

LUC-23 - ELASTOMERIC BEARING - METHOD A - PIER BEARINGS For Existing Beams

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Date: 3/13/2023

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Date: 3/14/2023

This sheet is used to design a rectangular elastomeric bearing using AASHTO LRFD Method A. The preferred design of elastomeric bearings is Method A (ODOT BDM S14.7.5).

This sheet is in accordance with AASHTO's LRFD Design Bridge Design Specification.

User inputs are highlighted in - Yellow

Sheet assumption are highlighted in - Blue
User may change if necessary

Sheet checks are highlighted in - Green

Inputs from other files are highlighted in purple - Purple

General Structure Data

Super_Material :=

Steel
Concrete

Select superstructure material

Bearing_Constraint :=

Fixed
Expansion

Select whether the bearing is constrained or not.

Bridge_Length := 281.5ft

Skew := 3.175deg

Span_Length_{ext} := 52ft

Span_Length_{int} := 86.5ft

Span_{max} := max(Span_Length_{ext}, Span_Length_{int}) = 86.500 ft

No_Spans := 4

Deck_{width} := 90ft + 10in = 90.833 ft

No_substructure_units := No_Spans + 1 = 5

Multi_Path_{width} := 14·ft + 0·in

Barrier_{left} := 1ft + 2in

Barrier_{right} := 1ft + 8in

Barrier_{sidewalk} := 2ft

Roadway_{width} := Deck_{width} - Multi_Path_{width} - Barrier_{left} - Barrier_{right} - Barrier_{sidewalk} = 72.000 ft

Beam_{wt_ext} := 230·plf W36x170

Beam_{wt_int} := 230·plf W36x170

Barrier_{ht} := 3.5ft

Beam_{d_prop} := 35.9·in W36x170

Beam_{d_exist} := 35.9·in W36x170

Beam_{d_max} := max(Beam_{d_prop}, Beam_{d_exist}) = 2.992 ft

b_{f_ext} := 16.47·in

b_{f_int} := 16.47·in

A_{ext} := 67.6·in²

A_{int} := 67.6·in²

t_{f_ext} := 1.26·in

t_{f_int} := 1.26·in

t_f := max(t_{f_ext}, t_{f_int}) = 1.260·in

$$\text{Deck}_{\text{thick}} := 8.5 \cdot \text{in} \quad \text{Deck}_{\text{thick_overhang}} := 10.5 \text{in}$$

$$\text{Asphalt}_{\text{thick}} := 1 \cdot \text{in} \quad \text{Haunch}_{\text{thick}} := 2 \cdot \text{in} \quad \text{From Plans}$$

$$\text{Deck_Overhang}_1 := 2 \cdot \text{ft} + 4 \cdot \text{in}$$

$$\text{Deck_Overhang}_2 := 2 \cdot \text{ft} + 6 \cdot \text{in}$$

$$\text{Beam_Space}_{\text{ext}} := 7 \text{ft} + 3 \text{in} = 7.250 \cdot \text{ft} \quad \text{Controlling Space} \quad \text{Beam_Space}_{\text{int}} := 7 \text{ft} + 3 \text{in} = 7.250 \cdot \text{ft} \quad \text{Controlling Space}$$

$$\text{No}_{\text{beams}} := 14$$

$$\text{No}_{\text{beams_phase1}} := 7 \quad \text{No}_{\text{beams_phase2}} := 7$$

$$\text{Clear_Slab}_{\text{top}} := 2.5 \cdot \text{in} \quad \text{Clear_Slab}_{\text{bot}} := 1.5 \cdot \text{in} \quad \text{ODOT BDM 304.4.9}$$

$$\text{Tributary}_{\text{width_ext}_1} := \text{Deck_Overhang}_1 + \frac{1}{2} \cdot \text{Beam_Space}_{\text{ext}} = 5.958 \text{ ft}$$

$$\text{Tributary}_{\text{width_ext}_2} := \text{Deck_Overhang}_2 + \frac{1}{2} \cdot \text{Beam_Space}_{\text{ext}} = 6.125 \text{ ft}$$

$$\text{Tributary}_{\text{width_int}} := \text{Beam_Space}_{\text{int}} = 7.250 \text{ ft}$$

Distance from average beam seat to average top of footing

$$\text{H}_{\text{col1}} := 23.3 \text{ft}$$

$$\text{H}_{\text{col2}} := 23.3 \text{ft}$$

$$\text{H}_{\text{col3}} := 23.3 \text{ft}$$

$$\text{H}_{\text{height}} := \frac{(\text{H}_{\text{col1}} + \text{H}_{\text{col2}} + \text{H}_{\text{col3}})}{3} = 23.3 \text{ ft}$$

*H for abutments is equal to the average height of the column supporting bridge deck from abutment to next expansion joint
H for columns and/or piers, is equal to the column, or pier height - AASHTO 4.7.4.4*

$$\text{Barrier}_{\text{height}} := 3 \text{ft} + 6 \text{in}$$

$$\text{Superstructure_Height} := \text{Barrier}_{\text{height}} + \text{Deck}_{\text{thick}} + \text{Haunch}_{\text{thick}} + \text{Beam}_{\text{d_max}} = 7.4 \text{ ft}$$

AASHTO - 3.8.1.2.1 -Average height of the top of the superstructure above surrounding ground or water surface

Merlin Dash Output

$$\gamma_{\text{conc}} := 150 \cdot \text{pcf}$$

$$\gamma_{\text{steel}} := 490 \cdot \text{pcf}$$

Existing Beams	DL	LL
Beam 1	112.17	102.88
Beam 2,3,4	116.59	132.08
Beam 5	100.58	111.52
Beam 6	101.16	111.51
Beam 7	106.73	120.79
Beam 8,9	106.35	120.79
Beam 10	100.55	113.64
Max	116.59	132.08

Total Dead Load for Bearing Calculations

$$DL_{\text{Dash}} := 116.59 \text{ kip}$$

Live Load

From Merlin Dash Output TABLE 1.2.7.1=LIVE LOAD REACTIONS (UNFACTORED)

Reactions are not multiplied by Load Modifiers (ductility, redundancy and operational importance).

$$LL_{\text{no_IM}} := 132.08 \text{ kip}$$

Maximum load - no impact as that is not needed for elastomeric bearings

Service I is normal operational use

Service II is for slip-control, and Service III and Service IV are for prestressed concrete

Combined DL

$$DL := DL_{\text{Dash}} = 116.590 \cdot \text{kip}$$

Horizontal Forces

Braking

The greater of 25% of the axle weights of the design truck or design tandem or 5% of the design truck or tandem plus lane load. Multiple presence factors shall apply.

Design truck controls over design tandem, use design truck loads for braking force.

$$HL_{\text{Truck_Axle_wt}} := 8 \cdot \text{kip} + 32 \cdot \text{kip} + 32 \cdot \text{kip} = 72.0 \cdot \text{kip} \quad \text{AASHTO LRFD - 3.6.1.2.2}$$

$$Lane_{\text{width}} := 12 \cdot \text{ft}$$

$$No_{\text{lanes}} := \text{floor}(\text{Roadway}_{\text{width}} \div Lane_{\text{width}}) = 6.000$$

$$m_{\text{lane}} := \begin{cases} 1.2 & \text{if } No_{\text{lanes}} < 2 \\ 1.0 & \text{if } 2 \leq No_{\text{lanes}} < 3 \\ 0.85 & \text{if } 3 \leq No_{\text{lanes}} < 4 \\ 0.65 & \text{otherwise} \end{cases} = 0.650$$

LL Reduction factors from - AASHTO LRFD - Table 3.6.1.1.2-1

$$Lane_{\text{Load}} := 0.64 \cdot \text{klf} \quad \text{AASHTO LRFD - 3.6.1.2.4}$$

$$R_{\text{Lane}} := \text{Bridge_Length} \cdot Lane_{\text{Load}} = 180.16 \cdot \text{kip}$$

Use whole bridge length for reaction
Even doing this BR_1 will still control

$$BR_1 := 0.25 \cdot HL_{\text{Truck_Axle_wt}} = 18.0 \cdot \text{kip}$$

$$BR_2 := 0.05 \cdot (HL_{\text{Truck_Axle_wt}} + R_{\text{Lane}}) = 12.61 \cdot \text{kip}$$

$$BR_{\text{max}} := m_{\text{lane}} \cdot No_{\text{lanes}} \cdot \max(BR_1, BR_2) = 70.2 \cdot \text{kip} \quad BR_1 \text{ Controls}$$

$$BR := BR_{\text{max}} \div (No_{\text{beams}}) = 5.014 \cdot \text{kip} \quad \text{There are 14 total bearings}$$

Centrifugal Forces (No centrifugal forces on this bridge)

$$f := \frac{4}{3} \quad \text{For load combinations other than fatigue.}$$

$$v := 0 \text{ mph} = 0.000 \quad \text{Highway design speed}$$

$$g := 1 \frac{\text{ft}}{\text{s}^2} \quad \text{Gravitation acceleration}$$

$$R_{\text{curve}} := 1 \text{ ft} \quad \text{Radius of curvature of traffic lane}$$

$$C_{\text{factor}} := f \cdot \frac{v^2}{g \cdot R_{\text{curve}}} = 0.000 \quad \text{AASHTO LRFD - 3.6.3-1}$$

$$CE_{\text{total}} := m_{\text{lane}} \cdot C_{\text{factor}} \cdot \text{HL_Truck_Axle}_{\text{wt}} = 0.000 \cdot \text{kip}$$

$$CE := CE_{\text{total}} \div (\text{No}_{\text{beams}}) = 0.000 \cdot \text{kip} \quad \text{There are 14 total bearings}$$

Horizontal Wind on Live Loads

For usual girder and slab bridges having a span length of not more 150 ft and a maximum height 30.0 ft above low ground or ground level, the following wind loading, both applied simultaneously, may be used

$$WL_{\text{long_line}} := 0.00254 \cdot \text{klf} \quad \text{AASHTO LRFD - 3.8.1.3}$$

$$WL_{\text{long}} := WL_{\text{long_line}} \cdot (\text{Bridge_Length}) \div (\text{No}_{\text{beams}}) \div \text{No_substructure_units} = 0.010 \cdot \text{kip}$$

$$WL_{\text{trans_line}} := 0.09746 \cdot \text{klf} \quad \text{AASHTO LRFD - 3.8.1.3}$$

$$WL_{\text{trans}} := WL_{\text{trans_line}} \cdot [(\text{Bridge_Length}) \div (\text{No}_{\text{beams}}) \div \text{No_substructure_units}] \div (\text{No}_{\text{beams}}) = 0.028 \cdot \text{kip}$$

Horizontal Wind on Superstructures

AASHTO LRFD - 3.8.1.2.3a - For usual girder and slab bridges having a span length of not more 125 ft and a maximum height 30.0 ft above low ground or ground level, the following wind loading, both applied simultaneously, may be used
Transverse - 100% of wind load calculated based on wind direction perpendicular to the longitudinal axis of the bridge

$$V_{\text{Ser_I}} := 70 \cdot \text{mph} \quad \text{AASHTO Table 3.8.1.1.2-1}$$

$$G_{\text{gust}} := 1.0 \quad \text{AASHTO Table 3.8.1.2.1-1 - for non-sound barriers}$$

$$C_D := 1.3 \quad \text{AASHTO Table 3.8.1.2.1-2 - Winward on I-beam superstructures}$$

$$Z := \max(\text{Superstructure_Height}, 33.0 \cdot \text{ft}) = 33.0 \text{ ft} \quad \text{AASHTO 3.8.1.2.1}$$

$$\text{Ground_Surface_Roughness} := \begin{array}{|l|} \hline \text{Category B} \\ \text{Category C} \\ \text{Category D} \\ \hline \end{array} \quad \text{AASHTO 3.8.1.1.4 - Urban and Suburban areas, wooded area, or other terrain with numerous closely spaced obstructions having the size of single-family dwelling or larger}$$

$$K_{Z_Ser_I} := 1.0 \quad \text{AASHTO 3.8.1.2.1}$$

$$P_{z_Ser_I} := 2.56 \cdot 10^{-6} \cdot \left[(V_{Ser_I} \div \text{mph})^2 \right] \cdot K_{z_Ser_I} \cdot G_{gust} \cdot C_D \cdot \text{ksf} = 0.016 \cdot \text{ksf}$$

$$\text{Exposed_Height_Barrier} := 3\text{ft} + 6\text{in} = 3.500\text{ft} \quad \text{Single slope concrete bridge railing - SBR-1-20}$$

$$\text{Exposed_height}_{super} := \text{Beam}_d_{max} + \text{Haunch}_{thick} + \text{Deck}_{thick} + \text{Exposed_Height_Barrier} = 7.367\text{ft}$$

$$\text{WS}_{Ser_I_{trans}} := P_{z_Ser_I} \cdot \text{Exposed_height}_{super} \cdot (\text{Bridge_Length}) \div (\text{No}_{beams}) \div \text{No_substructure_units} = 0.483 \cdot \text{kip}$$

$$\text{WS}_{Ser_I_{long}} := (25\%) \cdot \text{WS}_{Ser_I_{trans}} = 0.121 \cdot \text{kip} \quad \text{AASHTO 3.8.1.2.3a simplified procedure}$$

Temperature Strain

Used for checking the shear - AASHTO 14.7.6.3.4

$$\text{Temp}_{base} := 60 \cdot \text{deg} \quad \text{ODOT BDM S14.7.5.3.4}$$

$$\text{Temp}_{max_steel} := 120 \cdot \text{deg}$$

$$\text{Temp}_{min_steel} := -30 \cdot \text{deg}$$

ODOT BDM S3.12.2

$$\text{Temp}_{max_conc} := 95 \cdot \text{deg}$$

$$\text{Temp}_{min_conc} := 15 \cdot \text{deg}$$

$$\Delta_{temp} := \begin{cases} \max(\text{Temp}_{base} - \text{Temp}_{min_steel}, \text{Temp}_{max_steel} - \text{Temp}_{base}) & \text{if Super_Material} = \text{"Stl"} \\ \max(\text{Temp}_{base} - \text{Temp}_{min_conc}, \text{Temp}_{max_conc} - \text{Temp}_{base}) & \text{if Super_Material} = \text{"Conc"} \end{cases} = 90.0 \cdot \text{deg}$$

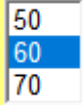
$$\alpha := \begin{cases} 6.5 \cdot 10^{-6} \frac{1}{\text{deg}} & \text{if Super_Material} = \text{"Stl"} \\ 6.0 \cdot 10^{-6} \frac{1}{\text{deg}} & \text{if Super_Material} = \text{"Conc"} \end{cases} = 0.0000065 \cdot \frac{1}{\text{deg}} \quad \begin{array}{l} \text{Steel - AASHTO 6.4.1} \\ \text{Conc - AASHTO 5.4.2.2} \end{array}$$

$$\epsilon_{temp_girder} := \Delta_{temp} \cdot \alpha = 0.000585 \quad \text{in. / in.} \quad \begin{array}{l} \text{Temperature Force to be determined later} \\ \text{when bearing parameters are established.} \end{array}$$

There may be a small amount of shrinkage force. However, it will most likely get resolved into the girders and not affect the bearings.

Bearing Material Properties AASHTO 14.7.6.2

Durometer :=



Select the Shore A Durometer Hardness of the bearing

ODOT BDM 306.4.2.1 - Elastomeric Bearings should be designed based on a durometer of either 50 or 60

AASHTO Table 14.7.6.2-1

Lower Limit of Range of Shear Modulus:

Upper Limit of Range of Shear Modulus:

$$G_{low} := \begin{cases} 0.095 \cdot \text{ksi} & \text{if Durometer} = 50 \\ 0.130 \cdot \text{ksi} & \text{if Durometer} = 60 \\ 0.200 \cdot \text{ksi} & \text{if Durometer} = 70 \end{cases} = 0.130 \cdot \text{ksi}$$

$$G_{up} := \begin{cases} 0.130 \cdot \text{ksi} & \text{if Durometer} = 50 \\ 0.200 \cdot \text{ksi} & \text{if Durometer} = 60 \\ 0.300 \cdot \text{ksi} & \text{if Durometer} = 70 \end{cases} = 0.200 \cdot \text{ksi}$$

General Design - Determine Bearing Dimensions

AASHTO 14.7.6.1

Bearing_{length} := 13·in
*Perpendicular to axis of rotation.
 Generally parallel to global long axis*

Bearing_{width} := 20·in
*Parallel to axis of rotation
 Generally parallel to global transverse axis*

$$\text{Bearing}_{\text{area}} := \text{Bearing}_{\text{length}} \cdot \text{Bearing}_{\text{width}} = 260.0 \cdot \text{in}^2$$

$h_{r_int} := .4 \cdot \text{in}$
 *h_{ri} is the thickness of internal layer. All internal layers are same thickness (AASHTO 14.7.6.1)
 So the i -th internal layer, h_{ri} is the same as the other layers. So call this h_{r_int}*

$h_{r_ext} := 0.25 \cdot \text{in}$
*Thickness of external layer
 AASHTO 14.7.6.1 - Cover Layers shall be no more than 70% of thickness of internal layers*

$n_{int} := 5$ *Number of internal layers*

$n_{ext} := 1$ *Number of external layers
 There is only 1 exterior layer as there is a top cover plate.*

$$n_s := (n_{int} + n_{ext}) - 1 = 5.000$$

$h_s := 0.1046 \cdot \text{in}$
*Thickness of laminate
 12 Gage Steel Plate*

$h_{s_limit} := \frac{1}{16} \cdot \text{in}$
The thickness of steel laminates are limited to 1/16"

Steel_thickness_{check} := if($h_s \geq h_{s_limit}$, "Okay", "No Good") = "Okay"

$F_y := 36 \cdot \text{ksi}$ *Yield stress of the laminates*

$\Delta F_{TH} := 24 \cdot \text{ksi}$
*Constant Amplitude Fatigue
 Threshold for Category A:
 AASHTO Table 6.6.1.2.5-3*

$$S_i := \frac{(\text{Bearing}_{\text{length}} \cdot \text{Bearing}_{\text{width}})}{2 \cdot h_{r_int} \cdot (\text{Bearing}_{\text{length}} + \text{Bearing}_{\text{width}})} = 9.848$$

AASHTO Eq. 14.7.5.1-1
All internal layers are similar. So the i -th internal layer is the same as the others

$$\text{Bearing}_{\text{geometry}} := \begin{cases} \frac{S_i^2}{n_{int}} & \text{if } h_{r_ext} < 0.5 \cdot h_{r_int} \\ \frac{S_i^2}{n_{int} + n_{ext} \cdot 0.5} & \text{otherwise} \end{cases} = 17.635$$

When h_{r_ext} is $\geq 0.5 \times h_{r_int}$, the parameter n (number of interior layers), may be increased by one-half for each such exterior layer. - AASHTO - 14.7.6

AASHTO 14.7.6.1 - For steel-reinforced elastomeric bearings in which the primary rotation is about the axis parallel to the transverse axis of the bridge, $S_i^2 / n < 22$ ($n = n_{int}$)

AASHTO Commentary 14.7.6.1 - For rectangular bearing pads, the specified limit of 22 for S_i^2 / n is appropriate except that a limiting value of 20 for S_i^2 / n should be considered when the value of n is greater than or equal to 3. ($n = n_{int}$)

Bearing_Geometry_{check} := if($\text{Bearing}_{\text{geometry}} < \text{if}(n_{int} \geq 3, 20, 22)$, "Okay", "No Good") = "Okay"

Check that the total height of the bearing excluding internal laminates is between 1" and 5" ODOT BDM 307.2.1

$$h_{rt} := (h_{r_int} \cdot n_{int}) + (h_{r_ext} \cdot n_{ext}) = 2.250 \cdot \text{in}$$

Total_Bearing_Height_{check} := if($1 \cdot \text{in} \leq h_{rt} \leq 5 \cdot \text{in}$, "Okay", "No Good") = "Okay"

Design Requirements AASHTO 14.7.6.3

Compressive Stress Requirements AASHTO 14.7.6.3.2

$$\sigma_{DL} := \frac{DL}{\text{Bearing}_{\text{area}}} = 0.448 \cdot \text{ksi}$$

Compressive stress due to Dead Load
conservatively include DW

$$\sigma_{L_no_IM} := \frac{LL_no_IM}{\text{Bearing}_{\text{area}}} = 0.508 \cdot \text{ksi}$$

Compressive stress due to Live Load without Impact

$$\sigma_s := \frac{DL + LL_no_IM}{\text{Bearing}_{\text{area}}} = 0.956 \cdot \text{ksi}$$

Compressive stress for applicable service load combinations.
Service I is normal operational use
Service II is for slip-control, and Service III and Service IV are for prestressed concrete

Therefore use only Service I which has a load factor of 1.0 for DC, DW, and LL

ODOT S14.7.5.3.2 - The effect of impact shall be ignored.

For steel reinforced elastomeric bearings designed in accordance with the provisions of AASHTO 14.7.6.3.2, the average compressive stress shall satisfy the following requirements. The stress limits may be increased by ten percent where shear deformation is prevented.

$$\sigma_s < 1.375 G \cdot S_i (1.10 \cdot 1.25) \text{ for bearings fixed against shear deformation and } \sigma_s < 1.25 G \cdot S_i \text{ for expansion bearings}$$

$$\sigma_{s_allow_1} := \text{if}(\text{Bearing_Constraint} = \text{"Fix"}, 1.375 \cdot G_{low} \cdot S_i, 1.25 \cdot G_{low} \cdot S_i) = 1.600 \cdot \text{ksi}$$

Use G_{bw} as it is conservative.

$$\sigma_s = 0.956 \cdot \text{ksi}$$

$$\sigma_{s_check_1} := \text{if}(\sigma_s \leq \sigma_{s_allow_1}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

AASHTO Eq 14.7.6.3.2-7

$$\sigma_s < 1.375 \text{ ksi } (1.10 \cdot 1.25) \text{ for bearings fixed against shear deformation and } \sigma_s < 1.25 \text{ ksi for expansion bearings}$$

$$\sigma_{s_allow_2} := \text{if}(\text{Bearing_Constraint} = \text{"Fix"}, 1.375 \cdot \text{ksi}, 1.25 \cdot \text{ksi}) = 1.250 \cdot \text{ksi}$$

$$\sigma_s = 0.956 \cdot \text{ksi}$$

$$\sigma_{s_check_2} := \text{if}(\sigma_s \leq \sigma_{s_allow_2}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

AASHTO Eq 14.7.6.3.2-8

Compressive Deflection AASHTO 14.7.6.3.3

In addition to the provisions of AASHTO 14.7.6.3.3, the provisions of AASHTO 14.7.5.3.6

$$E_c := 4.8 \cdot G_{low} \cdot S_1^2 = 60.523 \cdot \text{ksi}$$

AASHTO Eq. C14.6.3.2-1 - The load deflection curve of elastomeric is nonlinear, this is an acceptable approximation for the effective modulus
Use G_{bw} as it is conservative.

$$\epsilon_L = \delta / (4.8 \cdot G \cdot S^2) \quad \text{AASHTO Eq. C14.7.5.3.6-1}$$

Therefore: $\epsilon_L = \delta / (E_c)$

Instantaneous Live Load Deflection

$$\epsilon_{Li} := \frac{\sigma_{L_no_IM}}{E_c} = 0.0084 \quad \text{AASHTO Eq. C14.7.5.3.6-1}$$

ϵ_{Li} = instantaneous live load compressive strain in the i th elastomer layer

$$\delta_L := \epsilon_{Li} \cdot h_{r_int} = 0.003 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.6-1}$$

$$\delta_{L_max} := 0.125 \cdot \text{in}$$

AASHTO Commentary C14.7.7.5.3.6 recommends a maximum value of 0.125"

$$\delta_{L_initial_check} := \text{if}(\delta_L < \delta_{L_max}, "Okay", "No Good") = "Okay"$$

Initial Dead Load Deflection

$$\epsilon_{di} := \frac{\sigma_{DL}}{E_c} = 0.0074 \quad \text{AASHTO Eq. C14.7.5.3.6-1}$$

ϵ_{di} = initial dead load compressive strain in the i th elastomer layer

$$\delta_d := \epsilon_{di} \cdot h_{r_int} = 0.003 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.6-2}$$

$$\delta_{d_max} := 0.125 \cdot \text{in}$$

ODOT BDM 306.4.2.1 - vertical deformations of the bearings greater than 1/8" are to be compensated for in the elevations of the bridge bearing seats.

$$\delta_{d_initial_check} := \text{if}(\delta_d < \delta_{d_max}, "Okay", "No Good") = "Okay"$$

$$\text{Compressive_Deflection_Check} := \text{if}(\delta_L + \delta_d < 0.9 \cdot h_{r_int}, "Okay", "No Good") = "Okay" \quad \text{AASHTO Eq. 14.7.6.3.3}$$

Long-term dead load deflection, including the effects of creep

Long-term dead load deflections should be considered where joints and seals between sections of the bridge rest on bearings of different design and when estimating redistribution of forces in continuous bridges caused by settlement.

Creep deflection divided by initial dead load (Table may be used) AASHTO Table 14.7.6.2-1

$$a_{cr} := \begin{cases} 0.25 & \text{if Durometer} = 50 \\ 0.35 & \text{if Durometer} = 60 \\ 0.45 & \text{if Durometer} = 70 \end{cases} = 0.350$$

$$\delta_{lt} := \delta_d + a_{cr} \cdot \delta_d = 0.004 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.6-3} \quad \delta_{d_max} = 0.125 \cdot \text{in}$$

$$\delta_{d_long_term_check} := \text{if}(\delta_{lt} < \delta_{d_max}, "Okay", "No Good") = "Okay"$$

Check Total Load (excluding impact) deflection at internal layer

AASHTO 14.7.6.3.3

$$\varepsilon_{d_L_no_IM} := \frac{(\sigma_{DL} + \sigma_{L_no_IM})}{E_c} = 0.0158$$

AASHTO Eq. C14.7.5.3.6-1
 $\varepsilon_{d_L_no_IM}$ = initial combined DL and LL no IM
compressive strain in the *i*th elastomer layer

$$\delta_{d_L_no_IM} := \varepsilon_{d_L_no_IM} \cdot h_{r_int} = 0.0063 \cdot \text{in} \quad \text{Similar to AASHTO Eq. 14.7.5.3.6-1 through 14.7.5.3.6-3}$$

$$\delta_{d_L_no_IM_max} := 0.09 \cdot h_{r_int} = 0.036 \cdot \text{in} \quad \text{AASHTO 14.7.6.3.3}$$

$$\delta_{d_L_no_IM_check} := \text{if}(\delta_{d_L_no_IM} < \delta_{d_L_no_IM_max}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

Rotation AASHTO 14.7.6.3.5

AASHTO Commentary C14.7.6.3.5a - For steel-reinforced elastomeric bearings, rotation is not checked.
The check is implicit on the geometric and stress limits.

Stability AASHTO 14.7.6.3.6

Total thickness of the pad shall not exceed $L/3$ or $W/3$.

L - Generally parallel to the global longitudinal axis

W - Generally parallel to the global transverse direction

$$\text{Thickness}_{\text{allowable}} := \min\left(\frac{\text{Bearing}_{\text{length}}}{3}, \frac{\text{Bearing}_{\text{width}}}{3}\right) = 4.333 \cdot \text{in}$$

$$h_{\text{total}} := h_{rt} + n_s \cdot h_s = 2.773 \cdot \text{in}$$

$$\text{Stability}_{\text{check}} := \text{if}(h_{\text{total}} \leq \text{Thickness}_{\text{allowable}}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

Reinforcement AASHTO 14.7.6.3.7

Reinforcement for steel-reinforced elastomeric bearings shall be designed according to AASHTO 14.7.5.3.5

$$h_{s_service_limit} := 3 \cdot \frac{h_{r_int} \cdot \sigma_s}{F_y} = 0.0319 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.5-1}$$

$$h_s = 0.1046 \cdot \text{in}$$

$$\text{Reinforcement_Service}_{\text{check}} := \text{if}(h_s \geq h_{s_service_limit}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

$$h_{s_fatigue_limit} := 2 \cdot \frac{h_{r_int} \cdot \sigma_{L_no_IM}}{\Delta F_{TH}} = 0.0169 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.5-2}$$

$$h_s = 0.1046 \cdot \text{in}$$

$$\text{Reinforcement_Fatigue}_{\text{check}} := \text{if}(h_s \geq h_{s_fatigue_limit}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

Shear Deformation

AASHTO 14.7.6.3.4

The provisions of 14.7.5.3.2 shall apply except that

$h_{rt} \Rightarrow 2\Delta_s$ For steel reinforced elastomeric bearings

For the design of the shear deformation, determine the total shear force due to temperature based on the expansion length, and then divide the deformation evenly amongst all the bearing lines over that length.

$$\text{Span_Expansion_Length} := \frac{2}{3} \cdot \text{Bridge_Length} = 187.667 \text{ ft}$$

L = length of bridge deck to the adjacent expansion joint or end of bridge deck

$L_{\text{expand_max}} := \text{Span_Expansion_Length} = 187.667 \text{ ft}$ For highly skewed and wide bridges, take expanding length on a diagonal between slab corners to obtain most unfavorable expansion length. Since the skew is moderate, do not adjust the factors.

$$L_{\text{expand_min}} := \frac{1}{3} \cdot \text{Bridge_Length} = 93.833 \text{ ft}$$

$$\Delta_{T_total_max} := L_{\text{expand_max}} \cdot \Delta_{\text{temp}} \cdot \alpha = 1.317 \cdot \text{in}$$

AASHTO 3.12.2.3

May override Δ_T if bridge has unusual geometry that requires 3-d analysis.

$$\Delta_{T_total_min} := L_{\text{expand_min}} \cdot \Delta_{\text{temp}} \cdot \alpha = 0.659 \cdot \text{in}$$

$$\Delta_{T_max} := \Delta_{T_total_max} \div 3 = 0.439 \cdot \text{in}$$

Distribute the force for max expansion over 3 bearing lines

$$\Delta_{T_min} := \Delta_{T_total_min} \div 3 = 0.220 \cdot \text{in}$$

Distribute the force for min expansion over 3 bearing lines

$$\Delta_T := \max(\Delta_{T_max}, \Delta_{T_min}) = 0.439 \cdot \text{in}$$

Movements from post tensioning not applicable

$$\Delta_0 := 0.65 \cdot (\Delta_T) = 0.285 \cdot \text{in}$$

AASHTO 14.7.5.3.2 - The maximum horizontal displacement of the bridge superstructure shall be taken as 65% of Δ_T

$$\Delta_s := \Delta_0 = 0.285 \cdot \text{in}$$

The maximum shear deformation at service limit state Δ_s shall be Δ_0 - AASHTO 14.7.5.3.2

$$h_{rt} = 2.250 \cdot \text{in}$$

$$2 \cdot \Delta_s = 0.571 \cdot \text{in}$$

$$\text{Shear}_{\text{check}} := \text{if}(h_{rt} \geq 2 \cdot \Delta_s, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

AASHTO 14.7.5.3.2

Horizontal Force and Movement

AASHTO 14.6.3.1

According to BDM Section 1000, S14.6.3.2, no moment transferred from superstructure to substructure for elastomeric bearings without anchor bolts or only 2 anchor bolts centered at centerline of the bearing.

Determine Factored Horizontal Loads

The temperature and shrinkage forces acting on the bearings were not previously calculated as the force due to these load cases are based off of properties of the bearing by utilizing equation which equates horizontal force based on the deformation of the bearing. AASHTO Eq. 14.6.3.1-2:

$$H_{bu_temp} := G_{up} \cdot \text{Bearing}_{area} \cdot \frac{\Delta_s}{h_{rt}} = 6.597 \cdot \text{kip}$$

AASHTO Eq. 14.6.3.1-2
Use the maximum shear limit deformation

AASHTO 3.4.1- Service I is load case is related to normal operational use, Service II, III, and IV are not applicable

$$\gamma_{BR} := 1.0 \quad \gamma_{WS} := 1.0 \quad \gamma_{WL} := 1.0 \quad \gamma_{TU} := 1.2 \quad \text{AASHTO 3.4.1- Table 3.4.1-1}$$

$$H_{bu_long} := \gamma_{BR} \cdot BR + \gamma_{WS} \cdot WS_{Ser_I_{long}} + \gamma_{WL} \cdot WL_{long} + \gamma_{TU} \cdot H_{bu_temp} = 13.062 \cdot \text{kip}$$

Check maximum shear deformation. Use AASHTO Eq. 14.6.3.1-2 and solve for the allowable horizontal movement H_{bu_allow} with maximum deformation of $1/2 h_{rt}$

$$\Delta_{allow} := \frac{h_{rt}}{2} = 1.125 \cdot \text{in} \quad \text{AASHTO Eq. 14.7.5.3.2-1}$$

$$H_{bu_allow} := G_{up} \cdot \text{Bearing}_{area} \cdot \frac{\Delta_{allow}}{h_{rt}} = 26.000 \cdot \text{kip} \quad \text{AASHTO Eq. 14.6.3.1-2}$$

$$\text{Deform_CL}_{check} := \text{if}(H_{bu_allow} \geq H_{bu_long}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

S14.6.3.1 HORIZONTAL FORCE AND MOVEMENT

Bearings without directional seismic restraint are not required to accommodate seismic movements in the unrestrained direction. Irreparable damage due to seismic movement in accordance with BDM Section 301.4.4.1.c is permitted.

301.4.4.1.c REQUIREMENTS FOR BEARINGS

Unrestrained bearings that sustain irreparable damage during a seismic event are permissible provided loss of span is prevented by the design for the Horizontal Connection Force in BDM Section 301.4.4.1.b.

Seismic and Other Extreme Event Provisions

AASHTO 14.7.6.3.8 & ODOT BDM 301.4.4.1a

Expansion bearings designed according to Article 14.7.6 shall be provided with adequate seismic and other extreme event resistant anchorage to resist the horizontal forces in excess of those accommodated by shear in the pad unless the bearing is intended to act as a fuse or irreparable damage is permitted. The provisions of Article 14.7.5.3.7 shall also apply as applicable.

According to AASHTO 14.6.3.1 Adequate support length shall be provided for all bearings in accordance with Article 4.7.4.4.

$L_{\text{deck_length}} := (L_{\text{expand_max}}) = 187.667 \text{ ft}$ $L = \text{length of bridge deck to the adjacent expansion joint or end of bridge deck.}$
Typically equal to the expansion length calculated for the shear deformation

$H_{\text{height}} = 23.3 \text{ ft}$ $H \text{ for abutments is equal to the average height of the column supporting bridge deck}$
from abutment to next expansion joint - AASHTO 4.7.4.4

$N = \text{minimum support length measured normal to the centerline of bearing - AASHTO - 4.7.4.4-1}$

$$N_{\min} := \left(8 + 0.02 \cdot L_{\text{deck_length}} \cdot \frac{1}{\text{ft}} + 0.08 \cdot H_{\text{height}} \cdot \frac{1}{\text{ft}} \right) \cdot \left[1 + 0.000125 \cdot \left[\frac{(\text{Skew})}{\text{deg}} \right]^2 \right] \cdot \text{in} = 13.634 \cdot \text{in}$$

$$N_{\text{pier}} := 1.5 \text{ ft} = 18.000 \cdot \text{in}$$

Figure C4.7.4.4-1 Shows that the the support length is to the end of the beam. The N value states the distance is normal, however BDM Figure 301-3 shows to take into account the skew.

$$\text{Brg_Length}_{\text{check}} := \text{if}(N_{\text{pier}} \geq N_{\min}, \text{"Okay"}, \text{"No Good"}) = \text{"Okay"}$$

Check Summary

Bearing_Geometry_{check} = "Okay"

Total_Bearing_Height_{check} = "Okay"

σ_s _check_1 = "Okay"

σ_s _check_2 = "Okay"

δ_L _initial_check = "Okay"

δ_d _initial_check = "Okay"

δ_d _long_term_check = "Okay"

δ_d _L_no_IM_check = "Okay"

Shear_{check} = "Okay"

Stability_{check} = "Okay"

Reinforcement_Service_{check} = "Okay"

Reinforcement_Fatigue_{check} = "Okay"

Deform_CL_{check} = "Okay"

Brg_Length_{check} = "Okay"

Bearing Data Design Summary

Shore A Hardness:

Durometer = 60

Size:

Bearing_{length} = 13.000·in (*Longitudinal Dimension*)

Bearing_{width} = 20.000·in (*Transverse Dimension*)

Total Thickness, "Dim T":

$h_{\text{total}} = 2.773 \cdot \text{in}$

Internal Laminates:

Thickness: $h_{r_int} = 0.4000 \cdot \text{in}$

Number of Internal Laminates: $n_{int} = 5$

External Laminates:

Thickness: $h_{r_ext} = 0.2500 \cdot \text{in}$

Number of External Laminates: $n_{ext} = 1$

Steel Laminates:

Thickness: $h_s = 0.1046 \cdot \text{in}$

Number of Steel Laminates: $n_s = 5$

Loading Information

Dead Load: $DL = 116.6 \cdot \text{kip}$ /pad

Live Load (w/out Impact): $LL_{no_IM} = 132.1 \cdot \text{kip}$ /pad

Design Load: $DL + LL_{no_IM} = 248.7 \cdot \text{kip}$ /pad