APPENDIX A
EXAMPLE 4 - TYPE II BEARING (REINFORCED BEARING WITH PTFE)
METHOD B

GENERAL INFORMATION

Per CDOT Bridge Design Manual (BDM) Section 14.5.9, Type II bearings are Type I bearings with a PTFE sliding surface. Type II bearings shall meet the same requirements as steel reinforced bearings, in addition to providing adequate slip on the sliding plane to accommodate horizontal movements without causing excessive bearing pad deformation. The following example is in accordance with Method B procedures per AASHTO LRFD 7th Edition Section 14.7.5.

This example assumes a concrete superstructure that can displace under the effects of temperature, creep, and shrinkage and assumes a rectangular bearing shown below in Figures 1 and 2. The bearing is fixed in the transverse direction and free to move longitudinally. Assume temperature movements conform to AASHTO 3.12.2.2 Procedure B. The PTFE surface is assumed unfilled and lubricated and no externally bonded plates are present.

MATERIAL AND SECTION PROPERTIES

Bearing Dimensions

Bearing Width	$W =$	**24.00**	in		AASHTO 14.7.5.1
Bearing Length	$L =$	**10.00**	in		AASHTO 14.7.5.1
Bearing Pad Layers					
Exterior Elastomeric Thickness	$h_{re} =$	**0.125**	in	**OK**	< 70% h_{ri} AASHTO 14.7.5.1
Interior Elastomeric Thickness	$h_{ri} =$	**0.500**	in		
Steel Plate Thickness	$h_s =$	**0.125**	in		
No. of Steel Shim Plates	$n_{shims} =$	**5**			
No. of Interior Elastomer Layers	$n =$	**5**			AASHTO 14.7.5.3.3
Total Elastomer Thickness	$h_{rt} =$	**2.625**	in		
Total Bearing Height	$t =$	**3.250**	in	**OK**	2" minimum height per BDM 14.5.8
PTFE					
PTFE thickness	$h_{PTFE} =$	**0.094**	in	**OK**	AASHTO 14.7.2.3

Bearing Material Properties

Elastomer Grade	Grade =	**3**	(Zone C)	BDM 14.5.8, & AASHTO Table & Figure 14.7.5.2-1

Shear Modulus

Design drawings shall specify the shear modulus of the elastomer at 73°. With an acceptance variation of ± 15% of the specified value, the shear modulus used in design will vary. The shear modulus shall be taken as the least favorable value within the range to cause the more conservative outcome in the specific analysis being considered (AASHTO 14.7.5.2). The plan shear modulus below assumes a Durometer Hardness of 60.

	$G_{plan} =$	**0.150**	ksi		AASHTO T14.7.6.2-1
	$G_{max} =$	**0.173**	ksi		
	$G_{min} =$	**0.128**	ksi		
	Check =	0.08 ksi < G < 0.175 ksi		**OK**	AASHTO 14.7.5.2
Creep Deflection Factor	$\alpha_{cr} =$	**0.35**			AASHTO T14.7.6.2-1

Steel Shim Properties

Yield Strength of Steel	$F_y =$	**36.00**	ksi	AASHTO T6.4.1-1
Allowable Fatigue Threshold	$\Delta F_{TH} =$	**24.00**	ksi	AASHTO T6.6.1.2.3-1

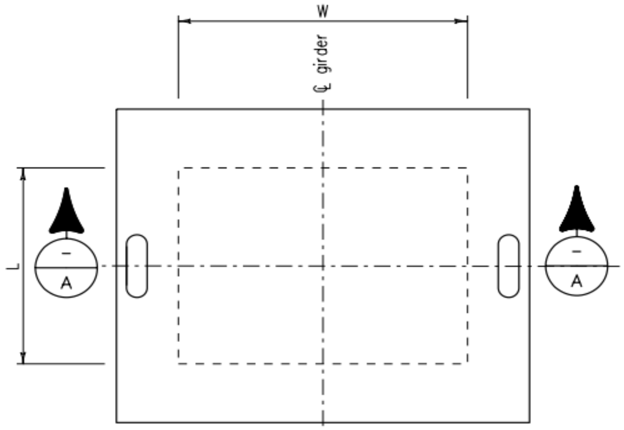

FIGURE 1 - TYPE II - STEEL REINFORCED BEARING PAD WITH PTFE - PLAN

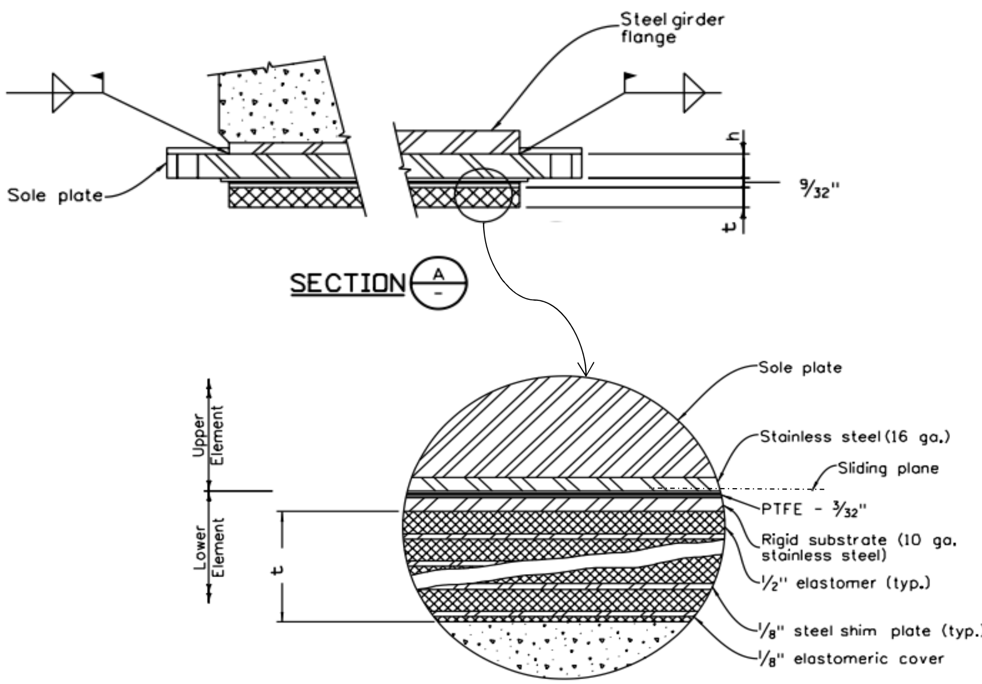

FIGURE 2 - TYPE II - STEEL REINFORCED BEARING PAD WITH PTFE - SECTION

BEARING LOADS

Loads acting on the bearing are dead and live load girder reactions at the service limit state. Per AASHTO 14.4.1, dynamic load allowance is excluded from the live load influence.

Service I Limit State Loads

DL =	**200.00**	kip
LL=	**60.00**	kip

BEARING ROTATIONS

Rotations include effects of girder camber. For all rotation values, positive indicates a downward rotation while negative indicates an upward rotation. Note this example does not account for profile grade differences between supports.

Service I Limit State Rotations

Dead Load Rotations	$\theta_d =$	**-0.001**	rad
Live Load Rotations	$\theta_L =$	**0.006**	rad

Include a construction tolerance of 0.005 radians to account for uncertainties in bearing fabrication and bearing seat construction. Per BDM 14.5.4, the flatness tolerance for bearing seat uncertainties is accounted for in the construction tolerance.

Construction Tolerance	$\theta_r =$	**0.005**	rad	AASHTO 14.4.2.1

HORIZONTAL MOVEMENT

Shear deformations include movements from temperature, creep and shrinkage, prestressing effects, and miscellaneous movement from loads such as live and wind loads from service load combinations per AASHTO C14.4.1. Assume the bearings are not adjusted after construction; therefore, the 65 percent reduction in thermal movement range per AASHTO 14.7.5.3.2 is not included per BDM 14.5.3.

Uniform Temperature Movement Range:

Maximum temperature	$T_{max} =$	**110**	°F		AASHTO F3.12.2.2-1
Minimum temperature	$T_{min} =$	**-10**	°F		AASHTO F3.12.2.2-2
Coeff. of thermal expansion	$\alpha =$	**6.0E-06**	in/in/ °F		AASHTO 6.4.1
Expansion length	$L =$	**150.00**	ft =	1800.00 in	
Service I Load Factor, TU	$\gamma_{TU} =$	**1.20**			AASHTO T3.4.1-1
AASHTO Reduction Factor	$\alpha_{AASHTO} =$	**1.00**			BDM 14.5.3

$\Delta_T = \alpha L(T_{max} - T_{min}) =$ 6.0E-6*1800.00*[110-(-10)] = 1.30 in AASHTO 3.12.2.3-1

Creep, Shrinkage, Elastic Shortening, and Miscellaneous Movements:

Creep movement	$\Delta_{CR} =$	**0.58**	in
Shrinkage movement	$\Delta_{SH} =$	**0.60**	in
Elastic shortening	$\Delta_{EL} =$	**0.05**	in
Live load movement	$\Delta_{LL} =$	**0.10**	in
Miscellaneous movement	$\Delta_{MISC} =$	**0.00**	in

$\Delta_o =$ Maximum horizontal displacement of the superstructure
$\Delta_s =$ Maximum shear deformation of the bearing modified to account for substructure stiffness

Assuming the substructure is stiff enough to prevent movement:

$$\Delta_o = \Delta_s = \sum \alpha_{AASHTO}\gamma_{TU}\Delta_T + \Delta_{CR} + \Delta_{SH} + \Delta_{EL} + \Delta_{LL} + \Delta_{MISC} =$$

AASHTO 14.7.5.3.2 & BDM Section 14.5.3

1.00*1.20*1.30+0.58+0.60+0.05+0.10+0.00 = 2.89 in

SOLUTION

Shape Factor

Rectangular, steel reinforced bearing shape factor without holes:

$$S_i = \frac{LW}{2h_{ri}(L+W)} =$$

(10.00*24.00) / [2*0.500*(10.00+24.00)] = 7.06 AASHTO 14.5.7.1-1

Computed Stresses AASHTO 14.7.2.4

Average Contact Stresses

$\sigma_s = \frac{DL + LL}{LW} =$ (200.00+60.00) / (10.00*24.00) = 1.08 ksi

$\sigma_s =$ average compressive stress due to total load from applicable service load combinations

$\sigma_L = \frac{LL}{LW} =$ 60.00 / (10.00*24.00) = 0.25 ksi

$\sigma_L =$ average compressive stress due to live load at the service limit state (cyclic load)

$\sigma_d = \frac{DL}{LW} =$ 200.00 / (10.00*24.00) = 0.83 ksi

$\sigma_d =$ average compressive stress due to dead load at the service limit state (static load)

Check AASHTO T14.7.2.4-1

$\sigma_s =$ 1.08 ksi < $\sigma_{Sallow} =$ 2.50 ksi **OK**

$\sigma_d =$ 0.83 ksi < $\sigma_{DLallow} =$ 1.50 ksi **OK**

Edge Contact Stresses AASHTO 14.7.2.4

The contact stress at the edge shall be determined by considering the maximum service moment transferred by the bearing, assuming a linear distribution of stress across the PTFE. The moment is assumed to occur at the centerline of the bearing, perpendicular to the direction of load.

$M_s = (0.5E_c I)\frac{\theta_s}{h_{rt}}$ Service moment due to total load AASHTO 14.6.3.2-3 AASHTO C14.6.3.2

where

$E_c = 4.8 G_{max} {S_i}^2 =$ 4.8*0.17*7.06^2 = 41.26 ksi AASHTO C14.6.3.2-1

$I = \frac{WL^3}{12} =$ 24.00*10.00^3 /12 = 2000.00 in^4

$\theta_s = \theta_d + \theta_r + \theta_L =$ -0.001+0.005+0.006= 0.010 rad

$M_s = (0.5E_c I)\frac{\theta_s}{h_{rt}} =$ (0.5*41.26*2000.00)*(0.010/2.63) = 157.17 k-in

$\sigma_{s,edge} = \sigma_s + \frac{M_s}{1/6WL^2} =$ 1.08 + [157.17 / ((1/6)*24.00*10.00^2)] = 1.48 ksi

$M_d = (0.5E_c I)\frac{\theta_D}{h_{rt}}$ Service moment due to dead load AASHTO 14.6.3.2-3 AASHTO C14.6.3.2

where

$\theta_D = \theta_d + \theta_r =$ -0.001 + 0.005 = 0.004 rad

$M_d = (0.5E_c I)\frac{\theta_D}{h_{rt}} =$ (0.5*41.26*2000.00)*(0.004/2.63) = 62.87 k-in

$\sigma_{d,edge} = \sigma_d + \frac{M_d}{1/6WL^2} =$ 0.83 + [62.87 / ((1/6)*24.00*10.00^2)] = 0.99 ksi

where $\frac{M_d}{1/6WL^2}$ is derived from My/I, where y is L/2, and I is $WL^3/12$

Check AASHTO T14.7.2.4-1

$\sigma_{s,edge}$ = 1.48 ksi < σ_{sallow} = 3.00 ksi **OK**

$\sigma_{d,edge}$ = 0.99 ksi < σ_{dallow} = 2.00 ksi **OK**

Coefficient of Friction of PTFE AASHTO 14.7.2.5

For the given minimum temperature and the average pressure at the service limit state, interpolate between values in AASHTO T14.7.2.5-1. Assume a lubricated PTFE surface.

σ_s = 1.083 ksi

T_{min} = -10

Temp. °F	Pressure (ksi)		
	1.0	**1.083**	**2.0**
68	0.030	0.0296	0.025
-10	0.044	0.0440	0.039
-13	0.045	0.0446	0.040

μ_{PTFE} = 0.044

Shear Deformations

Since a low friction sliding surface is implemented, Δs need not be taken larger than the deformation corresponding to first slip (AASHTO 14.7.5.3.2). The minimum pressure will create the largest coefficient of friction and the largest movement.
The minimum service shear force transferred by the sliding surface at the specified minimum temperature:

$H_b = \mu_{PTFE}(DL) =$ 0.044*(200.00) = 8.81 kip AASHTO 14.6.3.1-1

The deflection of the elastomeric bearing, before first slip of the sliding surface, is estimated as:

$$\Delta_{s,slip} = \frac{H_b h_{rt}}{G_{min} WL} = \frac{8.81*2.63}{0.13*24.00*10.00} = 0.76 \text{ in}$$ AASHTO 14.6.3.1-2

$h_{rt} \geq 2\Delta_{s,slip} =$ 2*0.76 = 1.51 in AASHTO 14.7.5.3.2-1

Check h_{rt} = 2.63 in > 1.51 in **OK**

The remaining movement is accommodated by the movement of the PTFE surface:

$\Delta_{sPTFE} = \Delta_s - \Delta_{s,slip} =$ 2.89 - 0.76 = 2.13 in

The Designer shall size the steel sliding surface, sole plate, anchor bolt holes, and edge distances accordingly to accommodate the above movement.

Compressive Deflections AASHTO 14.7.5.3.6

Live Load Compressive Deflection

Minimizing deflection from instantaneous live loads is recommended when bridge joints are present. For jointless bridges, these criteria may be omitted.

$\delta_L \leq 0.125"$ AASHTO C14.7.5.3.6

$\delta_L = \sum \varepsilon_{Li} h_{ri} = \varepsilon_{Li} h_{rt}$ AASHTO 14.7.5.3.6-1

$\varepsilon_{Li} =$ instantaneous live load compressive strain in elastomeric pad

$\varepsilon_{Li} = \dfrac{\sigma_L}{4.8 G_{min} {S_i}^2} =$ 0.25 / (4.8*0.128*7.06^2) = 0.008 AASHTO C14.7.5.3.6-1

$\delta_L = \varepsilon_{Li} h_{rt} =$ 0.008*2.625 = 0.022 in.

Check $\delta_L \leq 0.125"$ 0.022 in. < 0.125 in. **OK**

Dead Load Compressive Deflection

AASHTO Method B does not have limitations on initial or long term dead load deflections. The following calculation is for demonstration only. Engineering judgment shall be used in evaluating appropriate allowable deflections in the bearing.

Initial dead load deflection:

$\delta_d = \sum \varepsilon_{di} h_{ri} = \varepsilon_{di} h_{rt}$ AASHTO 14.7.5.3.6-2

$\varepsilon_{di} =$ initial dead load compressive strain in *i* th layer of elastomeric pad

$\varepsilon_{di} = \dfrac{\sigma_d}{4.8 G_{min} S^2} =$ 0.83 / (4.8*0.13*7.06^2) = 0.027 AASHTO C14.7.5.3.6-1

$\delta_d = \varepsilon_{di} h_{rt} =$ 0.027*2.625 = 0.072 in.

Long term dead load deflection: AASHTO 14.7.5.3.6-3

$\delta_{lt} = \delta_d + \alpha_{cr} \delta_d$

= 0.072+0.35*0.072 = 0.097 in AASHTO T14.7.6.2-1

Combined Compression, Rotation, and Shear AASHTO 14.7.5.3.3

For demonstration purposes, only rotation about the transverse direction is verified. The Designer shall evaluate the bearing about both the longitudinal and transverse axis as appropriate, especially in cases where the structure contains a significant skew (AASHTO C14.7.5.3.3). Cyclic loading shall consist of loads induced by traffic with all other loads considered static (AASHTO 14.7.5.3.3).

$$(\gamma_{a,st} + \gamma_{r,st} + \gamma_{s,st}) + 1.75(\gamma_{a,cy} + \gamma_{r,cy} + \gamma_{s,cy}) \leq 5.0$$ AASHTO 14.7.5.3.3-1

and

$$\gamma_{a,st} \leq 3.0$$ AASHTO 14.7.5.3.3-2

Axial Load Shear Strain

Axial strain from static loads: $\gamma_{a,st} = D_a \frac{\sigma_{s,st}}{GS_i}$ AASHTO 14.7.5.3.3-3

Axial strain from cyclic loads: $\gamma_{a,cy} = D_a \frac{\sigma_{s,cy}}{GS_i}$ AASHTO 14.7.5.3.3-3

where:

D_a = 1.40 AASHTO 14.7.5.3.3-4

$\sigma_{s,st} = \sigma_d$ = Compressive stress due to total static load at service limit state

$\sigma_{s,cy} = \sigma_L$ = Compressive stress due to cyclic load at service limit state

$\gamma_{a,st} = D_a \frac{\sigma_{s,st}}{G_{min} S_i} = \frac{1.40*0.83}{0.13*7.06}$ = 1.296

$\gamma_{a,cy} = D_a \frac{\sigma_{s,cy}}{G_{min} S_i} = \frac{1.40*0.25}{0.13*7.06}$ = 0.389

Rotational Shear Strain

Rotational strain from static loads: $\gamma_{r,st} = D_r \left(\frac{L}{h_{ri}}\right)^2 \frac{\theta_{s,st}}{n}$ AASHTO 14.7.5.3.3-6

Rotational strain from cyclic loads: $\gamma_{r,cy} = D_r \left(\frac{L}{h_{ri}}\right)^2 \frac{\theta_{s,cy}}{n}$ AASHTO 14.7.5.3.3-6

where

D_r = 0.50 AASHTO 14.7.5.3.3-7

$\theta_{s,st} = \theta_d + \theta_r$ = Maximum static service limit state design rotation

$\theta_{s,cy} = \theta_L$ = Maximum cyclic service limit state design rotation

$\gamma_{r,st} = D_r \left(\frac{L}{h_{ri}}\right)^2 \frac{\theta_{s,st}}{n} =$ 0.50 (10.00 / 0.500) ^2 *(-0.001 + 0.005) / 5 = 0.160

$\gamma_{r,cy} = D_r \left(\frac{L}{h_{ri}}\right)^2 \frac{\theta_{s,cy}}{n} =$ 0.50 (10.00 / 0.500) ^2 *(0.006) / 5 = 0.240

Shear Deformation Shear Strain

Shear strain from static loads: $\gamma_{s,st} = \frac{\Delta_{s,st}}{h_{rt}}$ AASHTO 14.7.5.3.3-10

Shear strain from cyclic loads: $\gamma_{s,cy} = \frac{\Delta_{s,cy}}{h_{rt}}$ AASHTO 14.7.5.3.3-10

where

$\Delta_{s,st} = \Delta_{s,slip} =$ 0.755 in.

$\Delta_{s,cy} = \Delta_{LL} =$ 0.100 in.

$\gamma_{s,st} = \frac{\Delta_{s,st}}{h_{rt}} =$ 0.755 / 2.625 = 0.288

$\gamma_{s,cy} = \frac{\Delta_{s,cy}}{h_{rt}} =$ 0.100 / 2.625 = 0.038

Combined Shear Strains Checks

$$(\gamma_{a,st} + \gamma_{r,st} + \gamma_{s,st}) + 1.75(\gamma_{a,cy} + \gamma_{r,cy} + \gamma_{s,cy}) \leq 5.0$$

= 1.296+0.160+0+ 1.75(0.389+0.240+0.038) = 2.91 < 5.00 **OK**

$\gamma_{a,st} \leq 3.0$ $\gamma_{a,st} =$ 1.296 < 3.00 **OK**

Stability AASHTO 14.7.5.3.4

If the following is satisfied, no further investigation of stability is required:

$2A \leq B$ AASHTO 14.5.3.4-1

where

$A = \frac{1.92 \frac{h_{rt}}{L}}{\sqrt{1 + \frac{2.0L}{W}}} =$ 1.92*(2.625 / 10.00) / SQRT [1 + (2*10.00) / 24.00] = 0.37 AASHTO 14.7.5.3.4-2

$B = \frac{2.67}{(S_i + 2.0)(1 + \frac{L}{4.0W})} =$ 2.67 / (7.06+2.0) * [1+10.00 / (4.0*24.00)] = 0.27 AASHTO 14.7.5.3.4-3

Note that if L is greater than W, stability shall be investigated by interchanging L and W.

L= 10.00 in
W= 24.00 in

Check $2A =$ 2*0.37 = 0.74 > 0.27 = B **FAILS**

If the above criteria for stability are not satisfied, the following equations shall be investigated:

For a bridge deck that is free to translate horizontally:
For demonstration only. Designer shall determine movement capability of bridge on a case by case basis.

$$\sigma_s \le \frac{G_{min} S_i}{2A - B} = \frac{0.13*7.06}{2*0.37 - 0.27} = 1.88 \text{ ksi}$$ AASHTO 14.7.5.3.4-4

Check $\sigma_s =$ 1.08 ksi < 1.88 ksi **OK** **Bearing is Stable**

If the above criteria for stability are not satisfied, the following equations shall be investigated:

For a bridge deck that is fixed against horizontal translation:
For demonstration only. Designer shall determine movement capability of bridge on a case by case basis.

$$\sigma_s \le \frac{G_{min} S_i}{A - B} = \frac{0.13*7.06}{0.37 - 0.27} = 8.55 \text{ ksi}$$ AASHTO 14.7.5.3.4-5

Check $\sigma_s =$ 1.08 ksi < 8.55 ksi **OK** **Bearing is Stable**

Reinforcement AASHTO 14.7.5.3.5
Note that holes are not present in the bearing. The allowable thickness does not need to be increased per AASHTO 14.7.5.3.5.

The minimum thickness of steel reinforcement shall satisfy the following:

$$h_s \ge 0.0625 in$$

and

(Service Limit State)

$$h_s \ge \frac{3 h_{ri} \sigma_s}{F_y} = \frac{3*0.500*1.08}{36} = 0.045 \text{ in}$$ AASHTO 14.7.5.3.5-1

and

(Fatigue Limit State)

$$h_s \ge \frac{2 h_{ri} \sigma_L}{\Delta F_{TH}} = \frac{2*0.500*0.25}{24.00} = 0.010 \text{ in}$$ AASHTO 14.7.5.3.5-2

Check

$h_s =$	0.125 in	>	0.0625 in	**OK**
	0.125 in	>	0.045 in	**OK**
	0.125 in	>	0.010 in	**OK**

Bearing Anchorage AASHTO 14.7.5.4

For bearings without externally bonded plates, a restraint system is required to secure the bearing against horizontal movement if:

$$\frac{\theta_s}{n} \geq \frac{3\varepsilon_a}{S_i}$$ AASHTO 14.7.5.4-1

where

$\theta_s =$ total of static and cyclic service limit state design rotation. Cyclic component is multiplied by 1.75

$\varepsilon_a =$ total of static and cyclic average axial strain. Cyclic component is multiplied by 1.75

$$\theta_s = \theta_{s,st} + 1.75\theta_{s,cy} = \theta_d + \theta_r + 1.75\theta_L =$$

= -0.001+0.005 + 1.75*0.006= 0.015 rad

$\varepsilon_a = \varepsilon_{st} + 1.75\varepsilon_{cy} = \varepsilon_d + 1.75\varepsilon_L =$ 0.027 + 1.75*0.008 = 0.042

Check

$\frac{\theta_s}{n} \geq \frac{3\varepsilon_a}{S_i} =$ $\frac{0.015}{5}$ = 0.003 < $\frac{3*0.042}{7.06}$ = 0.018 **FAILS** **Restraint Required**

If the Engineer elects to use externally bonded plates, limitations on hydrostatic pressure per AASHTO 14.7.5.3.3-11 shall be satisfied.

Anchorage (Bearing Pad Slip) AASHTO 14.8.3

The bearing pad must be secured against horizontal movement if the shear force sustained by the deformed pad exceeds the minimum vertical force due to permanent loads modified for the concrete friction. The allowable slip of the pad is calculated and compared to the pad deformation using both G_{max} and G_{min} to determine the controlling scenario. Note this example considers longitudinal deformations only; wind, braking, and seismic loads shall also be considered as appropriate, in the direction of consideration.

$$H_b = \mu P_{min}$$ AASHTO 14.6.3.1-1

and

$$H_b = G_{min} A \frac{\Delta_s}{h_{rt}}$$ AASHTO 14.6.3.1-2

Combining equations:

$\Delta_{s,allow} = \frac{\mu P_{min} h_{rt}}{G_{min} A} =$ 0.20*200.00*2.63 / (0.13*240.00) = 3.43 in

where

$\mu =$	0.20		Coefficient of friction AASHTO C14.8.3.1
$P_{min} = \text{DL} =$	200.00	kip	
$A = LW =$	240.00	in^2	
$h_{rt} =$	2.63	in	

Check

$Using\ G_{min}$:	$\Delta_{s,allow} =$	3.43 in.	>	$\Delta_{s,slip} =$	0.76 in.	**OK**
$Using\ G_{max}$:	$\Delta_{s,allow} =$	2.54 in.	>	$\Delta_{s,slip} =$	0.56 in.	**OK**

In cases where $\Delta_{s,slip}$ exceeds $\Delta_{s,allow}$, anchor bolts shall be sized and designed in accordance with those Articles specified in AASHTO 14.8.3