
R10	-0.010	0.083	-0.336	-0.001	-0.057	0.227
R11	0.015	0.099	-0.637	-0.018	-0.073	0.452
R12	-0.020	0.006	-0.072	0.018	-0.006	-0.002
R13	-0.009	0.012	-0.117	0.004	-0.007	0.046
R14	0.027	0.019	-0.274	-0.040	-0.018	0.204

+ Refer FE model coordinates (Figure 3-14)
++ Refer Tracker measurement coordinates (Figure 3-32)

Table B-5. Longitudinal Bearing Translation over South Abutment (in.) – Loading Scenario III

Girder Label	FE Analysis	Tracker
A	-0.014	0.073
B	-0.018	-
C	-0.024	0.070
D	-0.033	-
E	-0.046	0.068
F	-0.063	-
G	-0.086	0.083

Table B-6. Girder Translations – Loading Scenario III

Measurement Point	FE Analysis (in.)+			Tracker Measurement (in.)++		
	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
R1	-0.072	-0.056	-0.344	0.072	0.015	0.171
R2	-0.028	-0.050	-0.125	0.054	0.012	0.084
R3	-0.011	-0.037	-0.015	0.053	0.003	0.051
R4	-0.045	-0.090	-0.528	0.046	0.041	0.239
R5	-0.028	-0.092	-0.286	0.042	0.040	0.129
R6	-0.016	-0.064	-0.104	0.043	0.016	0.054
R7	-0.010	-0.050	-0.015	0.046	0.006	0.035
R8	-0.016	-0.082	-0.482	0.024	0.043	0.192
R9	-0.012	-0.085	-0.260	0.027	0.043	0.081
R10	-0.011	-0.061	-0.101	0.035	0.023	0.011
R11	-0.008	-0.049	-0.012	0.037	0.007	-0.005
R12	-0.001	-0.043	-0.274	0.006	0.035	0.053
R13	-0.004	-0.039	-0.092	0.023	0.027	0
R14	-0.005	-0.027	-0.009	0.021	0.009	-0.035

+ Refer FE model coordinates (Figure 3-14)

++ Refer Tracker measurement coordinates (Figure 3-32)

Table B-7. Longitudinal Bearing Translation over South Abutment (in.) – Loading Scenario IV

Girder Label	FE Analysis	Tracker
A	-0.030	0.103
B	-0.037	-
C	-0.048	0.102
D	-0.064	-
E	-0.085	0.113
F	-0.113	-
G	-0.152	0.149

Table B-8. Girder Translations – Loading Scenario IV

Measurement Point	FE Analysis (in.)+			Tracker Measurement (in.)++		
	Longitudinal	Transverse	Vertical	Longitudinal	Transverse	Vertical
R1	-0.132	-0.088	-0.565	0.139	0.032	0.325
R2	-0.055	-0.077	-0.220	0.099	0.026	0.170
R3	-0.024	-0.063	-0.041	0.090	0.014	0.135
R4	-0.093	-0.148	-0.903	0.098	0.073	0.456
R5	-0.057	-0.145	-0.494	0.089	0.072	0.241
R6	-0.034	-0.102	-0.197	0.081	0.035	0.111
R7	-0.020	-0.081	-0.048	0.079	0.019	0.076
R8	-0.044	-0.143	-0.891	0.049	0.075	0.385
R9	-0.031	-0.147	-0.476	0.056	0.085	0.177
R10	-0.023	-0.100	-0.192	0.059	0.044	0.045
R11	-0.016	-0.079	-0.042	0.060	0.020	0.010
R12	-0.008	-0.080	-0.544	0.014	0.064	0.141
R13	-0.010	-0.074	-0.175	0.043	0.050	-0.033
R14	-0.010	-0.044	-0.028	0.046	0.014	-0.070

+ Refer FE model coordinates (Figure 3-14)
++ Refer Tracker measurement coordinates (Figure 3-32)

APPENDIX C

DESIGN PROCEDURE FOR LINK SLABS

OVERVIEW

AASHTO LRFD (2010) requires combined live and thermal load effects for the service limit state design. The Design Procedure described in the appendix will follow the rationale developed by Ulku et al. (2009). Link slab design moments are calculated using the girder end rotations. HL-93 loading is used to calculate the girder end rotations under live load. Girder end rotations caused by the temperature gradient are calculated using the procedure described by Saadeghvaziri and Hadidi (2002) by ensuring strain and curvature compatibility among sections and reinforcements.

One major improvement in the process presented in this appendix compared to what is given in Ulku et al. (2009) is the inclusion of 3D and skew effects to calculate the resultant link slab design moments and forces.

In order to apply loading, the first step is to establish a composite girder-deck cross-section with an effective width as per AASHTO LRFD (2010) Section 4.6.2.6, the composite moment of inertia, and the modulus of elasticity for concrete.

Girder End Rotations due to Live Load

AASHTO LRFD (2010) procedures can be followed without considering the effects of the link slab.

- Apply HL-93 loading [HS-20 truck with impact and distribution factor (LRFD section 3.6.2.1 and 4.6.2.2.2) + 0.64 kips/ft lane loading (LRFD 3.6.1.2.4)] on the simply supported spans to compute maximum girder end rotations.

Girder End Rotations due to Temperature Gradient

Girder end rotations caused by the temperature gradient are calculated following the procedure described by Saadeghvaziri and Hadidi (2002).

The girder-deck composite cross-section is subjected to the temperature gradient as described in AASHTO LRFD section 3.12.3 (Figure C-1).

Figure C-2 illustrates the compatibility forces and moments developed in the sections and the temperature gradient profile along the cross-section height.

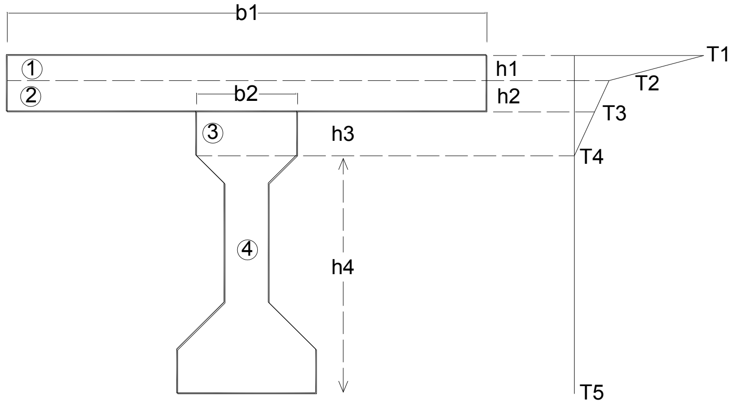

Figure C-1. Temperature profile along cross-section

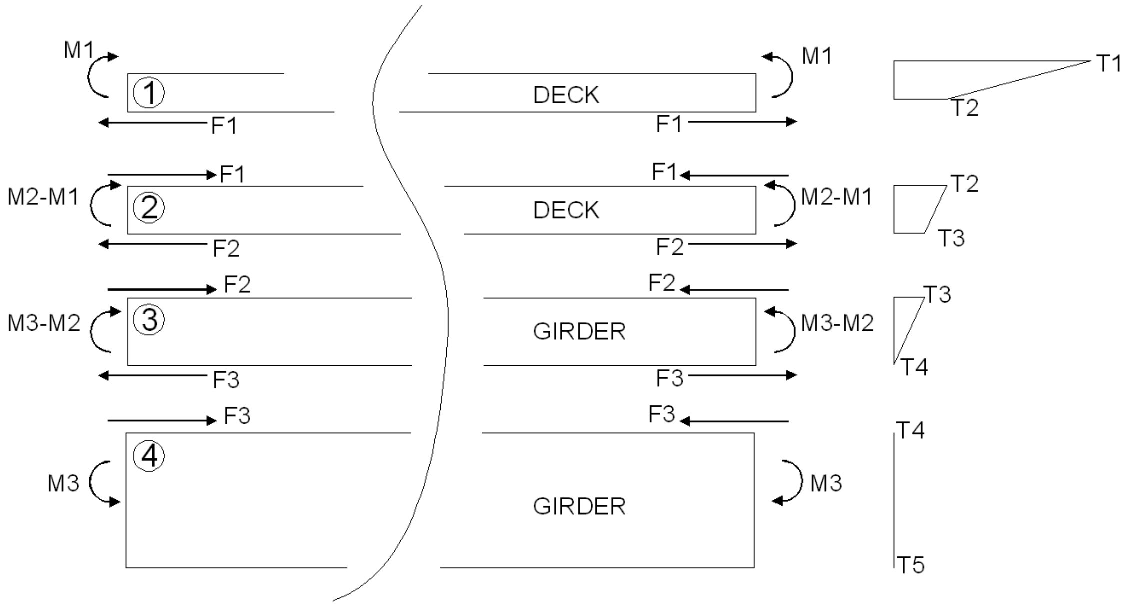

Figure C-2. Compatibility forces and moments and temperature profile along cross-section height

Strain Compatibility

For strain compatibility between sections 1 and 2 (ignoring reinforcement contribution);

$$\varepsilon_{Bottom1} = \alpha_1(T_2) + \frac{M_1}{E_1 S_{b1}} + \frac{F_1}{E_1 A_1} + \frac{F_1 d_{b1}}{E_1 S_{b1}} = \varepsilon_{Top2}$$

$$\varepsilon_{Top2} = \alpha_2(T_2) + \frac{M_2 - M_1}{E_2 S_{t2}} + \frac{F_2 - F_1}{E_2 A_2} + \frac{F_2 d_{b2} + F_1 d_{t2}}{E_2 S_{t2}} \qquad \text{(C-1)}$$

For strain compatibility between sections 2 and 3;

$$\varepsilon_{Bottom2} = \alpha_2(T_3) + \frac{M_2 - M_1}{E_2 S_{b2}} + \frac{F_2 - F_1}{E_2 A_2} + \frac{F_2 d_{b2} + F_1 d_{t2}}{E_2 S_{b2}} = \varepsilon_{Top3}$$

$$\varepsilon_{Top3} = \alpha_3(T_3) + \frac{M_3 - M_2}{E_3 S_{t3}} + \frac{F_3 - F_2}{E_3 A_3} + \frac{F_3 d_{b3} + F_2 d_{t3}}{E_3 S_{t3}} \tag{C-2}$$

For strain compatibility between sections 3 and 4;

$$\varepsilon_{Bottom3} = \alpha_3(T_4) + \frac{M_3 - M_2}{E_3 S_{b3}} + \frac{F_3 - F_2}{E_3 A_3} + \frac{F_3 d_{b3} + F_2 d_{t3}}{E_3 S_{b3}} = \varepsilon_{Top4}$$

$$\varepsilon_{Top4} = \alpha_4(T_4) - \frac{M_3}{E_4 S_{t4}} - \frac{F_3}{E_4 A_4} + \frac{F_3 d_{t4}}{E_4 S_{t4}} \tag{C-3}$$

Curvature Compatibility

For curvature compatibility between sections 1 and 2;

$$\frac{1}{R_1} = \alpha_1(\frac{T_2 - T_1}{h_1}) + \frac{M_1}{E_1 I_1} + \frac{F_1 d_{b1}}{E_1 I_1} = \frac{1}{R_2}$$

$$\frac{1}{R_2} = \alpha_2(\frac{T_3 - T_2}{h_2}) + \frac{M_2 - M_1}{E_2 I_2} + \frac{F_1 d_{t2} + F_2 d_{b2}}{E_2 I_2} \tag{C-4}$$

For curvature compatibility between sections 2 and 3;

$$\frac{1}{R_2} = \alpha_2(\frac{T_3 - T_2}{h_2}) + \frac{M_2 - M_1}{E_2 I_2} + \frac{F_1 d_{t2} + F_2 d_{b2}}{E_2 I_2} = \frac{1}{R_3}$$

$$\frac{1}{R_3} = \alpha_3(\frac{T_4 - T_3}{h_3}) + \frac{M_3 - M_2}{E_3 I_3} + \frac{F_2 d_{t3} + F_3 d_{b3}}{E_3 I_3} \tag{C-5}$$

For curvature compatibility between sections 3 and 4;

$$\frac{1}{R_3} = \alpha_3(\frac{T_4 - T_3}{h_3}) + \frac{M_3 - M_2}{E_3 I_3} + \frac{F_2 d_{t3} + F_3 d_{b3}}{E_3 I_3} = \frac{1}{R_4}$$

$$\frac{1}{R_4} = \alpha_3(\frac{T_5 - T_4}{h_4}) - \frac{M_3}{E_4 I_4} + \frac{F_3 d_{t4}}{E_4 I_4} \tag{C-6}$$

where

α_i : Coefficient of thermal expansion for Section i

T_i : Girder and deck temperature changes as given in Figure C-1 and Figure C-2

F_i : Force resultant of stresses between section i and i+1

M_i : Moment resultant of stresses between section i and i+1

d_{bi} : Distance from centroid to bottom fiber of Section i

d_{ti} : Distance from centroid to top fiber of Section i

S_{bi} : Bottom section modulus for Section i

S_{ti} : Top section modulus for Section i

E_i : Modulus of elasticity of Section i

A_i : Cross-sectional area of Section i

I_i : Moment of inertia of Section i

Solving the above six simultaneous equations for six unknowns (F_1, F_2, F_3, M_1, M_2, M_3), corresponding strain and curvature values can be obtained.

More details including the effect of reinforcement and some other boundary conditions can be found at Saadeghvaziri and Hadidi (2002).

Once the curvature is known, end-slopes can be obtained by integrating curvature along the length;

$$\frac{d\theta}{dx} = \frac{1}{R_1} = \frac{1}{R_2} = \frac{1}{R_3} = \frac{1}{R_4} = \frac{1}{R} \quad \theta(x) = \int \frac{1}{R}dx = \frac{x}{R} + C_1 \tag{C-7}$$

For a simply supported span with length L, since the slope at mid-span will be equal to zero under gradient loading, integration constant C_1 can be calculated as;

$$\theta(\frac{L}{2}) = \frac{L}{2R} + C_1 = 0 \quad C_1 = -\frac{L}{2R} \tag{C-8}$$

Then, the slope equation and the slope at the end will be equal to;

$$\theta(x) = \frac{x}{R} - \frac{L}{2R} \quad \theta(L) = \frac{L}{R} - \frac{L}{2R} = \frac{L}{2R} \tag{C-9}$$

Link slab moments can be calculated using Eq. C-10 once the girder end rotations are calculated under live and thermal gradient loads.

$$M_a = \frac{2E_c I_d \theta}{L_L} \tag{C-10}$$

where,

I_d : Moment of inertia of the link slab

L_L : Length of the link slab (Debond zone length: sum of 5 % of each adjacent girder span + gap between beam ends)

DESIGN AXIAL FORCE

Axial force for the RHHR support condition can be calculated using a two-span-continuous model and neglecting the effects of debonding.

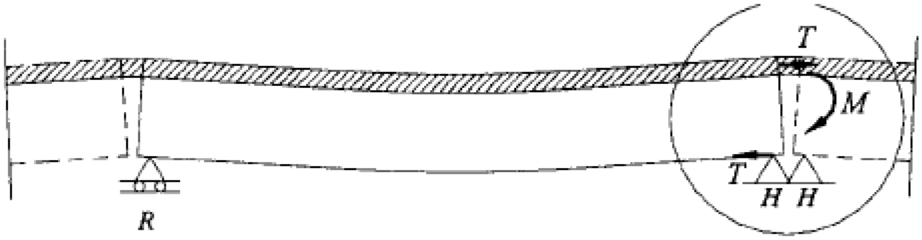

Figure C-3. Effect of RHHR type support condition on continuity (Okeil and El-Safty 2005)

For a two-span system with RHHR boundaries, tensile force developed in the link slab would be equal to the horizontal reactions at the interior supports, and this reaction is equal to the continuity moment divided by the distance between the centroid of deck and bearing location (Figure C-3).

Continuity Moment due to Live Load

Under live load, each span is loaded so as to create maximum negative moment at the interior support (Figure C-4) with composite cross-section properties and neglecting debonding.

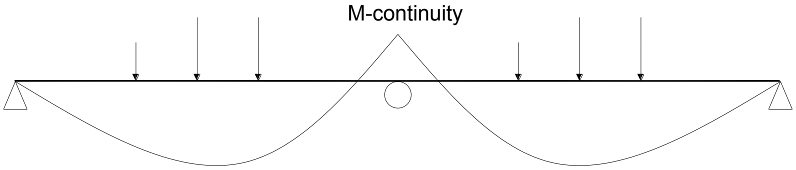

Figure C-4. Continuity moment at the interior support under live load

Continuity Moment due to Temperature Gradient

The continuity moment under temperature gradient loading can be calculated using the superposition concept as given in Saadeghvaziri and Hadidi (2002). For a two-span-continuous system with constant cross-section in both spans, continuity moment $M_{continuity}$ can be calculated as;

$$M_{continuity} = \frac{(F_2 d_{tg} - M_3)(3E_{Composite} I_{Composite})}{2E_{Girder} I_{Girder}} \qquad \text{(C-11)}$$

where

F_2 : Force resultant of stresses between section 2 and 3 calculated from six simultaneous equations

M_3 : Moment resultant of stresses between section 2 and 3 calculated from six simultaneous equations

d_{tg} : Distance from centroid to top fiber of girder

$E_{Composite}$: Modulus of elasticity of composite section

$I_{Composite}$: Moment of inertia of composite section

E_{Girder} : Modulus of elasticity of girder

I_{Girder} : Moment of inertia of girder

Once the continuity moment is found, tensile force in the link slab is;

$$T = \frac{M_{continuity}}{h} \tag{C-12}$$

where, h is the distance between the centroid of deck and bearing location.

Numerical Example – Skew Link slab Design

STEP 1: Material and Geometric Properties

Cross-section properties of the girder and the composite section are given in Figure C-5.

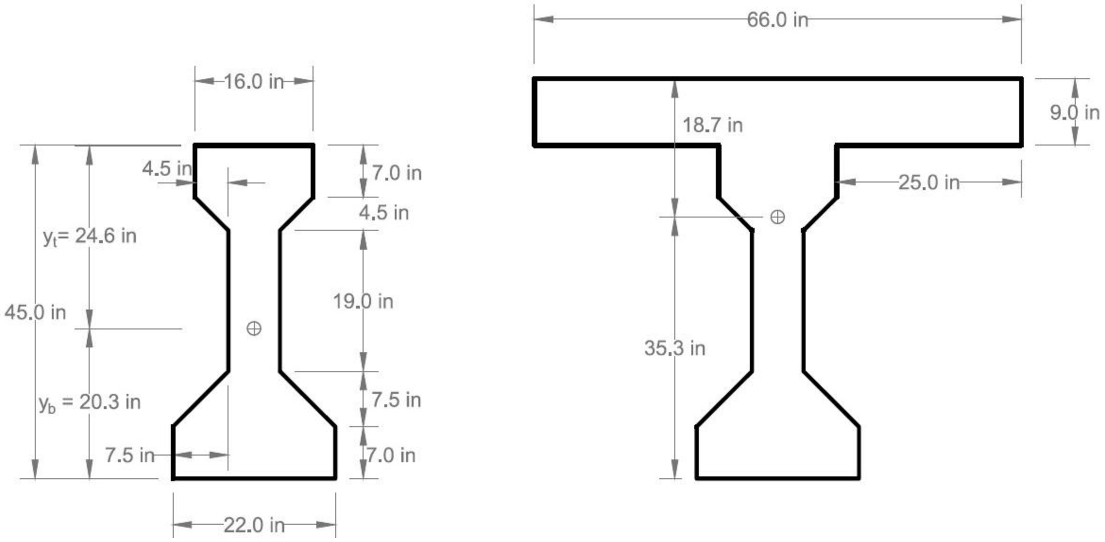

Figure C-5. Girder and composite section geometric properties

Boundary condition	RHHR
Skew (θ)	45^0
Compressive strength of concrete (f_c')	4,500 psi
Unit weight of concrete (w_c)	0.15 kcf
Concrete modulus of elasticity (E_c) (AASHTO LRFD Section 5.4.2.4)	4,067 ksi
Reinforcement yield strength (f_y)	60 ksi
Steel modulus of elasticity (E_s)	29,000 ksi
Link slab length (L_{LS})$^+$	84.4 in.
Effective deck width (B)$^{++}$	66 in.
Link slab thickness	9 in.
Moment of inertia of link slab (I_{LS})	4,009.5 in^4
Deck overhang (on either side of the beam)	25 in.
Moment of inertia of the composite section ($I_{composite}$)	375,678 in^4

+ Link slab length = 69.5×12×5%×2 + 1 in. gap = 84.4 inches

++ Link slab section perpendicular to bridge longitudinal axis is considered in the example because design moments are calculated perpendicular to bridge longitudinal axis.

STEP 2: Design Moments

Step 2.1: Live Load Moment

HL-93 (AASHTO LRFD 2010) loading is applied at a location to create maximum end rotation on the 69.5 ft span of the bridge. The impact factor is taken as 1.33 from Section 3.6.2.1 of AASHTO LRFD (2010). As per Section 3.6.1.3 AASHTO LRFD (2010), a lane load of 0.64 k/ft is used in addition to the axle loads. Girder end rotation under HL-93 loading is 3.47×10^{-3} radians. The distribution factor is calculated as 0.508 assuming two or more lanes are loaded from the formulation in AASHTO LRFD (2010) Table 4.6.2.2.2b-1.

The maximum girder-end design rotation is calculated as 1.763×10^{-3} radians when the front axle is located 18.4 feet away from the end of the span.

Moment induced by live load =

$M_a = (2E_cI_d\theta)/L_L = (2\times4067\times4009.5\times0.001763)/(84.4\times12) = -56.77$ ft-kips OR

For a 66 in. wide effective section

$$M_a = \frac{2E_{cI_d}\theta}{L_L} = \frac{2\times4067\times4009.5\times0.001763}{84.4\times12\times(66/12)} = -10.32\ ft - kips/ft$$

Step 2.2: Moment due to Temperature Gradient Loading

Required information, solutions to simultaneous equations, curvature, girder end rotation, and moments due to temperature gradient loads are presented in chapter 4 and Appendix D.

Moment induced by positive temperature gradient (PTG):

$M_a = (2E_cI_d\theta)/L_L = (2\times4067\times4009.5\times1.613\times10^{-3})/(84.4\times12) = 51.9$ ft-kips OR

For a 66 in. wide effective section

$$M_a = \frac{2E_{cI_d}\theta}{L_L} = \frac{2\times4067\times4009.5\times1.613\times10^{-3}}{84.4\times12\times(66/12)} = 9.44\ ft - kips/ft$$

Moment caused by negative thermal gradient (NTG) is -0.3 times the positive gradient loading.

$M_a = 51.9 \times -0.3 = -15.57$ ft-kips OR

For a 66 in. wide effective section

M_a = 15.57/(66/12) = -2.83 ft-kips/ft

The following table summarizes the moments calculated in step 2.1 and 2.2.

Table C-1 Summary of Analytical Girder End Rotations and Analytical Design Moments

Load Case	Analytical Rotation Magnitude (Radians) (a)	Distribution Factor (b)	Analytical Design Rotation Magnitude (Radians) (c) = (a) × (b)	Analytical Design Moment$^+$ (k-ft)/ft (d)
Live	0.003470	0.508	0.001763	-10.32
PTG	0.001613	N/A	0.001613	9.44
NTG	0.000484	N/A	0.000484	-2.83

+ Negative moments cause tension at link slab top fiber. Sign convention is stated in chapter 4

Step 2.3: Moment Reduction due to 3D Effect

AASHTO LRFD (2010) distribution factors are to incorporate 3D effect on load distribution and to find the girder design moments. The following table shows ratios of link slab moments calculated from 3D FE analysis of the specific straight bridge configuration described in chapter 4 of the report to analytical design moments summarized in the above table (i.e., moments calculated in step 2.1 and 2.2). HRRR, RRHR, and RHHR represent different support configurations of a two-span bridge (H-hinge or fixed bearing, R- roller or expansion bearing; HRRR represents expansion bearings underneath the link slab). It is seen that there is a significant reduction in link slab moments based on support configuration and the type of load acting on the bridge. Further, there are no load distribution factors given in AASHTO LRFD (2010) for thermal loads.

Table C-2. Ratios of 3D FE to Analytical Design Moment for a Straight Bridge

Load Case	HRRR	RRHR	RHHR
Live	0.218	0.257	0.887
PTG	0.092	0.111	0.967
NTG	0.080	0.100	0.961

Table C-3. Link Slab Design Moment for a Straight Bridge with RHHR

Load Case	Moment Ratio (a)	Analytical Design Moment (k-ft)/ft (b)	Link Slab Design Moment (k-ft)/ft (c) = a×b
Live	0.887	-10.32	-9.2
PTG	0.967	9.44	9.1
NTG	0.961	-2.83	-2.7

Step 2.4: Moment Reduction due to Skew Effect (Skew Reduction Factors)

Table C-4. Skew Reduction Factors for RHHR

Skew (Degree)	**Ratio of Maximum Link-Slab Effective Moment (Skew/Zero Skew) (Skew Reduction Factors)**					
	Lane 1 (a)	**Lane 2 (b)**	**Lane Alt 1 (c)**	**Lane Alt 2 (d)**	**NTG (e)**	**PTG (f)**
0	1.00	1.00	1.00	1.00	1.00	1.00
20	0.96	0.96	0.97	0.95	≈ 1.00	≈ 1.00
30	0.91	0.90	0.91	0.89	≈ 1.00	≈ 1.00
45	0.77	0.74	0.76	0.72	≈ 1.00	≈ 1.00

Analysis results presented in chapter 4 of the report demonstrated that the *Lane 2* load is the governing live load case. There is no increase or reduction in moments developed in a skew link slab under NTG or PTG for RHHR support configurations; however, there are skew reduction/amplification factors for other support configurations.

The design example is for a 45^0 skew bridge. Hence, live load moment shall be multiplied by 0.74, and there is no reduction for NTG or PTG moments.

Table C-5. Link Slab Design Moment for Skew Bridge with RHHR

Load Case	Link Slab Design Moment of a Straight Bridge (k-ft)/ft (a)	Skew Reduction Factor (b)	Link Slab Design Moment of a Skew Bridge (k-ft)/ft (c) = a×b
Live	-9.2	0.74	-6.8
PTG	9.1	1.00	9.1
NTG	-2.7	1.00	-2.7

Step 2.5: Resultant Combined Moments

Thermal gradient loading [i.e., NTG and PTG] and live load need to be combined to create critical load combinations. The following load combinations are developed as per AASHTO LRFD (2010) section 3.4. AASHTO LRFD (2010) service 1 load combination requires using load factor of 1.0 for the temperature gradient when the live load is not considered. Exclusion of live load when PTG effect is used in the design yields the critical load combination for positive moment. Hence, it is recommended to use factor of 1.0 for PTG loads.

Service I-Negative Moment: 1.0 Live Load + 0.5 NTG
Service I-Positive Moment: 1.0 PTG

Service I-Negative Moment:

$$M_{SI\text{-}N} = -6.8 + 0.5\times -2.7 = -8.15 \text{ ft-kips/ft}$$

Service I-Positive Moment:

$$M_{SI\text{-}P} = 9.1 = 9.1 \text{ ft-kips/ft}$$

Step 2.6: Cracking Moment

Note: Cracking moment calculated using modulus of rupture of $0.24\sqrt{f_c'}, ksi$ is less than both $M_{SI\text{-}N}$ and $M_{SI\text{-}P}$. Hence, the links slab cracks and the amount of top and bottom layer reinforcement should be calculated using $M_{SI\text{-}N}$ and $M_{SI\text{-}P}$, respectively. Detailed example of calculating link slab top and bottom layer reinforcement is provided in Ulku et al. (2009). The amount of reinforcement calculated from these two moments is less than the minimum reinforcement required in AASHTO LRFD section 5.4.2.6. Hence, the minimum reinforcement calculation process as per AASHTO LRFD section 5.4.2.6 is presented here.

Modulus of rupture of 4500 psi strength concrete for calculating the minimum reinforcement

f_r =785 psi ($0.37\sqrt{f_c'}, ksi$) and

Cracking moment

$$M_{cr} = S_c\left(f_r + f_{cpe}\right) - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right) \geq S_c f_r$$

M_{dnc} - Total unfactored dead load moment acting on the link slab that can be eliminated by considering casting sequence of the link slab (e.g., in retrofit applications expansion joint is removed and link slab is replaced).

f_{cpe} - compressive stress in concrete due to effective prestress forces which is zero in this example because there is no prestress forces in the link slab.

S_c - section modulus of the link slab (I_g / y_t)

I_g - moment of inertia of the gross section

y_t - distance from the neutral axis to the extreme tension fiber

Considering a 9 in. thick, 12 in. wide link slab section;

I_g = 12 x 9^3 / 12 = 729 in^4

y_t = 4.5 in.

Cracking moment of 9 in. thick, 12 in. wide link slab section;

$M_{cr} = S_c\, f_r$ = 10.6 *ft-kips / ft*

Step 2.7: Minimum Flexural Reinforcement

AASHTO LRFD (2010) section 5.7.3.3.2 requires providing adequate steel to develop a factored flexural resistance (M_r) equal to the lesser of 1.2×M_{cr} or 1.33×(factored moment required by the applicable strength load combinations).

$1.2 \times M_{cr} = 1.2 \times 10.6$ *ft-kips / ft* = 12.72 *ft-kips / ft*

AASHTO LRFD (2010) recommends using a zero (0) load factor for the thermal load gradient when a Strength I combination is used. Hence, "1.33×(the factored moment required by the applicable strength load combinations)" always yields negative moments. For negative moment at the link slab;

$1.33 \times (1.75 \times -6.8 + 0.0 \times -2.7) = -15.83$ *ft-kips / ft*

When the specification requirements are considered, calculation of amount of minimum negative moment reinforcement (top reinforcement) is governed by $M_r = 1.2 \times M_{cr} = 12.72$ ft-kips/ft.

AASHTO LRFD section 5.7.3.3.2 requirement of "1.33×(the factored moment required by the applicable strength load combinations)" never yield a positive moment to calculate positive moment reinforcement (i.e., link slab bottom reinforcement). Also, $M_{SI\text{-}P} < M_{cr}$.

Hence, using $M_r = 1.2 \times M_{cr} = 12.72$ ft-kips/ft is recommended for calculating positive moment reinforcement.

Step 2.7.1 Negative Moment Reinforcement (i.e., top fiber in tension)

The minimum amount of steel reinforcement is calculated considering 40% of the yield strength, $j \approx 0.9$, and d = 6.375 in.

Effective depth (d) is calculated assuming #6 bars are used as the transverse reinforcement in the deck and the clear cover to the top transverse bar is 3 in.

d =(link slab thickness) - (clear cover to transverse rebar) + (0.5 x diameter of #6 bar)
d = 9 in. - 3 in. + 0.5x0.75 in. = 6.375 in.

$A_{steel} = M_r/(0.4 f_y.j.d)$ = (12.72 ft-kips/ft) x 12 / (0.4×60 ksi×0.9×6.375 in.)

= 1.11 in^2/ft

Use #6 bars @ 4 in. = $A_{steel} = 1.32\ \text{in.}^2 > 1.11\ \text{in}^2$

Step 2.7.2 Positive Moment Reinforcement (i.e., bottom fiber in tension)

The amount of steel reinforcement is calculated considering 40% of the yield strength, $j \approx 0.9$, and d = 6.75 in.

Effective depth (d) is calculated assuming #6 bars are used as the transverse reinforcement in the deck and the distance from bottom surface to the centerline of the bottom transverse bar is 1.5 in.

d =(link slab thickness) - (cover to centerline of transverse rebar) - (diameter of #6 bar)
d = 9 in. - 1.5 in. - 0.75 in. = 6.75 in.

$A_{steel} = M_r/(0.4f_y.j.d)$ = (12.72 ft-kips/ft) x 12 / (0.4×60 ksi×0.9×6.75 in.)

= 1.05 in^2/ft

Use #6 bars @ 4 in. = A_{steel} = 1.32 in.^{2} > 1.05 in^2

Step 2.7.3 Steel Stress and Crack Width Parameter Limits

Section 5.7.3.4 *Control of Cracking by Distribution of Reinforcement* is not discussed here because the amount of reinforcement provided satisfies crack width limit criterion. Please refer Ulku et al. (2009) for the detailed procedure.

STEP 3: **Design Axial Force**

Step 3.1: Axial Force due to Live Load

For an RHHR boundary condition, the axial force in the link slab needs to be calculated using the maximum negative moment at the interior support of a two-span continuous system. HL-93 (AASHTO LRFD 2010) loading is applied at both spans to create a maximum negative moment of -724 ft-kips at the interior support.

Axial force (F) acting on the link slab due to HL-93 loading:

$$F = \frac{M_{continuity}}{h} = \frac{-724\times 12}{(54-9/2)} = -176\ kips\ \ or -27.8\ kips/ft \qquad \text{(Tension)}$$

Step 3.2: Axial Force due to PTG

Axial force acting on the link slab due to positive temperature gradient:

$M_{continuity} = [(F_2 d_{tg} - M_3)(3E_{composite}\, I_{composite})]/(2E_{girder} I_{girder})$

$= [(25.257\times 24.73 + 31.742)\cdot(3\times 4067\times 375{,}678)]/(2\times 4067\times 125{,}390)$

= 2,950 in-kips

$F = M_{continuity}/h = 2950/(54 - 9/2) = 60$ kips or 11 kips/ft (compression)

Note that F_2 is the force at layer 2, d_{tg} is the distance from girder top to the girder centroid, and M_3 is the moment at layer 3. F_2 and M_3 calculation is given in MathCAD sheet provided in Appendix D.

Step 3.3: Axial Force due to NTG

Axial force acting on the link slab due to negative temperature gradient:

$$T_{NG} = -0.3T_{PG} = -0.3 \times 60 = 18\ kips \quad \text{or } -3.2\ \text{kips/ft} \qquad \text{(Tension)}$$

Step 3.4: 3D and Skew Effects on Axial Force

3D and skew effects discussed in *Step 2.3* and *2.4* can be directly applied to calculate axial load in a skew link slab due to similarities in moment and force ratios. (See chapter 4 of the report for further details.)

Table C-6. Link Slab Design Force for Straight Bridge with RHHR

Load Case	Design Force Ratio (a)	Analytical Design Force (kips)/ft (b)	Link Slab Design Force of a Straight Bridge (kips)/ft (c) = a×b
Live	0.887	-27.8	-24.7
PTG	0.967	11.0	10.6
NTG	0.961	-3.2	-3.1

Table C-7. Link Slab Design Force for Skew Bridge with RHHR

Load Case	Link Slab Design Force of a Straight Bridge k/ft (a)	Skew Reduction Factor (b)	Link Slab Design Force of a Skew Bridge k/ft (c) = a×b
Live	-24.7	0.74	-18.3
PTG	10.6	1.00	10.6
NTG	-3.1	1.00	-3.1

Step 3.4: Resultant Combined Forces

Thermal gradient loading [i.e., NTG and PTG] and live load need to be combined to create critical load combinations.

Service I-Negative Force: 1.0 Live Load + 0.5 NTG
Service I-Positive Force: 1.0 PTG

Service I-Negative force:

F_{SI-N} = -18.3 + 0.5×-3.1 = -19.85kips/ft

Service I-Positive Force:

F_{SI-P} = 10.6 = 10.6 kips/ft

Step 3.5: Check for Axial Load Capacity

Steel area provided in the link-slab = 0.88 in^2 + 0.88 in^2 = 1.76 in^2/ft
Assuming steel carries the total axial load
f_{steel} = (19.45 kips/ft) / (1.76 in^2/ft) = *11.05* ksi < f_{sa} = 0.6×60 ksi = 36 ksi OK.

STEP 4: Moment-Force Interaction

Load Combination	Moment (from Step 2) ft-kips/ft	Axial Force (from Step 3) kips/ft
Service I - Positive	9.1 (i.e., top fiber compression)	10.60 (Compression)
Service I - Negative	8.15 (i.e., top fiber tension)	19.85 (Tension)

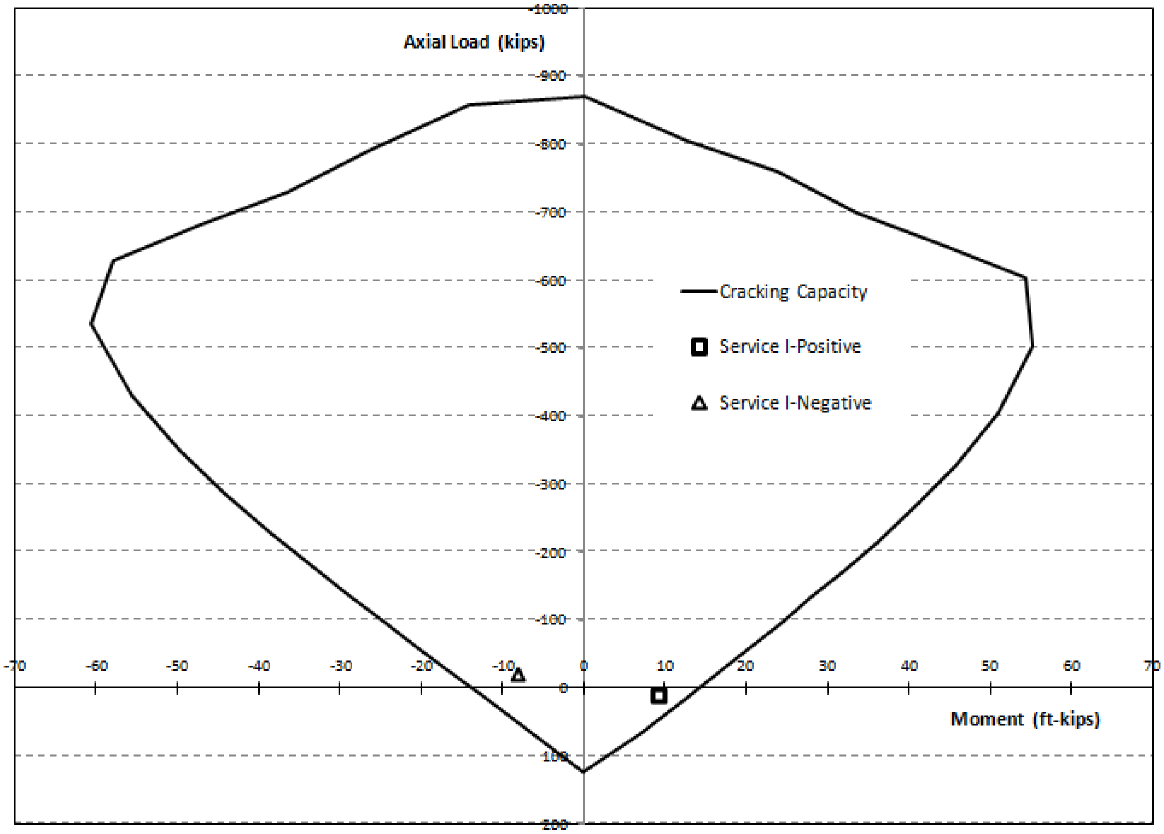

Figure C-1. Moment and Interaction Diagram under Service Loads for unit link slab width

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APPENDIX D – LINK SLAB MOMENT DUE TO THERMAL GRADIENT (MathCAD)

Temperature profile through the deck-girder composite section for Postive Temeperature Gradient (PTG)

$T_1 := 41$ $T_2 := 11$ $T_3 := 6.42$ $T_4 := 0$ $T_5 := 0$

Material properties

Concrete modulus $E_c := 4067$ ksi

Thermal expansion coefficients, in/in/F

$\alpha_1 := 6 \cdot 10^{-6}$ $\alpha_2 := 6 \cdot 10^{-6}$ $\alpha_3 := 6 \cdot 10^{-6}$ $\alpha_4 := 6 \cdot 10^{-6}$

Section properties (length in inches; area in inches^2)

$b_1 := 66$ $b_2 := 16$ $h_1 := 4$ $h_2 := 5$ $h_3 := 7$ $h_4 := 38$

$d_{b1} := 2$ $d_{t1} := 2$ $d_{b2} := 2.5$ $d_{t2} := 2.5$ $d_{b3} := 3.5$ $d_{t3} := 3.5$ $d_{b4} := 14.91$ $d_{t4} := 23.09$

$A_1 := h_1 \cdot b_1$ $A_2 := h_2 \cdot b_1$ $A_3 := h_3 \cdot b_2$ $A_4 := 447.5$

$A_1 = 264$ $A_2 = 330$ $A_3 = 112$ $A_4 = 447.5$

Length of bridge span (in.)

$L := 834$

Length of link slab (in.)

$L_L := L \cdot 0.05 \cdot 2 + 1$ $L_L = 84.4$

Moment of inertia of each layer (in.^{4}).

$I_1 := b_1 \cdot \frac{h_1^{\ 3}}{12}$ $I_2 := b_1 \cdot \frac{h_2^{\ 3}}{12}$ $I_3 := b_2 \cdot \frac{h_3^{\ 3}}{12}$ $I_4 := 61889.67$

$I_1 = 352$ $I_2 = 687.5$ $I_3 = 457.333$ $I_4 = 6.189 \times 10^4$

Section modulus ($in.^3$).

$$S_{b1} := \frac{I_1}{d_{b1}} \qquad S_{b2} := \frac{I_2}{d_{b2}} \qquad S_{b3} := \frac{I_3}{d_{b3}} \qquad S_{b4} := \frac{I_4}{d_{b4}}$$

$$S_{t1} := \frac{I_1}{d_{t1}} \qquad S_{t2} := \frac{I_2}{d_{t2}} \qquad S_{t3} := \frac{I_3}{d_{t3}} \qquad S_{t4} := \frac{I_4}{d_{t4}}$$

$$S_{b1} = 176 \qquad S_{b2} = 275 \qquad S_{b3} = 130.667 \qquad S_{b4} = 4.151 \times 10^3$$

$$S_{t1} = 176 \qquad S_{t2} = 275 \qquad S_{t3} = 130.667 \qquad S_{t4} = 2.68 \times 10^3$$

Moment of inertia of the link slab (in^4)

$$I_d := b_1 \cdot \frac{(h_1 + h_2)^3}{12} \qquad I_d = 4.01 \times 10^3$$

Solution process of six simultaneous equatons

Initial estimates

$$M_1 := 100 \qquad M_2 := 100 \qquad M_3 := 100 \qquad M_4 := 100$$

$$F_1 := 100 \qquad F_2 := 100 \qquad F_3 := 100 \qquad F_4 := 100$$

Given

$$\alpha_1 \cdot T_2 + \frac{M_1}{E_c \cdot S_{b1}} + \frac{F_1}{E_c \cdot A_1} + F_1 \cdot \frac{d_{b1}}{E_c \cdot S_{b1}} - \alpha_2 \cdot T_2 - \frac{(M_2 - M_1)}{E_c \cdot S_{t2}} - \frac{(F_2 - F_1)}{E_c \cdot A_2} + \frac{(F_2 \cdot d_{b2} + F_1 \cdot d_{t2}) \cdot -1}{E_c \cdot S_{t2}} = 0$$

$$\alpha_2 \cdot T_3 + \frac{(M_2 - M_1)}{E_c \cdot S_{b2}} + \frac{(F_2 - F_1)}{E_c \cdot A_2} + \frac{(F_2 \cdot d_{b2} + F_1 \cdot d_{t2})}{E_c \cdot S_{b2}} - \alpha_3 \cdot T_3 - \frac{(M_3 - M_2)}{E_c \cdot S_{t3}} - \frac{(F_3 - F_2)}{E_c \cdot A_3} - \frac{(F_3 \cdot d_{b3} + F_2 \cdot d_{t3})}{E_c \cdot S_{t3}} = 0$$

$$\alpha_3 \cdot T_4 + \frac{(M_3 - M_2)}{E_c \cdot S_{b3}} + \frac{(F_3 - F_2)}{E_c \cdot A_3} + \frac{(F_3 \cdot d_{b3} + F_2 \cdot d_{t3})}{E_c \cdot S_{b3}} - \alpha_4 \cdot T_4 - \frac{(M_3) \cdot -1}{E_c \cdot S_{t4}} - \frac{(F_3) \cdot -1}{E_c \cdot A_4} - \frac{(F_3 \cdot d_{t4})}{E_c \cdot S_{t4}} = 0$$

$$\alpha_1 \cdot \frac{(T_2 - T_1)}{h_1} + \frac{M_1}{E_c \cdot I_1} + F_1 \cdot \frac{d_{b1}}{E_c \cdot I_1} - \alpha_2 \cdot \frac{(T_3 - T_2)}{h_2} - \frac{(M_2 - M_1)}{E_c \cdot I_2} - \frac{(F_1 \cdot d_{t2} + F_2 \cdot d_{b2})}{E_c \cdot I_2} = 0$$

$$\alpha_2 \cdot \frac{(T_3 - T_2)}{h_2} + \frac{(M_2 - M_1)}{E_c \cdot I_2} + \frac{(F_1 \cdot d_{t2} + F_2 \cdot d_{b2})}{E_c \cdot I_2} - \alpha_3 \cdot \frac{(T_4 - T_3)}{h_3} - \frac{(M_3 - M_2)}{E_c \cdot I_3} - \frac{(F_2 \cdot d_{t3} + F_3 \cdot d_{b3})}{E_c \cdot I_3} = 0$$

$$\alpha_3 \cdot \frac{(T_4 - T_3)}{h_3} + \frac{(M_3 - M_2)}{E_c \cdot I_3} + \frac{(F_2 \cdot d_{t3} + F_3 \cdot d_{b3})}{E_c \cdot I_3} - \alpha_3 \cdot \frac{(T_5 - T_4)}{h_4} - \frac{(M_3 \cdot -1)}{E_c \cdot I_4} - \frac{(F_3 \cdot d_{t4})}{E_c \cdot I_4} = 0$$

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ M_1 \\ M_1 \\ M_1 \end{bmatrix} := Find(F_1,\ \ F_2,\ \ F_3,\ \ M_1,\ \ M_2,\ \ M_3)$$

$F_1 = -33.11$ $F_2 = 25.257$ $F_3 = 40.79$ kips

$M_1 = 136.178$ $M_2 = 181.992$ $M_3 = -31.742$ kip-in

$$\mathrm{Curvature} := \alpha_3 \cdot \frac{(T_4 - T_3)}{h_3} + \frac{(M_3 - M_2)}{E_c \cdot I_3} + \frac{(F_2 \cdot d_{t3} + F_3 \cdot d_{b3})}{E_c \cdot I_3}$$

$\mathrm{Curvature} = 3.868 \times 10^{-6}$

$\theta_{PTG} := \mathrm{Curvature} \cdot \frac{L}{2}$ $\theta_{PTG} = 1.613 \times 10^{-3}$ rad

$\theta_{NTG} := \theta_{PTG} \cdot -0.3$ $\theta_{NTG} = -4.839 \times 10^{-4}$ rad

Moment calculations

$\mathrm{Moment}_{PTG} := 2 \cdot E_c \cdot I_d \cdot \frac{\theta_{PTG}}{L_L \cdot 12}$ $\mathrm{Moment}_{NTG} := \mathrm{Moment}_{PTG} \cdot -0.3$

$\mathrm{Moment}_{PTG} = 51.938$ ft − kips $\mathrm{Moment}_{NTG} = -15.581$ ft − kips

Design moment for 66 in. wide effective section

$\mathrm{Des}_{M.PTG} := \mathrm{Moment}_{PTG} \cdot \frac{12}{66}$ $\mathrm{Des}_{M.NTG} := \mathrm{Moment}_{NTG} \cdot \frac{12}{66}$

$\mathrm{Des}_{M.PTG} = 9.443$ $\frac{\text{ft} - \text{kips}}{\text{ft}}$ $\mathrm{Des}_{M.NTG} = -2.833$ $\frac{\text{ft} - \text{kips}}{\text{ft}}$

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APPENDIX E

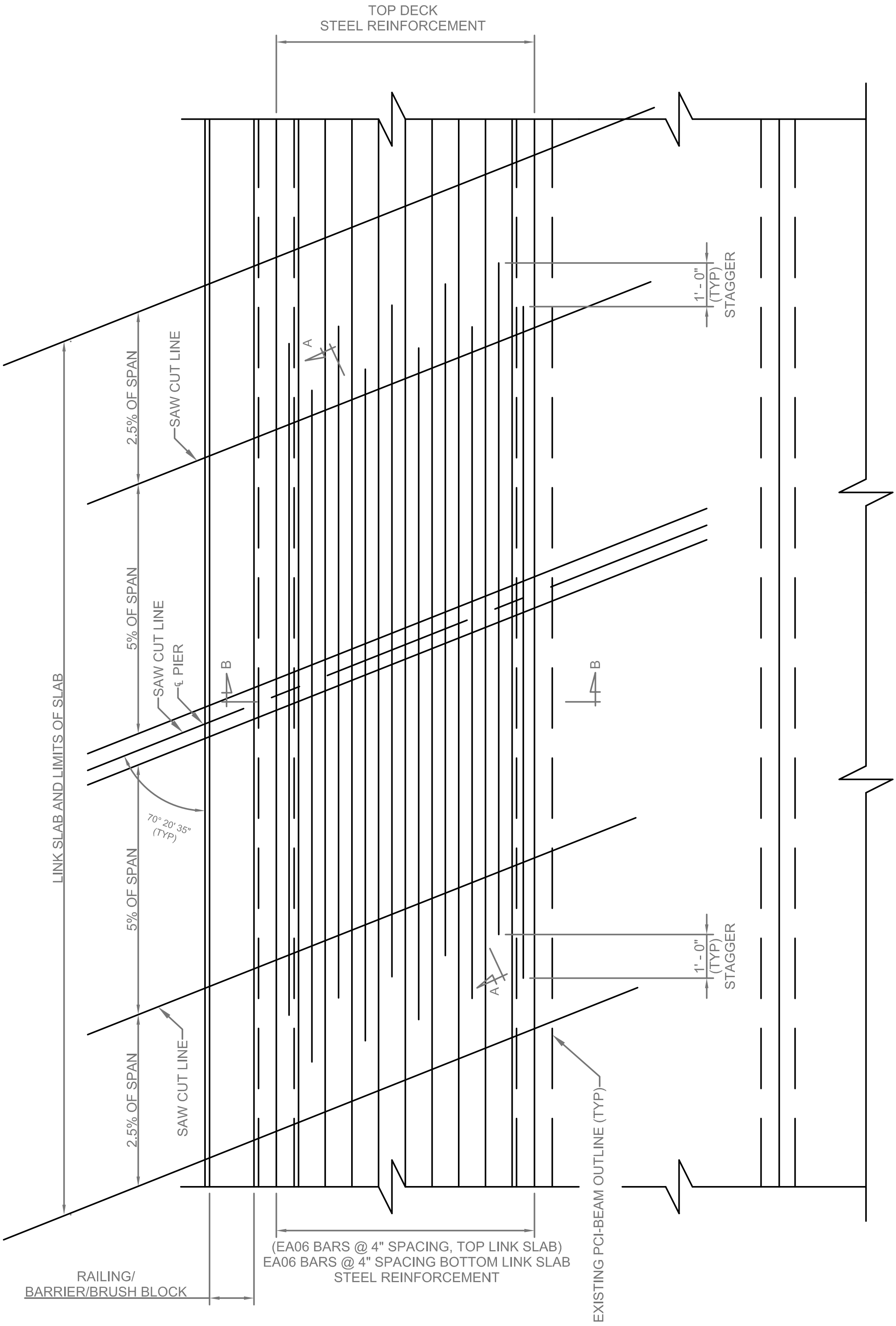
Proposed Design Details in MDOT Design Guide Format
- Skew Link Slab

DRAWN BY:
APPROVED BY:
CHECKED BY:

FIGURE E-1: PROPOSED DETAIL

SKEW LINK SLAB DETAIL

ISSUED:
SUPEREDES:



PARTIAL DECK PLAN @ PIER

TRANSVERSE REINFORCING STEEL IS NOT SHOWN)

NOTE:

STEEL REINFORCEMENT FOR THE RAILING AND BRUSH BLOCK SHALL BE REPLACED IN KIND AS DIRECTED BY THE ENGINEER AND AS DETAILED ON PLANS.

ALL SAW CUTS FOR DECK, BRIDGE RAILING AND BRUSH BLOCK REMOVAL SHALL BE INCLUDED IN THE PAY ITEM "Structures, Rehabilitation, Rem Portions (S12-25042 EB)".

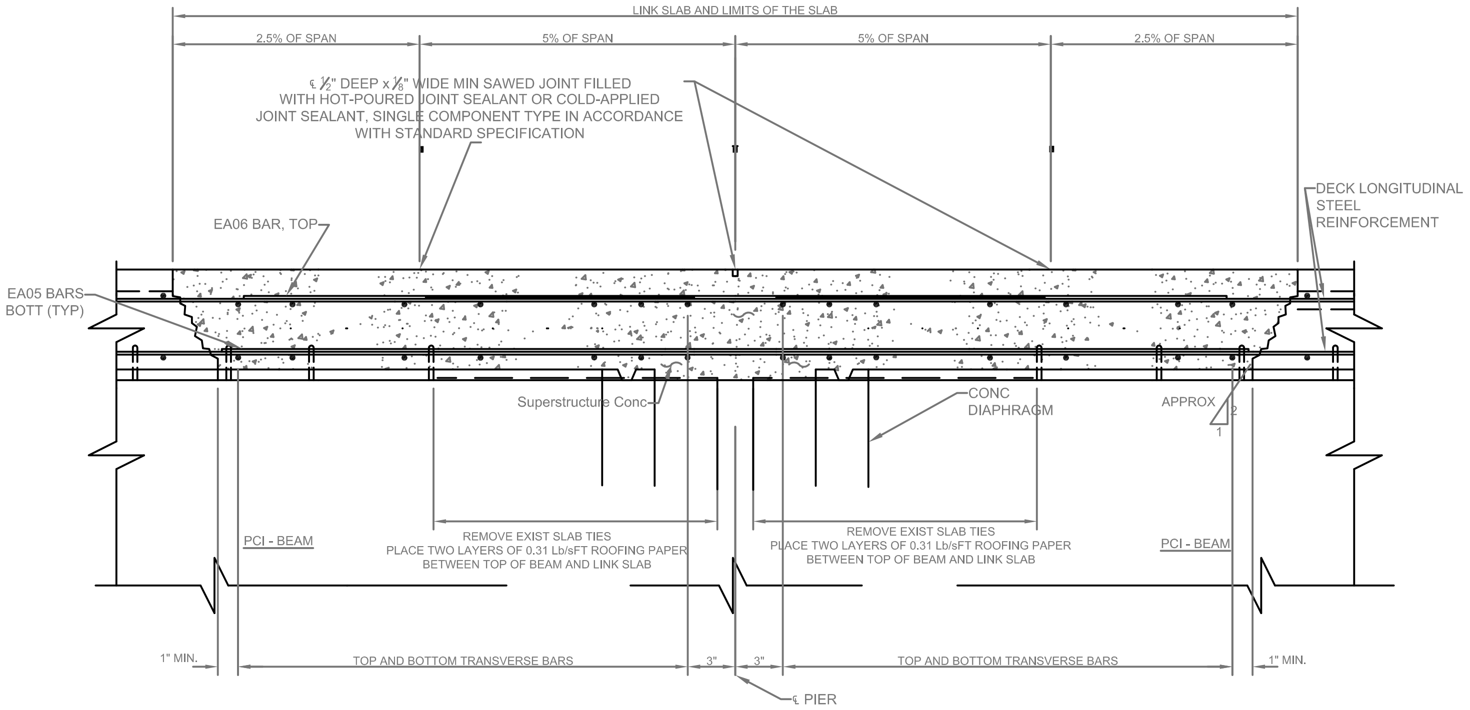
PREPARED BY

DRAWN BY:
APPROVED BY:
CHECKED BY:

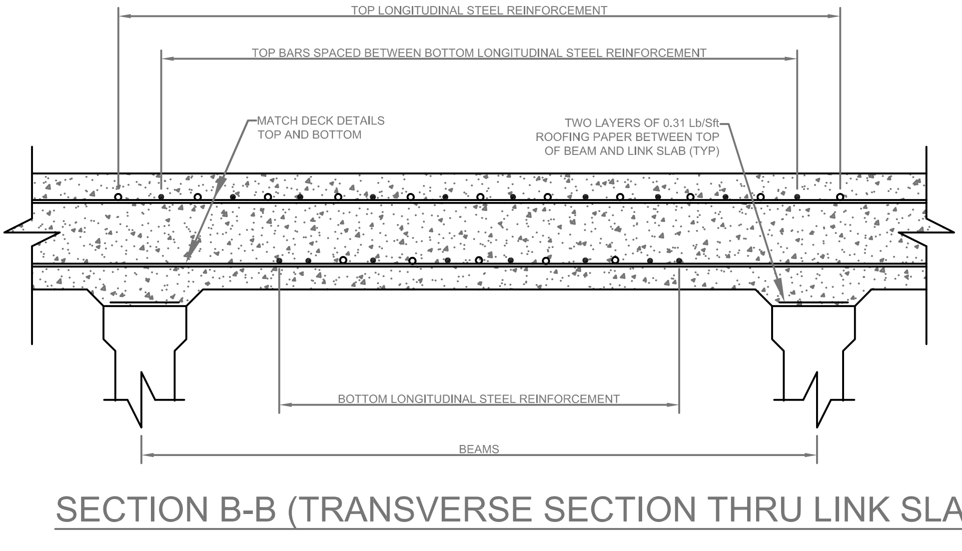
FIGURE E-2: PROPOSED DETAIL

SKEW LINK SLAB DETAIL

ISSUED:
SUPEREDES:



SECTION A-A (LONGITUDINAL SECTION THRU LINK SLAB)



SECTION B-B (TRANSVERSE SECTION THRU LINK SLAB)

PREPARED BY

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APPENDIX F

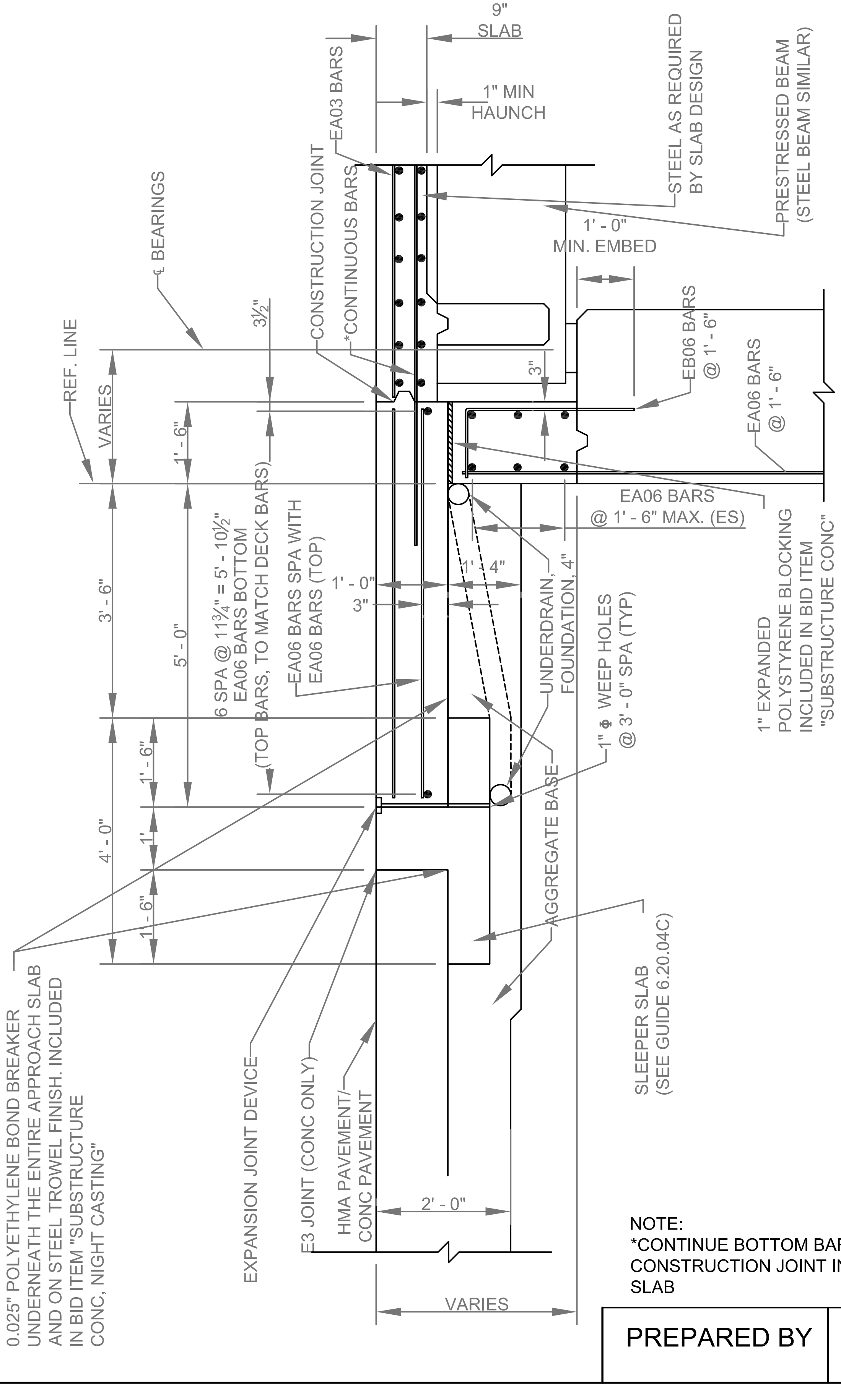
Proposed Design Details in MDOT Design Guide Format
- Deck Sliding over Backwall System

DRAWN BY:
APPROVED BY:
CHECKED BY:

FIGURE F-1: PROPOSED DETAILS

INDEPENDENT BACKWALL

ISSUED BY:
SUPEREDES:



NOTE:
*CONTINUE BOTTOM BARS 24" PAST
CONSTRUCTION JOINT INTO THE APPROACH
SLAB

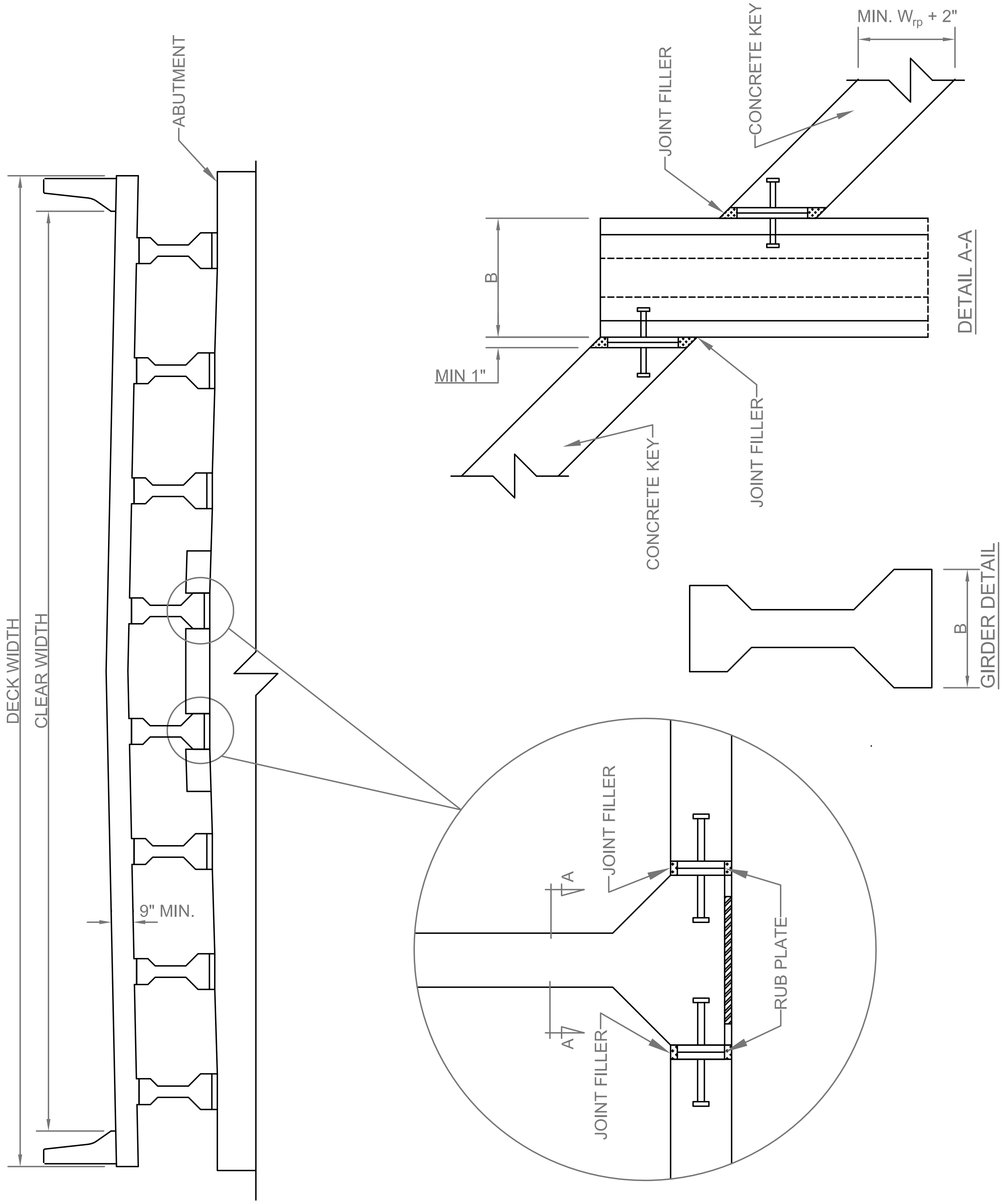
PREPARED BY

DRAWN BY:
APPROVED BY:
CHECKED BY:

FIGURE F-2: PROPOSED DETAILS

DETAILS OF GIRDER END RESTRAIN - INDEPENDENT BACKWALL

ISSUED BY:
SUPEREDES:



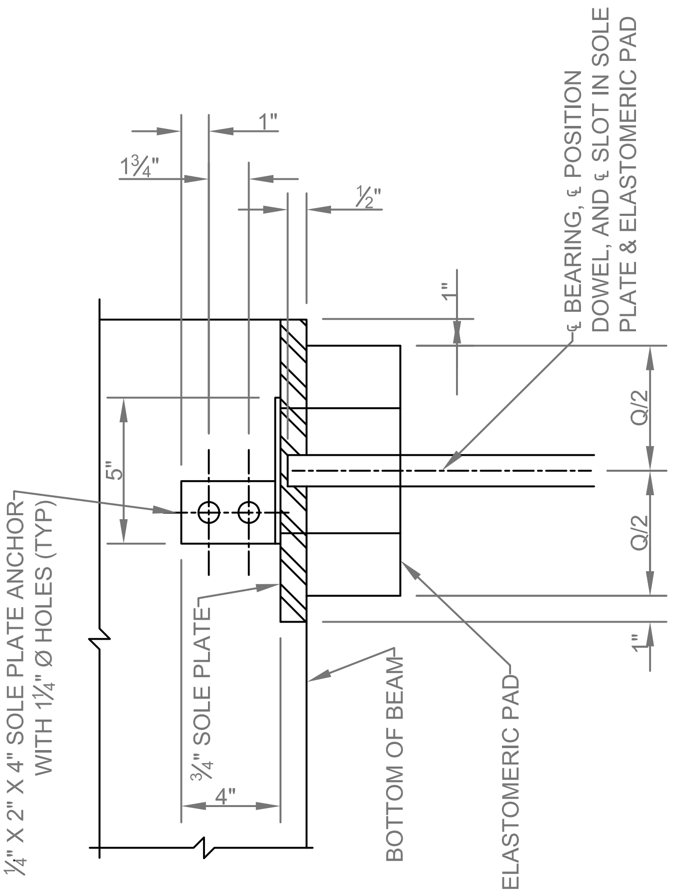
PREPARED BY

DRAWN BY:
APPROVED BY:
CHECKED BY:

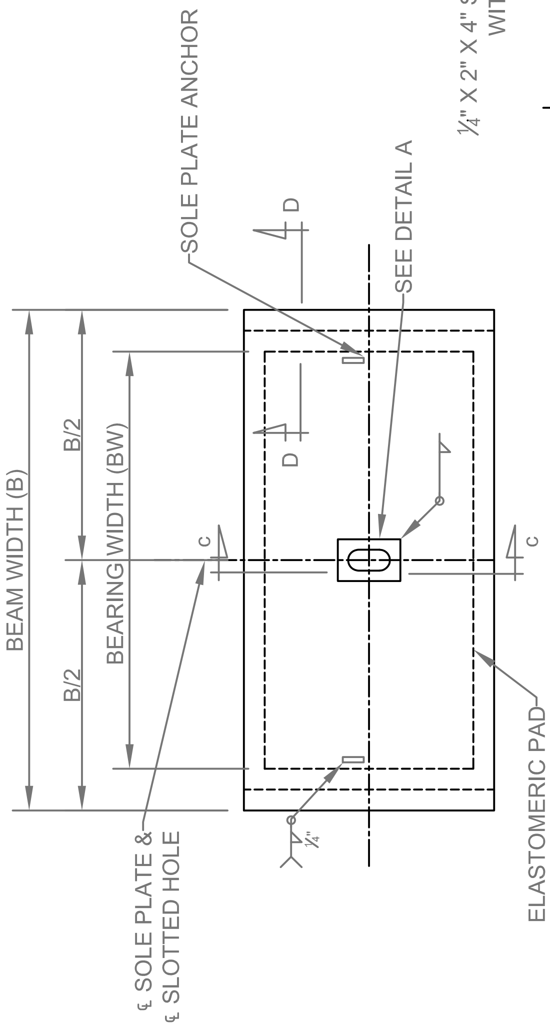
FIGURE F-3: PROPOSED DETAILS

TYPICAL BEARING DETAIL

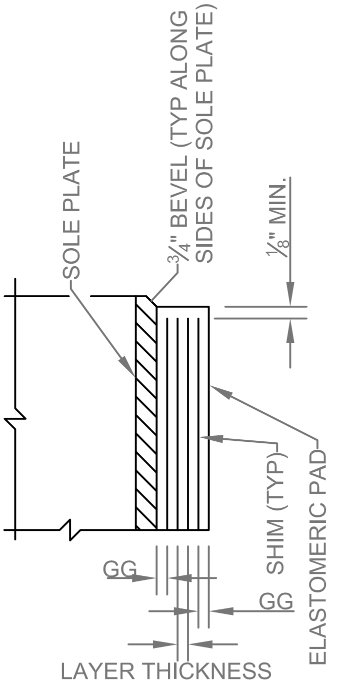
ISSUED BY:
SUPEREDES:



SECTION C-C



PLAN



SECTION D-D

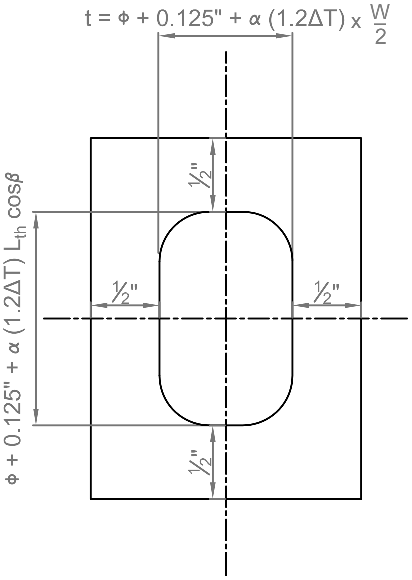
PREPARED BY

DRAWN BY:
APPROVED BY:
CHECKED BY:

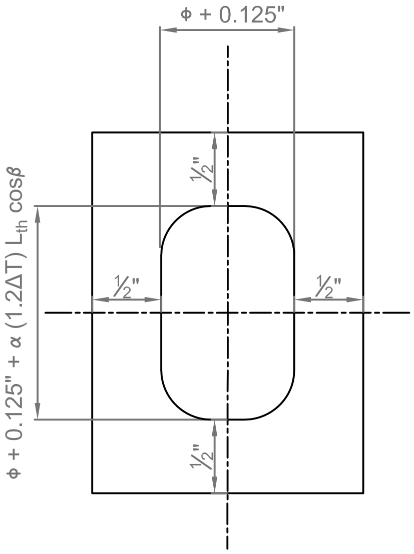
FIGURE F-4: PROPOSED DETAILS

DETAIL A - DIMENSION OF THE SLOT IN SOLE PLATE
& BEARING FOR INDEPENDENT BACKWALL SYSTEM

ISSUED BY:
SUPEREDES:

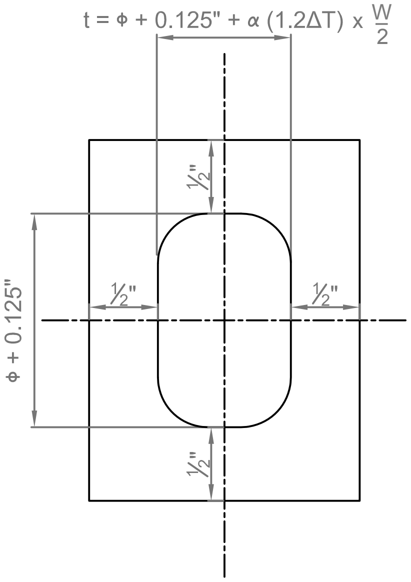


(A) TYPICAL SLOT DETAILS

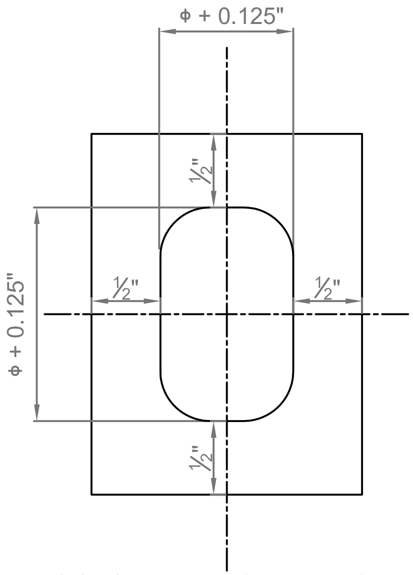


(B) SLOT DETAILS FOR BEARINGS AT
GIRDER ENDS RESTRAINT WITH CONCRETE KEYS *

EXPANSION BEARINGS



(C) TYPICAL SLOT DETAILS



(D) FOR BEARING AT BRIDGE
CENTERLINE

FIXED BEARINGS

NOTE:
* SEE DETAILS OF GIRDER END RESTRAIN
L: LENGTH OF THE DIAGNAL BETWEEN ACUTE CORNERS (SEE RUB PLATE DESIGN EXAMPLE)
W: DECK WIDTH
β: ANGLE (SEE RUB PLATE DESIGN EXAMPLE)
Φ: DIAMETER OF THE POSITION DOWEL
ΔT: |MAXIMUM TEMPERATURE| + |MINIMUM TEMPERATURE| FROM TABLE 5-2

PREPARED BY

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APPENDIX G

Rub Plate Design Procedure

DRAWN BY:
APPROVED BY:
CHECKED BY:

FIGURE G-1: PROPOSED RUB PLATE DESIGN PROCEDURE

RUB PLATE DESIGN -
GIRDER END RESTRAIN

ISSUED:
SUPEREDES:

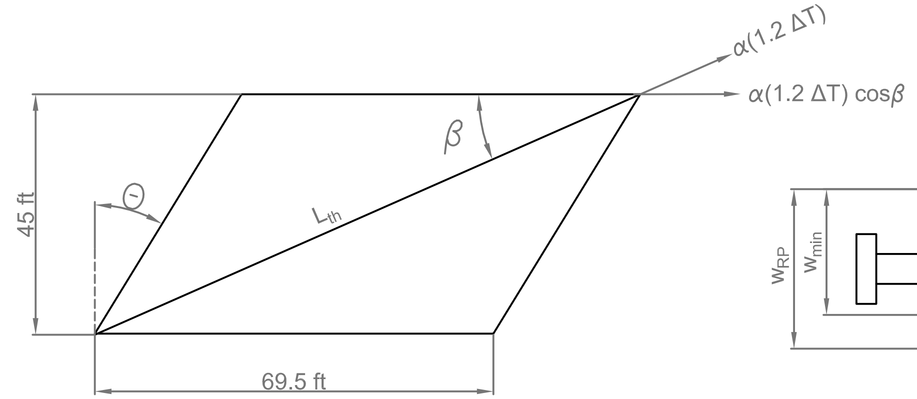
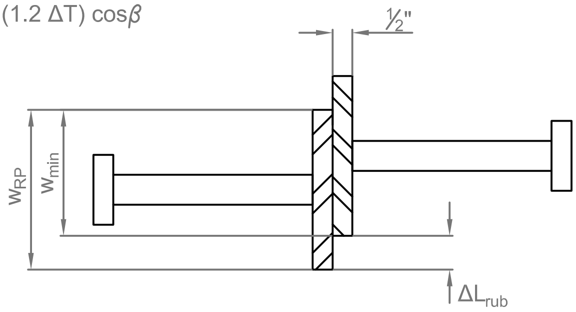


FIGURE A



RUB PLATE DESIGN
TWO GIRDER ENDS ARE RESTRAINED
FORCES ON THE RUB PLATE (R_p) = (10% x TOTAL VERTICAL BEARING REACTION)/2
= (10% x 1000 kips)/2 = 50 kips

DETERMINE SIZE OF RUB PLATES:
ΔT = |MAXIMUM TEMPERATURE| + |MINIMUM TEMPERATURE| = 115°F (TABLE 5-2)
L_{th} = EFFECTIVE LENGTH OF THERMAL MOVEMENT, 123 ft

EXTIMATED MAXIMUM MOVEMENT IN ONE DIRECTION AT THE ABUTMENT.
$(\Delta L_{rub})_c = L_{th} \times \alpha \times 1.2 \times \Delta T_c = 123\text{ft}\ (12\ {}^{in}/_{ft})\ (6 \times 10^{-6}\ /°\text{F}) \times (1.2 \times 72.7°\text{F}) = 0.8$ inch
$(\Delta L_{rub})_e = L_{th} \times \alpha \times 1.2 \times \Delta T_e = 123\text{ft}\ (12\ {}^{in}/_{ft})\ (6 \times 10^{-6}\ /°\text{F}) \times (1.2 \times 42.3°\text{F}) = 0.5$ inch
WHERE ΔT_c = CONTRACTION THERMAL LOAD
ΔT_e = EXPANSION THERMAL LOAD

$(\Delta L_{rub})_c > (\Delta L_{rub})_e$, SO CONSIDER $(\Delta L_{rub})_c$ FOR FURTHER CALCULATIONS

HEIGHT OF RUB PLATE:
$h_{rp} = T_{bottom\ flange}$ - 2 inch = 7 inch - 2 inch = 5 inch

THIS EXAMPLE CONSIDERS AASHTO TYPE III GIRDER, OF WHICH BOTTOM FLANGE THICKNESS IS 7 in.
CLEARANCE FROM TOP AND BOTTOM IS 1 inch.

MAXIMUM "GALLING STRESS" FOR ASTM A276 TYPE 316 STEEL, OF WHICH THE RUB PLATES ARE CONSTRUCTED:
F_g = 2000 psi

ALLOWABLE GALLING STRESS:
$f_g = 0.55\ F_g$ = 1100 psi

MINIMUM RUB PLATE WIDTH:
$w_{min} = {}^{Rp}/_{hrp\ (fg)} = {}^{50\ kip\ (1000\ lbs/1\ kip)}/_{[5\ in\ (1100\ psi)]}$ = 9 inch

ENSURE THE MINIMUM RUB PLATE WIDTH IS MAINTAINED DURING EXTREMES OF THE TEMPERATURE CYCLE
$w = w_{min} + (\Delta L_{rub})_c$ = 9 inch + 0.8 inch = 9.8 inch ≈ 10 inch

USE 5 inch x 10 inch x 0.5 inch in rub plate

NOTE: LENGTH OF THE CONCRETE KEY ALONG GIRDER CENTER LINE SHOULD BE MINIMUM OF 10 INCH.

PREPARED BY

APPENDIX H

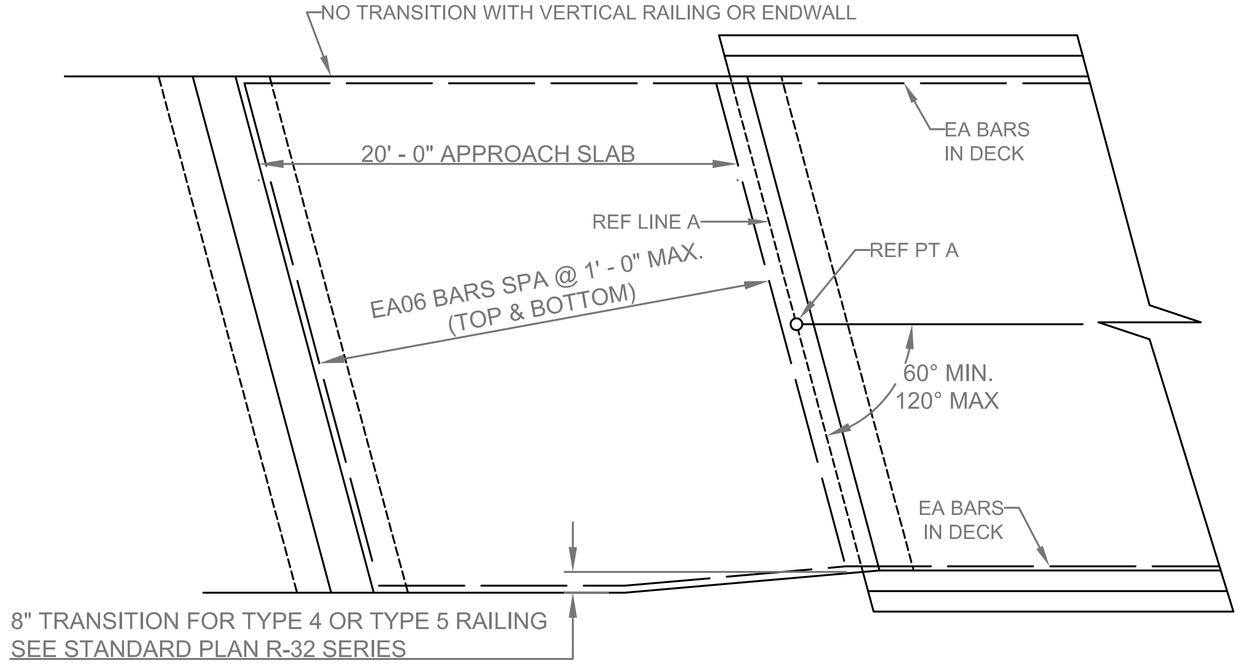
Proposed Design Details in MDOT Design Guide Format
- Semi – Integral Abutments

DRAWN BY:
APPROVED BY:
CHECKED BY:

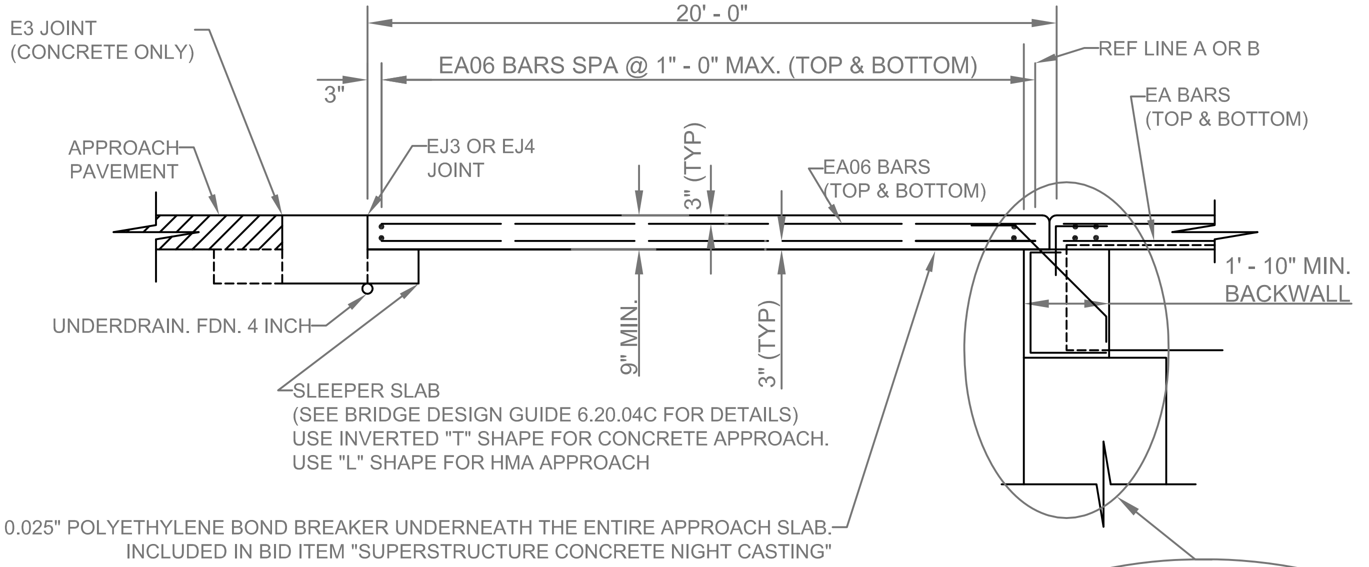
FIGURE H-1: PROPOSED DETAILS

SEMI INTEGRAL ABUTMENT EMPIRICAL APPROACH SLAB DETAILS FOR LINK SLAB BRIDGES

ISSUED:
SUPEREDES:



PLAN OF APPROACH



APPROACH SECTION

SLAB THICKNESS WILL MATCH THE ROAD APPROACH PAVEMENT THICKNESS (9" MIN.)

NOTES:

ATTACH APPROACH CURB AND GUTTER TO THE APPROACH SLAB WITH BOTTOM MAT TRANSVERSE REINFORCEMENT AND TO THE BRIDGE DECK WITH BOTTOM MAT LONGITUDINAL REINFORCEMENT

POUR APPROACH SLABS FROM EXPANSION LOCATION TOWARD REFERENCE LINE.

APPROACH SLABS SHOULD BE CAST AT NIGHT WITH NIGHT TIME CASTING OF SUPERSTRUCTURE CONCRETE

EJ3 OR EJ4 JOINT WIDTH TO ACCOMMODATE THERMAL MOVEMENT $= L_{th} \times 1.2 (\Delta T_e) \cos\beta$

REFER RUB PLATE DESIGN SHEET FOR L_{th}, ΔT_e AND β DEFINITIONS

USE SLEEPER SLAB WITH ALL APPROACH SLABS INCLUDING HMA ROADWAY

PREPARED BY:

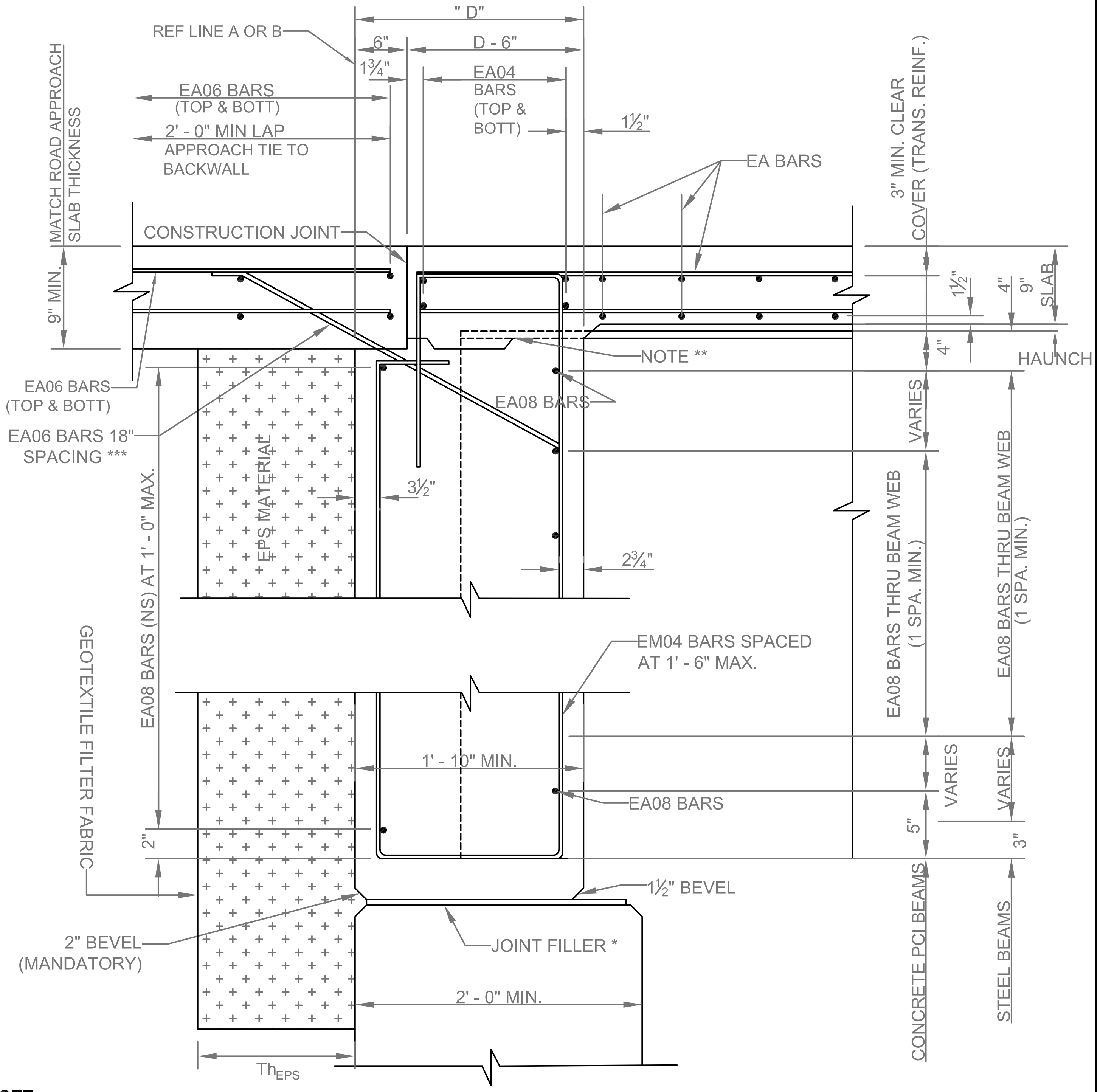
PROPOSAL FOR
6.20.04B

DRAWN BY:
APPROVED BY:
CHECKED BY:

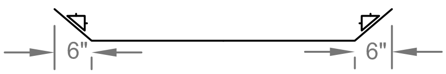
FIGURE H-2 - PROPOSED DETAIL

SEMI - INTEGRAL ABUTMENT DETAILS
WITH BACKWALL IN-LINE WITH ABUTMENT

ISSUED:
SUPEREDES:



NOTE:
* THICKNESS = BEARING VERTICAL DEFORMATION PLUS 1"
** OPT. CONSTRUCTION JOINT (IF CONSTRUCTION JOINT IS USED, CAST LOWER PORTION OF BACKWALL PRIOR TO PLACING DECK REINFORCEMENT
*** EA06 BARS



THE THICKNESS OF THE EPS LAYER (Th_{EPS}) SHALL BE DETERMINED USING THE FOLLOWING FORMULA:
h = HEIGHT OF BACKWALL IN INCHES
ΔL = THERMAL MOVEMENT FOR THE ENTIRE TEMPERATURE RANGE IN INCHES (EXPANSION +CONTRACTION)
Th_{EPS} = EPS THICKNESS IN INCHES (SHALL NOT BE <10°)
$Th_{EPS} = 10\,[0.01h + 0.67\,(\Delta L)]$

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6.20.04

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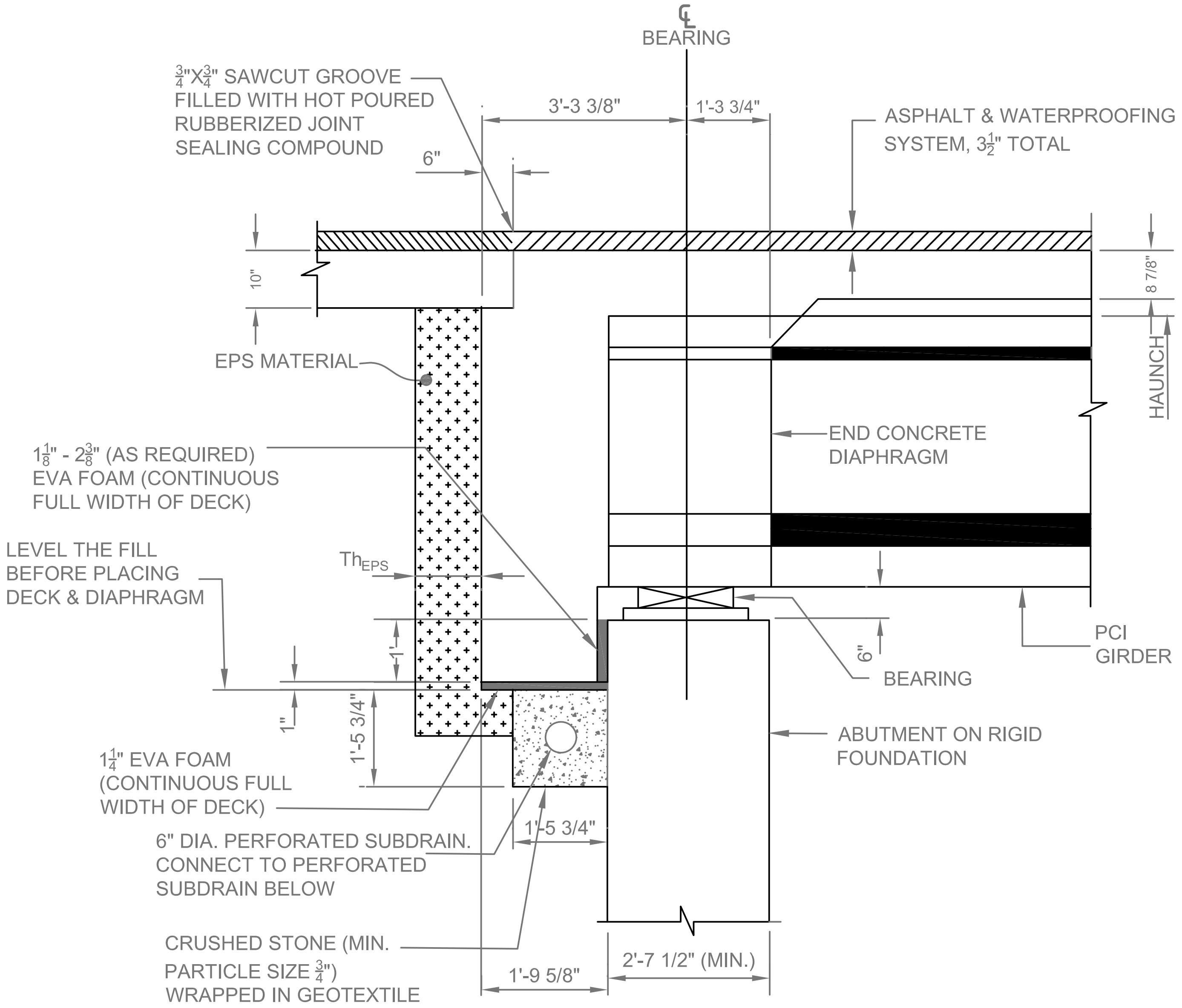
APPROVED BY:
CHECKED BY:

FIGURE H-3: PROPOSED DETAIL

SEMI - INTEGRAL ABUTMENT DETAILS WITH BACKWALL OFFSET FROM ABUTMENT

ISSUED:
SUPEREDES:



NOTE:

THE THICKNESS OF THE EPS LAYER (Th_{EPS}) SHALL BE DETERMINED USING THE FOLLOWING FORMULA:

h = HEIGHT OF BACKWALL IN INCHES
ΔL = THERMAL MOVEMENT FOR THE ENTIRE TEMPERATURE RANGE IN INCHES (EXPANSION +CONTRACTION)
Th_{EPS} = EPS THICKNESS IN INCHES (SHALL NOT BE <10°)
$Th_{EPS} = 10\ [0.01h + 0.67\ (\Delta L)]$

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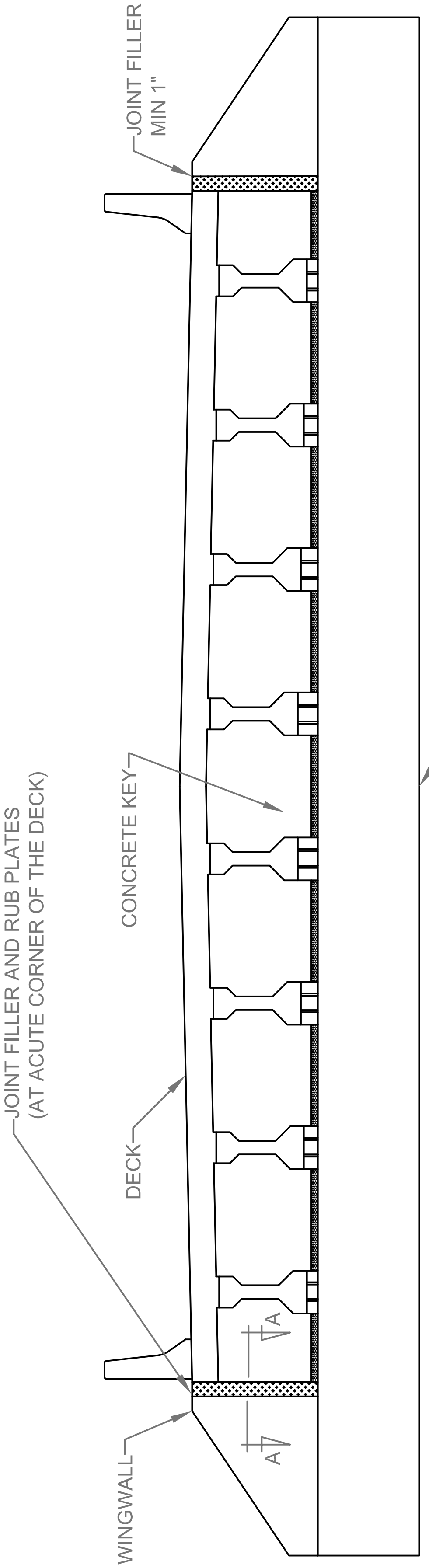
CHECKED BY:

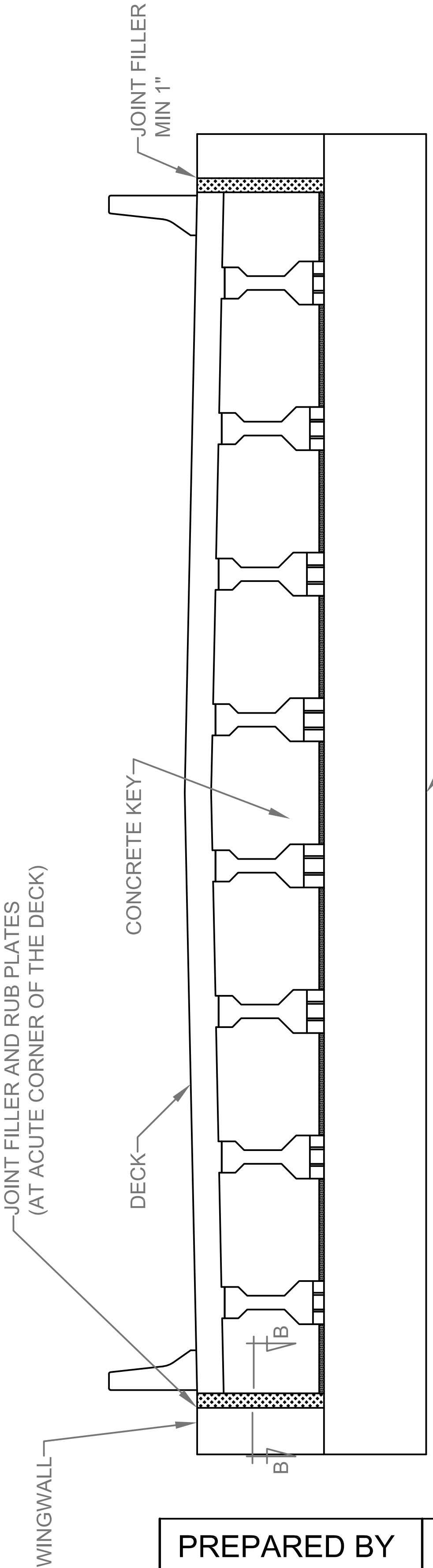
FIGURE H-4: PROPOSED DETAIL

ELEVATION VIEW OF SEMI-INTEGRAL ABUTMENT
WITH BACKWALL IN-LINE WITH ABUTMENT

ISSUED:
SUPEREDES:



ELEVATION VIEW OF WINGWALL CONFIGURATION 1



ELEVATION VIEW OF WINGWALL CONFIGURATION 2

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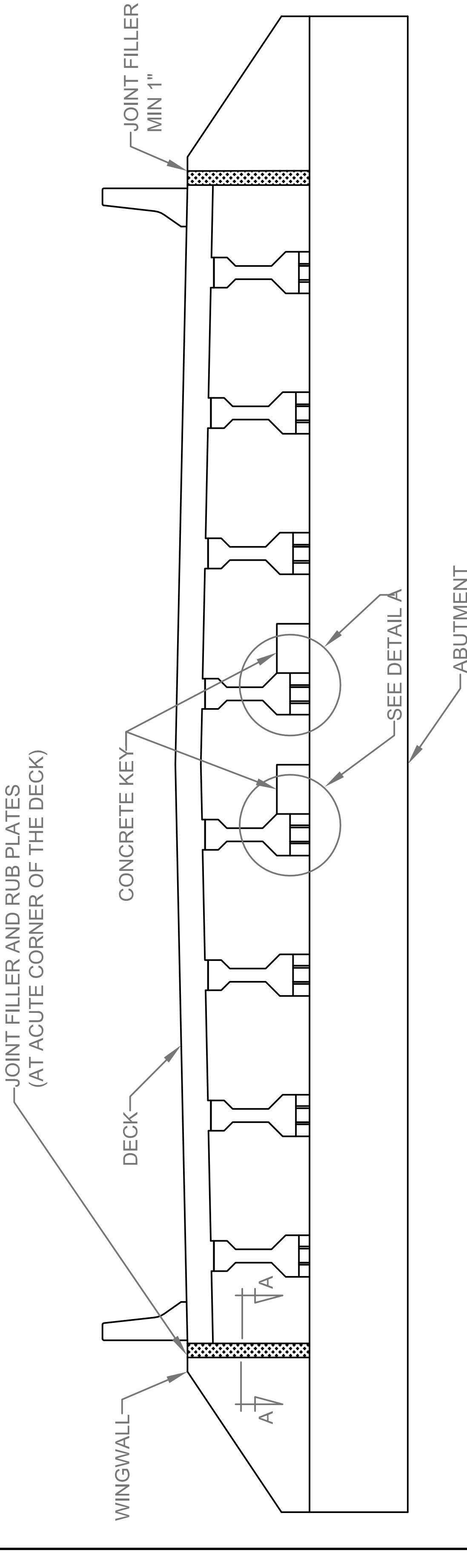
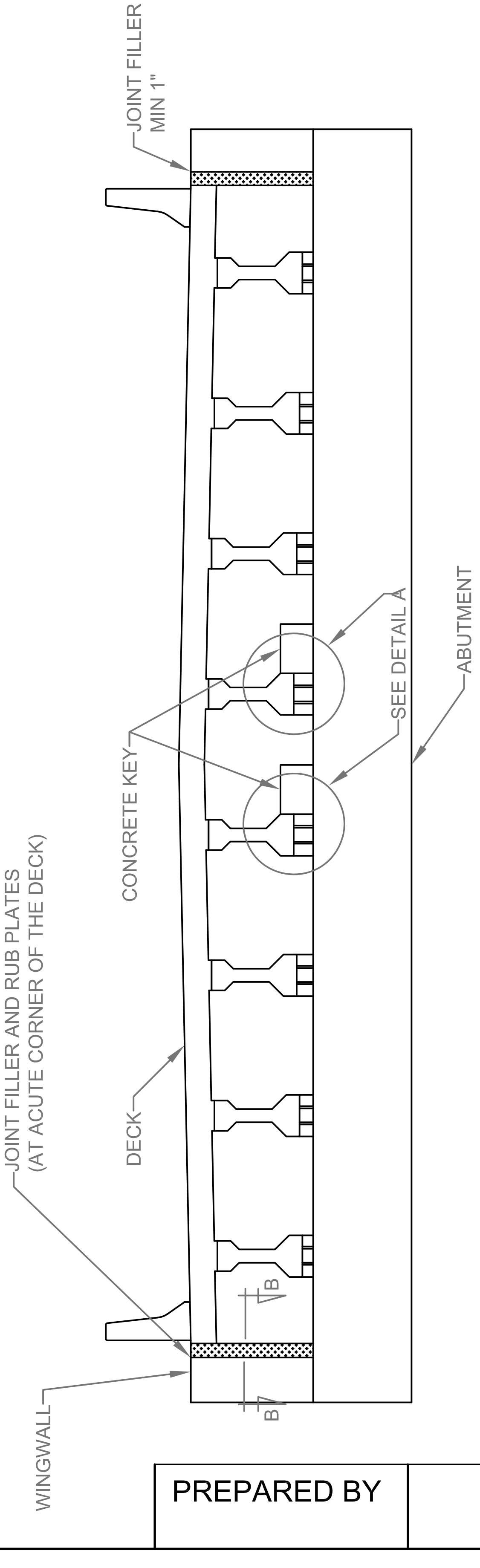
FIGURE H-5: PROPOSED DETAIL

ELEVATION VIEW OF SEMI-INTEGRAL ABUTMENT
WITH BACKWALL OFFSET FROM ABUTMENT

ISSUED:
SUPEREDES:



ELEVATION VIEW OF WINGWALL CONFIGURATION 1



ELEVATION VIEW OF WINGWALL CONFIGURATION 2

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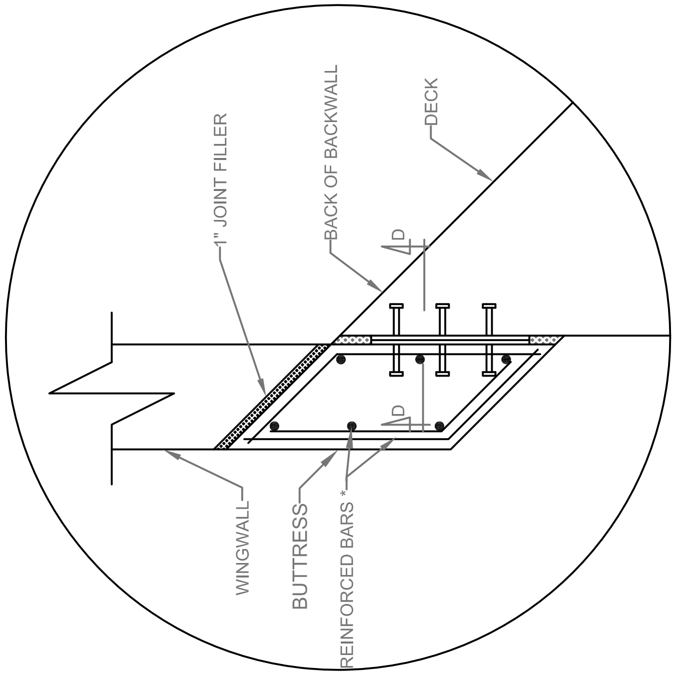
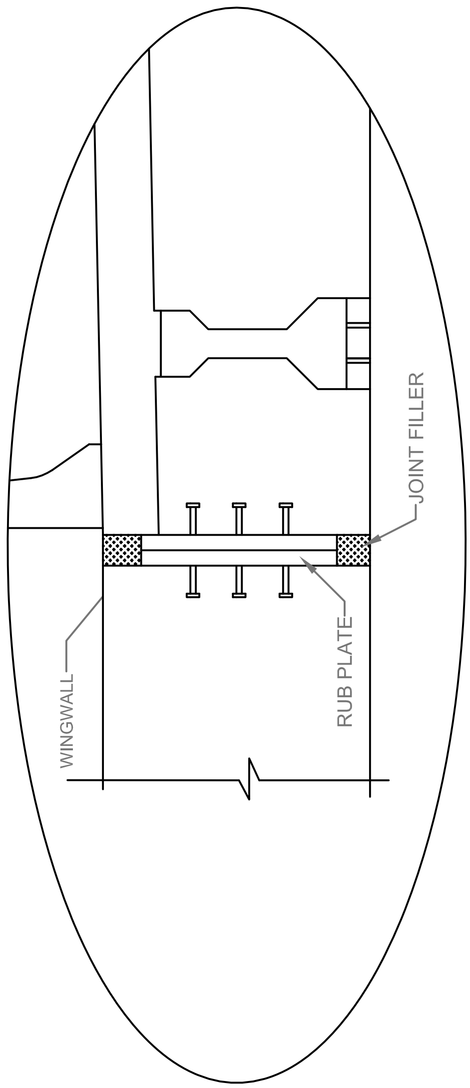
FIGURE H-6: PROPOSED DETAIL

WINGWALL CONFIGURATION DETAIL

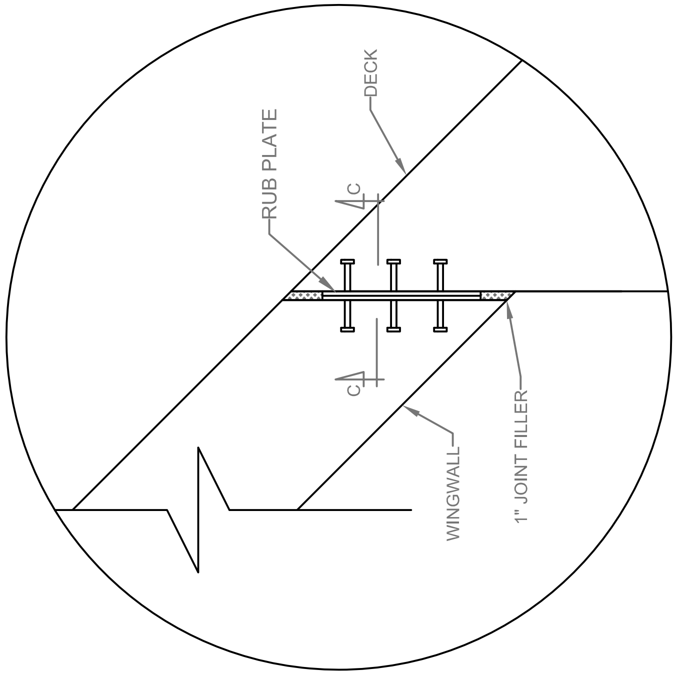
ISSUED:
SUPEREDES:



DETAIL B-B - WINGWALL CONFIGURATION 2



SECTION C AND D



DETAIL A-A - WINGWALL CONFIGURATION 1

NOTE:
* SHOULD BE DESIGNED FOR MOMENT SHEAR

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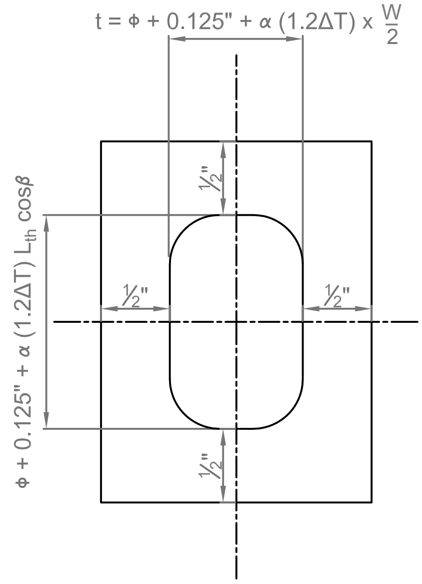
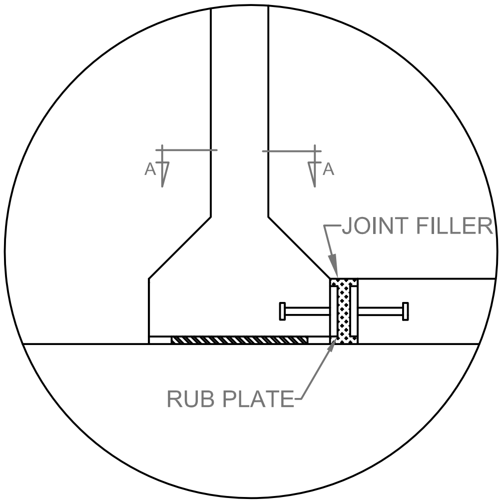
FIGURE H-7: PROPOSED DETAIL

DETAIL A - DIMENSION OF THE SLOT AND CONCRETE KEY
WITH RUB PLATES FOR SEMI-INTEGRAL ABUTMENT

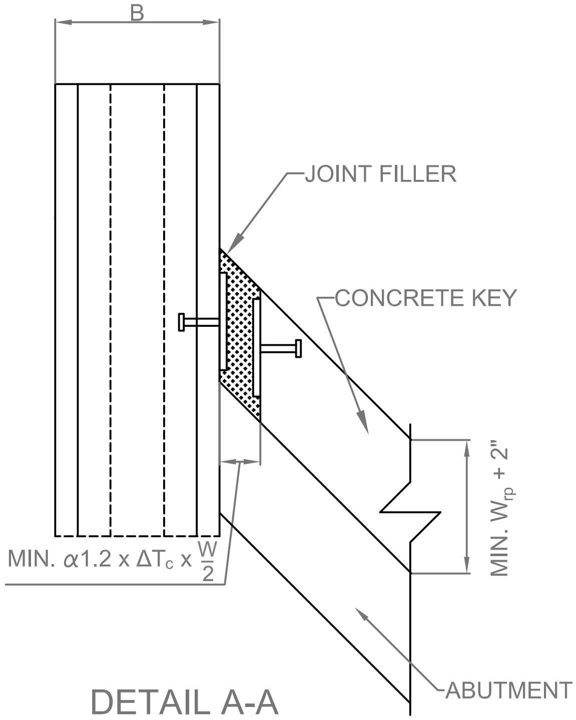
ISSUED BY:
SUPEREDES:



(A) TYPICAL SLOT DETAILS FOR BEARINGS
AT THE SEMI-INTEGRAL ABUTMENT



DETAIL A



DETAIL A-A

GIRDER END RESTRAIN DETAILS FOR BACKWALL OFFSET FROM ABUTMENT CONFIGURATION

NOTE:
* SEE DETAILS OF GIRDER END RESTRAIN
L_{th}: LENGTH OF THE DIAGNAL BETWEEN ACUTE CORNERS (SEE RUB PLATE DESIGN EXAMPLE)
W: DECK WIDTH
β: ANGLE (SEE RUB PLATE DESIGN EXAMPLE)
Φ: DIAMETER OF THE POSITION DOWEL
ΔT: |MAXIMUM TEMPERATURE| + |MINIMUM TEMPERATURE| FROM TABLE 5-2

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