APPENDIX A
EXAMPLE 3 - TYPE I BEARING (STEEL REINFORCED)
METHOD B

GENERAL INFORMATION

Per CDOT Bridge Design Manual (BDM) Section 14.5.8, steel reinforced bearing pads shall be designed using Method B. This example follows AASHTO LRFD 7th Edition Section 14.7.5.

This example assumes a steel superstructure that can displace under the effects of temperature and assumes a rectangular bearing shown below in Figures 1 and 2. Externally bonded plates are not used. The structure is assumed to move freely in the longitudinal direction only for the range of temperatures conforming to AASHTO 3.12.2.1 Procedure A.

MATERIAL AND SECTION PROPERTIES

Bearing Dimensions

Bearing Width	W =	**20.00**	in		AASHTO 14.7.5.1
Bearing Length	L =	**15.00**	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} =	**10**			
No. of Interior Elastomer Layers	n =	**9**			AASHTO 14.7.5.3.3
Total Elastomer Thickness	h_{rt} =	**4.750**	in		
Total Bearing Height	t =	**6.00**	in	**OK**	2" minimum height per BDM 14.5.8

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	ΔF_{TH} =	**24.00**	ksi	AASHTO T6.6.1.2.3-1

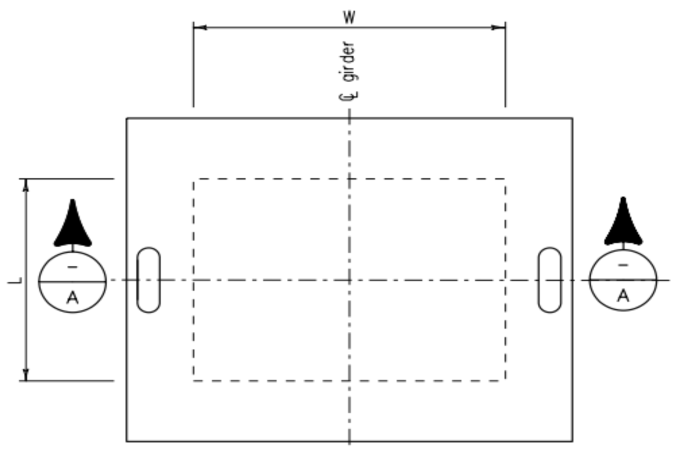

FIGURE 1 - TYPE I - STEEL REINFORCED BEARING DETAIL - PLAN

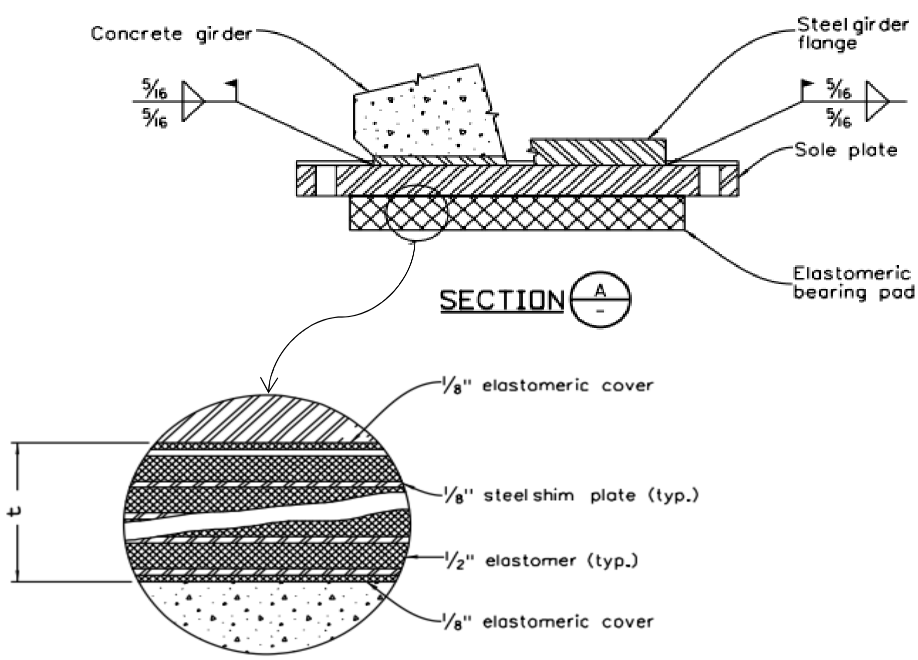

FIGURE 2 - TYPE I - STEEL REINFORCED BEARING DETAIL - SECTION

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. Loads are per bearing.

Service I Limit State Loads

DL =	**115.00**	kip
LL=	**85.00**	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	$\theta_d =$	**-0.002**	rad
Live Load Rotations	$\theta_L =$	**0.001**	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	$T_{max} =$	**120**	°F		AASHTO T3.12.2.1-1
Minimum temperature	$T_{min} =$	**-30**	°F		AASHTO T3.12.2.1-1
Coeff. of thermal expansion	$\alpha =$	**6.5E-06**	in/in/ °F		AASHTO 6.4.1
Expansion length	$L =$	**80.00**	ft =	960.00 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

$$\Delta_T = \alpha L(T_{max} - T_{min}) =$$

6.5E-6*960.00*[120-(-30)] = 0.94 in AASHTO 3.12.2.3-1

Creep, Shrinkage, Elastic Shortening, Live Load, and Miscellaneous Movements:

Creep movement	$\Delta_{CR} =$	**0.00**	in
Shrinkage movement	$\Delta_{SH} =$	**0.00**	in
Elastic shortening	$\Delta_{EL} =$	**0.00**	in
Live load movement	$\Delta_{LL} =$	**0.04**	in
Miscellaneous movement	$\Delta_{MISC} =$	**0.50**	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 14.5.3

1.00*1.20*0.94+0.00+0.00+0.00+0.04+0.50 = 1.66 in

SOLUTION

Shape Factor

Rectangular, steel reinforced bearing shape factor without holes:

AASHTO 14.5.7.1-1

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

(15.00*20.00) / [2*0.500*(15.00+20.00)] = 8.57

Computed Compressive Stresses

$$\sigma_s = \frac{DL + LL}{LW} =$$ (115.00+85.00) / (15.00*20.00) = 0.67 ksi

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

$$\sigma_L = \frac{LL}{LW} =$$ 85.00 / (15.00*20.00) = 0.28 ksi

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

$$\sigma_d = \frac{DL}{LW} =$$ 115.00 / (15.00*20.00) = 0.38 ksi

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

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

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

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

$$\varepsilon_{Li} = \frac{\sigma_L}{4.8 G_{min} S_i^2} =$$ 0.28 / (4.8*0.13*8.57^2) = 0.006 AASHTO C14.7.5.3.6-1

$$\delta_L = \varepsilon_{Li} h_{rt} =$$ 0.006*4.750 = 0.030 in

Check $\delta_L \leq 0.125"$ 0.030 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:

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

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

$$\varepsilon_{di} = \frac{\sigma_d}{4.8 G_{min} S_i^2} =$$ 0.38 / (4.8*0.13*8.57^2) = 0.009 AASHTO C14.7.5.3.6-1

$$\delta_d = \varepsilon_{di} h_{rt} =$$ 0.009*4.750 = 0.040 in.

Long term dead load deflection: AASHTO 14.7.5.3.6-3

$$\delta_{lt} = \delta_d + \alpha_{cr} \delta_d$$ = 0.040+0.35*0.040 = 0.055 in. AASHTO T14.7.6.2-1

Shear Deformations

Total elastomer thickness = h_{rt}

$h_{rt} \geq 2\Delta_s =$ 2*1.66 = 3.33 in AASHTO 14.7.5.3.2-1

Check $h_{rt} =$ 4.75 in > 3.33 in **OK**

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

<u>Axial Load Shear Strain</u>

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

Axial strain from cyclic loads: $\gamma_{a,cy} = D_a \dfrac{\sigma_{s,cy}}{GS_i}$ 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

$$\gamma_{a,st} = D_a \frac{\sigma_{s,st}}{G_{min}S_i} = \frac{1.40*0.38}{0.13*8.57} = 0.491$$

$$\gamma_{a,cy} = D_a \frac{\sigma_{s,cy}}{G_{min}S_i} = \frac{1.40*0.28}{0.13*8.57} = 0.363$$

<u>Rotational Shear Strain</u>

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

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

$\gamma_{r,st} = D_r \left(\dfrac{L}{h_{ri}}\right)^2 \dfrac{\theta_{s,st}}{n} =$ 0.50 (15.00 / 0.500) ^2 *(-0.002+0.005) / 9 = 0.150

$\gamma_{r,cy} = D_r \left(\dfrac{L}{h_{ri}}\right)^2 \dfrac{\theta_{s,cy}}{n} =$ 0.50 (15.00 / 0.500) ^2 *(0.001) / 9 = 0.050

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

$\Delta_{s,st} = \Delta_s - \Delta_{LL} =$ 1.663 in

$\Delta_{s,cy} = \Delta_{LL} =$ 0.040 in

$\gamma_{s,st} = \frac{\Delta_{s,st}}{h_{rt}} =$ 1.663 / 4.750 = 0.350

$\gamma_{s,cy} = \frac{\Delta_{s,cy}}{h_{rt}} =$ 0.040 / 4.750 = 0.008

Combined Shear Strains Checks

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

= 0.491+0.150+0+ 1.75(0.363+0.050+0.008) = 1.73 < 5.00 **OK**

$\gamma_{a,st} \leq 3.0$ $\gamma_{a,st} =$ 0.491 < 3.00 **OK**

Stability AASHTO 14.7.5.3.4

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

AASHTO 14.5.3.4-1

$$2A \leq B$$

where

AASHTO 14.7.5.3.4-2

$$A = \frac{1.92\frac{h_{rt}}{L}}{\sqrt{1 + \frac{2.0L}{W}}} =$$ 1.92*(4.750 / 15.00) / SQRT [1 + (2*15.00) / 20.00] = 0.38

AASHTO 14.7.5.3.4-3

$$B = \frac{2.67}{(S_i + 2.0)(1 + \frac{L}{4.0W})} =$$ 2.67 / (8.57+2.0) * [1+15.00 / (4.0*20.00)] = 0.21

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

L= 15.00 in
W= 20.00 in

Check $2A =$ 2*0.38 = 0.77 > 0.21 = 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.

$$\sigma_s \le \frac{G_{min}S_i}{2A - B} = \frac{0.13*8.57}{2*0.38 - 0.21} = 1.96 \text{ ksi}$$ AASHTO 14.7.5.3.4-4

Check $\sigma_s =$ 0.67 ksi < 1.96 ksi **OK** **Bearing is Stable**

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.

$$\sigma_s \le \frac{G_{min}S_i}{A - B} = \frac{0.13*8.57}{0.38 - 0.21} = 6.36 \text{ ksi}$$ AASHTO 14.7.5.3.4-5

Check $\sigma_s =$ 0.67 ksi < 6.36 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:

$$h_s \ge .0625in$$

and

(Service Limit State)

$$h_s \ge \frac{3h_{ri}\sigma_s}{F_y} = \frac{3*0.500*0.67}{36} = 0.028 \text{ in}$$ AASHTO 14.7.5.3.5-1

and

(Fatigue Limit State)

$$h_s \ge \frac{2h_{ri}\sigma_L}{\Delta F_{TH}} = \frac{2*0.500*0.28}{24.00} = 0.012 \text{ in}$$ AASHTO 14.7.5.3.5-2

Check

$h_s =$	0.125 in	>	0.0625 in	**OK**
	0.125 in	>	0.028 in	**OK**
	0.125 in	>	0.012 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

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

= -0.002+0.005+1.75*0.001= 0.005 rad

$\varepsilon_a = \varepsilon_{st} + 1.75\varepsilon_{cy} = \varepsilon_d + 1.75\varepsilon_L =$ 0.009+ 1.75*0.006= 0.020

Check

$\frac{\theta_s}{n} \geq \frac{3\varepsilon_a}{S_i} =$ $\frac{0.005}{9}$ = 0.001 < $\frac{3*0.020}{8.57}$ = 0.007 **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. G_{max} is used since the pad is stiffer at colder temperatures and will produce larger shear forces. 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

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

Combining equations:

$\Delta_{s,allow} = \frac{\mu P_{min} h_{rt}}{G_{max} A} =$ 0.20*115.00*4.75 / (0.17*300.00) = 2.11 in

where

$\mu =$ 0.20 Coefficient of friction AASHTO C14.8.3.1

$P_{min} = \mathrm{DL} =$ 115.00 kip

$A = LW =$ 300.00 in^2

$h_{rt} =$ 4.75 in

Check

$\Delta_{s,allow} =$ 2.11 in > $\Delta_s =$ 1.66 in **OK**

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