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27.1 General

Bridges supported in the conventional way by abutments and piers require bearings to transfer girder reactions without overstressing the supports, ensuring that the bridge functions as intended. Bridges usually require bearings that are more elaborate than those required for building columns, girders and trusses. Bridge bearings require greater consideration in minimizing forces caused by temperature change, friction and restraint against elastic deformations. A more detailed analysis in bridge bearing design considers the following:

- Bridges are usually supported by reinforced concrete substructure units, and the magnitude of the horizontal thrust determines the size of the substructure units. The coefficient of friction on bridge bearings should be as low as possible.
- Bridge bearings must be capable of withstanding and transferring dynamic forces and the resulting vibrations without causing eventual wear and destruction of the substructure units.
- Most bridges are exposed to the elements of nature. Bridge bearings are subjected to more frequent and greater total expansion and contraction movement due to changes in temperature than those required by buildings. Since bridge bearings are exposed to the weather, they are designed as maintenance-free as possible.

WisDOT policy item:

WisDOT uses an installation temperature of 60°F for designing bearings. The temperature range considered for prestressed concrete girder superstructures is 5°F to 85°F, resulting in a range of 60° - 5° = 55° for bearing design. For prestressed girders an additional shrinkage factor of 0.0003 ft/ft should also be accounted for. The temperature range considered for steel girder superstructures is -30°F to 120°F, resulting in a range of 60° - (-30°) = 90° for bearing design.

WisDOT policy item:

According to **LRFD [14.4.1]**, the influence of dynamic load allowance need not be included for bearings. However, dynamic load allowance shall be included when designing bearings for bridges in Wisconsin. Apply dynamic load allowance in **LRFD [3.6.2]** to HL-93 live loads as stated in **LRFD [3.6.1.2, 3.6.1.3]** and distribute these loads, along with dead loads, to the bearings.

27.2 Bearing Types

Bridge bearings are of two general types: expansion and fixed. Bearings can be fixed in both the longitudinal and transverse directions, fixed in one direction and expansion in the other, or expansion in both directions. Expansion bearings provide for rotational movements of the girders, as well as longitudinal movement for the expansion and contraction of the bridge spans. If an expansion bearing develops a large resistance to longitudinal movement due to corrosion or other causes, this frictional force opposes the natural expansion or contraction of the span, creating a force within the span that could lead to a maintenance problem in the future. Fixed bearings act as hinges by permitting rotational movement, while at the same time preventing longitudinal movement. The function of the fixed bearing is to prevent the superstructure from moving longitudinally off of the substructure units. Both expansion and fixed bearings transfer lateral forces, as described in **LRFD [3]**, from the superstructure to the substructure units. Both bearing types are set parallel to the direction of structural movement; bearings are not set parallel to flared girders.

When deciding which bearings will be fixed and which will be expansion on a bridge, several guidelines are commonly considered:

- The bearing layout for a bridge must be developed as a consistent system. Vertical movements are resisted by all bearings, longitudinal horizontal movements are resisted by fixed bearings and facilitated in expansion bearings, and rotations are generally allowed to occur as freely as possible.

- For maintenance purposes, it is generally desirable to minimize the number of deck joints on a bridge, which can in turn affect the bearing layout.

- The bearing layout must facilitate the anticipated thermal movements, primarily in the longitudinal direction, but also in the transverse direction for wide bridges.

- It is generally desirable for the superstructure to expand in the uphill direction, wherever possible.

- If more than one substructure unit is fixed within a single superstructure unit, then forces will be induced into the fixed substructure units and must be considered during design. If only one pier is fixed, unbalanced friction forces from expansion bearings will induce force into the fixed pier.

- For curved bridges, the bearing layout can induce additional stresses into the superstructure, which must be considered during design.

- Forces are distributed to the bearings based on the superstructure analysis.

A valuable tool for selecting bearing types is presented in **LRFD [Table 14.6.2-1]**, in which the suitability of various bearing types is presented in terms of movement, rotation and resistance to loads. In general, it is best to use a fixed or semi-expansion bearing utilizing an unreinforced elastomeric bearing pad whenever possible, provided adverse effects such as excessive force transfer to the substructure does not occur. Where a fixed bearing is required with greater rotational capacity, steel fixed bearings can be utilized. Laminated elastomeric bearings are the preferred choice for expansion bearings. When such expansion bearings fail to meet project requirements, steel Type "A-T" expansion bearings should be used. For curved and/or highly skewed bridges, consideration should be given to the use of pot bearings.

27.2.1 Elastomeric Bearings

Elastomeric bearings are commonly used on small to moderate sized bridges. Elastomeric bearings are either fabricated as plain bearing pads (consisting of elastomer only) or as laminated (steel reinforced) bearings (consisting of alternate layers of steel reinforcement and elastomer bonded together during vulcanization). A sample plain elastomeric bearing pad is illustrated in Figure 27.2-1, and a sample laminated (steel reinforced) elastomeric bearing is illustrated in Figure 27.2-2.

These bearings are designed to transmit loads and accommodate movements between a bridge and its supporting structure. Plain elastomeric bearing pads can be used for small bridges, in which the vertical loads, translations and rotations are relatively small. Laminated (steel reinforced) elastomeric bearing pads are often used for larger bridges with more sizable vertical loads, translations and rotations. Performance information indicates that elastomeric bearings are functional and reliable when designed within the structural limits of the material. See **LRFD [14]** and *AASHTO LRFD Bridge Construction Specifications*, 2nd Edition, 2004, Section 18 for design and construction requirements of elastomeric bearings.

WisDOT policy item:

WisDOT currently uses plain or laminated (steel reinforced) elastomeric bearings which are rectangular in shape. No other shapes or configurations are used for elastomeric bearings in Wisconsin.

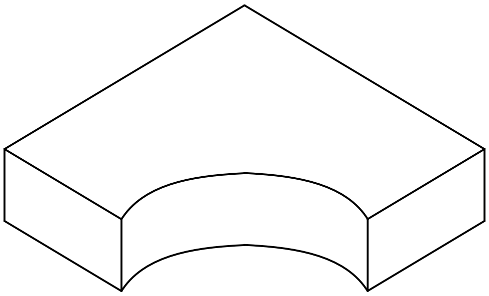

Figure 27.2-1

Plain Elastomeric Bearing

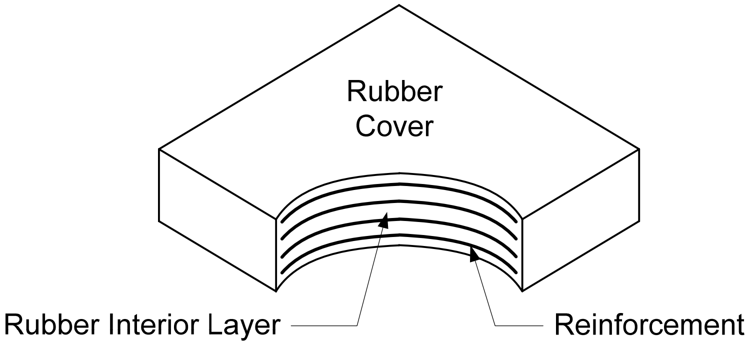

Figure 27.2-2
Laminated (Steel Reinforced) Elastomeric Bearing

AASHTO LRFD does not permit tapered elastomer layers in reinforced bearings. Laminated (steel reinforced) bearings must be placed on a level surface; otherwise gravity loads will produce shear strain in the bearing due to inclined forces. The angle between the alignment of the underside of the girder (due to the slope of the grade line, camber and dead load rotation) and a horizontal line must not exceed 0.01 radians, as per **LRFD [14.8.2]**. If the angle is greater than 0.01 radians or if the rotation multiplied by the top plate length is 1/8” or more, the 1 1/2" top steel plate must be tapered to provide a level load surface along the bottom of this plate under these conditions. The tapered plate will have a minimum thickness of 1 1/2". The angle between the alignment of the underside of the girder (due to the slope of the grade line, the rotation of the girder due to dead load plus live load, and camber) and the alignment of the bottom of the bearing must not exceed the allowable rotation angle, θ_s, as per **LRFD [14.7.6.3.5]**, when a tapered plate is not used. If a tapered plate is used, the angle between the alignment of the underside of the tapered plate (due to live load rotation) and the alignment of the bottom of the bearing (due to construction tolerances) must not exceed the allowable rotation, θ_s.

Plain and laminated (steel reinforced) elastomeric bearings can be designed by Method A as outlined in **LRFD [14.7.6]** and NCHRP-248 or by Method B as shown in **LRFD [14.7.5]** and NCHRP-298.

WisDOT policy item:

WisDOT uses Method A, as described in **LRFD [14.7.6]**, for elastomeric bearing design.

Method A results in a bearing with a lower capacity than a bearing designed using Method B. However, the increased capacity resulting from the use of Method B requires additional testing and quality control.

A preliminary value for bearing height, H, based on expansion length can be found in the Standard for Elastomeric Bearings for Prestressed Concrete Girders. The corresponding bearing length, L, based on stability requirements can also be found there. The bearing width, W, is then chosen (bottom flange width minus 2" for non-wide flanged prestressed concrete girders; bottom flange width minus 6” for wide flanged prestressed concrete girders; bottom flange width for steel girders) and is checked against stability requirements. Using these values for H, L and W, the *AASHTO LRFD* requirements for compressive stress, compressive deflection, shear deformation, rotation, steel reinforcement thickness and anchorage can be checked and the preliminary values adjusted as required.

The design of an elastomeric bearing generally involves the following steps:

1. Obtain required design input **LRFD [14.4 & 14.6]**

2. Select a feasible bearing type – plain or laminated (steel reinforced)

3. Select preliminary bearing properties **LRFD [14.7.6.2]**

4. Check shear deformation **LRFD [14.7.6.3.4]**

5. Check compressive stress **LRFD [14.7.6.3.2]**

6. Check stability **LRFD [14.7.6.3.6]**

7. Check compressive deflection **LRFD [14.7.5.3.6, 14.7.6.3.3]**

8. Check anchorage

WisDOT exception to AASHTO:

Design anchorage for laminated elastomeric bearings if the unfactored dead load stress is less than 200 psi. This is an exception to **LRFD [14.8.3]** based on past practice and good performance of existing bearings.

9. Check reinforcement **LRFD [14.7.5.3.5, 14.7.6.3.7]**

10. Check rotation **LRFD [14.7.6.3.5]**

The required design input for the design of an elastomeric bearing at the service limit state is dead load, live load plus dynamic load allowance, minimum vertical force due to permanent load, design rotation and design translation. The required design input at the strength limit state is shear force. Other required design input is expansion length, girder or beam bottom flange width, minimum grade of elastomer and temperature zone.

The preliminary bearing properties can be obtained from **LRFD [14.7.6.2]** or from past experience. The preliminary bearing properties include elastomer cover thickness, elastomer internal layer thickness, elastomer hardness, elastomer shear modulus, elastomer creep deflection, pad length, pad width, number of steel reinforcement layers, steel reinforcement thickness, steel reinforcement yield strength and steel reinforcement constant-amplitude fatigue threshold. WisDOT uses the following properties:

- Elastomer cover thickness = 1/4"

- Elastomer internal layer thickness = 1/2"

- Elastomer hardness: Durometer 60 +/- 5
- Elastomer shear modulus (G): $0.1125 \text{ ksi} < G < 0.165 \text{ ksi}$
- Elastomer creep deflection @ 25 years divided by instantaneous deflection = 0.30
- Steel reinforcement thickness = 1/8"
- Steel reinforcement yield strength = 36 ksi or 50 ksi
- Steel reinforcement constant-amplitude fatigue threshold = 24 ksi

However, not all of these properties are needed for a plain elastomeric bearing design.

Shear deformation, Δ_S, is the sum of deformation from thermal effects, Δ_{ST}, as well as creep and shrinkage effects, $\Delta_{Scr/sh}$. ($\Delta_S = \Delta_{ST} + \Delta_{Scr/sh}$)

$$\Delta_{ST} = (\text{Expansion length})(\Delta_T)(\alpha)$$

Where:

Δ_T = Change in temperature (see 27.1) (degrees)

α = Coefficient of thermal expansion (6×10^{-6} / °F for concrete and 6.5×10^{-6} / °F for steel)

Shear deformation due to creep and shrinkage effects, $\Delta_{Scr/sh}$, should be added to Δ_{ST} for prestressed concrete girder structures. The value of $\Delta_{Scr/sh}$ is computed as follows:

$$\Delta_{Scr/sh} = (\text{Expansion length})(0.0003 \text{ ft/ft})$$

LRFD [14.7.6.3.4] provides shear deformation limits to help prevent rollover at the edges and delamination. The shear deformation, Δ_S, can be checked as specified in **LRFD [14.7.6.3.4]** and by the following equation:

$$h_{rt} \geq 2\,\Delta_S$$

Where:

h_{rt} = Smaller of total elastomer or bearing thickness (inches)

Δ_S = Maximum total shear deformation of the bearing at the service limit state (inches)

The compressive stress, σ_S, at the service limit state can be checked as specified in **LRFD [14.7.6.3.2]** and by the following equations:

$$\sigma_s \leq 0.80 \text{ ksi} \text{ for plain elastomeric pads}$$

$\sigma_s \leq 1.25\text{ ksi}$ and $\sigma_s \leq 1.25GS$ for laminated (steel reinforced) elastomeric pads

Where:

σ_s = Service average compressive stress due to total load (ksi)

G = Shear modulus of the elastomer (ksi)

S = Shape factor for the thickest layer of the bearing

LRFD [14.7.6.3.2] states that the stress limits may be increased by 10 percent where shear deformation is prevented, but this is not considered applicable to WisDOT bearings.

The shape factor for individual elastomer layers is the plan area divided by the area of the perimeter free to bulge. For laminated (steel reinforced) elastomeric bearings, the following requirements must be satisfied before calculating the shape factor:

- All internal layers of elastomer must be the same thickness.
- The thickness of the cover layers cannot exceed 70 percent of the thickness of the internal layers.

The shape factor, S_i, for rectangular bearings without holes can be determined as specified in **LRFD [14.7.5.1]** and by the following equation:

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

Where:

S_i = Shape factor for the ith layer

h_{ri} = Thickness of ith elastomeric layer in elastomeric bearing (inches)

L = Length of a rectangular elastomeric bearing (parallel to longitudinal bridge axis) (inches)

W = Width of the bearing in the transverse direction (inches)

For stability, the total thickness of the rectangular pad must not exceed one-third of the pad length or one-third of the pad width as specified in **LRFD [14.7.6.3.6]**, or expressed mathematically:

$$H \leq \frac{L}{3} \text{ and } H \leq \frac{W}{3}$$

Where:

H = Total thickness of the elastomeric bearing (excluding top plate) (inches)

L = Length of a rectangular elastomeric bearing (parallel to longitudinal bridge axis) (inches)

W = Width of the bearing in the transverse direction (inches)

The compressive deflection, δ, of the bearing shall be limited to ensure the serviceability of the deck joints, seals and other components of the bridge. Deflections of elastomeric bearings due to total load and to live load alone should be considered separately. Relative deflections across joints must be restricted so that a step doesn't occur at a deck joint. **LRFD [C14.7.5.3.6]** recommends that a maximum relative live load deflection across a joint be limited to 1/8".

WisDOT policy item:

WisDOT uses a live load + creep deflection limit of 1/8” for elastomeric bearing design.

Laminated (steel reinforced) elastomeric bearings have a nonlinear load deflection curve in compression. In the absence of information specific to the particular elastomer to be used, **LRFD [Figure C14.7.6.3.3-1]** may be used as a guide. Creep effects should be determined from information specific to the elastomeric compound used. Use the material properties given in this section. The compressive deflection, δ, can be determined as specified in **LRFD [14.7.5.3.6, 14.7.6.3.3]** and by the following equation:

$$\delta = \sum \varepsilon_i \ h_{ri}$$

Where:

δ = Instantaneous deflection (inches)

ε_i = Instantaneous compressive strain in i^{th} elastomer layer of a laminated (steel reinforced) bearing

h_{ri} = Thickness of i^{th} elastomeric layer in a laminated (steel reinforced) bearing (inches)

Based on **LRFD [14.7.6.3.3]**, the initial compressive deflection of a plain elastomeric pad or in any layer of a laminated (steel reinforced) elastomeric bearing at the service limit state without dynamic load allowance shall not exceed $0.07h_{ri}$.

The bearing pad must be secured against horizontal movement if the service dead load stress is less than 200 psi.

The factored force due to the deformation of an elastomeric element shall be taken as specified in **LRFD [14.6.3.1]** by the following equation:

$$H_u > GA\frac{\Delta_u}{h_{rt}}$$

Where:

H_u = Lateral load from applicable strength load combinations in **LRFD [Table 3.4.1-1]** (kips)

G = Shear modulus of the elastomer (ksi)

A = Plan area of elastomeric element or bearing (inches^2)

Δ_u = Factored shear deformation (inches)

h_{rt} = Total elastomer thickness (inches)

Reinforcing steel plates increase compressive and rotational stiffness, while maintaining flexibility in shear. The reinforcement must have adequate capacity to handle the tensile stresses produced in the plates as they counter the lateral bulging of the elastomer layers due to compression. These tensile stresses increase with compressive load. The reinforcement thickness must also satisfy the requirements of the *AASHTO LRFD Bridge Construction Specifications*, 2nd Edition, 2004. The reinforcing steel plates can be checked as specified in **LRFD [Equation 14.7.5.3.5-1,2]**:

$$h_s \geq \frac{3\, h_{max}\, \sigma_s}{F_y} \text{ for service limit state}$$

$$h_s \geq \frac{2.0\, h_{max}\, \sigma_L}{\Delta F_{TH}} \text{ for fatigue limit state}$$

Where:

h_s = Thickness of the steel reinforcement (inches)

h_{max} = Thickness of the thickest elastomeric layer in elastomeric bearing (inches)

σ_s = Service average compressive stress due to total load (ksi)

F_y = Yield strength of steel reinforcement (ksi)

σ_L = Service average compressive stress due to live load (ksi)

ΔF_{TH} = Constant amplitude fatigue threshold for Category A as specified in **LRFD [6.6]** (ksi)

If holes exist in the reinforcement, the minimum thickness shall be increased by a factor equal to twice the gross width divided by the net width.

Rotation is controlled by ensuring that no point in the bearing experiences net uplift between the bearing and the structure and by limiting the shear strains in the elastomer. The rotation can be checked as specified in **LRFD [14.7.6.3.5]** and by the following equations:

For plain elastomeric pads **LRFD [Equation 14.7.6.3.5b-1,2]**

$$\sigma_s \geq 0.5\,G\,S\left(\frac{L}{h_{rt}}\right)^2 \theta_{s,x} \text{ and } \sigma_s \geq 0.5\,G\,S\left(\frac{W}{h_{rt}}\right)^2 \theta_{s,z}$$

For laminated (steel reinforced) elastomeric pads **LRFD [Equation 14.7.6.3.5d1,2]**

$$\sigma_s \geq 0.5\,G\,S\left(\frac{L}{h_{ri}}\right)^2 \left(\frac{\theta_{s,x}}{n}\right) \text{ and } \sigma_s \geq 0.5\,G\,S\left(\frac{W}{h_{ri}}\right)^2 \left(\frac{\theta_{s,z}}{n}\right)$$

Where:

σ_s = Service average compressive stress due to total load associated with the maximum rotation (ksi)

G = Shear modulus of the elastomer (ksi)

S = Shape factor for the thickest layer of the bearing

L = Length of a rectangular elastomeric bearing (parallel to longitudinal bridge axis) (inches)

h_{rt} = Total elastomer thickness in an elastomeric bearing (inches)

h_{ri} = Thickness of i^{th} elastomeric layer in a laminated (steel reinforced) bearing (inches)

W = Width of the bearing in the transverse direction (inches)

$\theta_{s,x}$ = Service rotation due to total load about transverse axis (radians)

$\theta_{s,z}$ = Service rotation due to total load about longitudinal axis (radians) (not considered)

n = Number of interior layers of elastomer, where interior layers are defined as those layers which are bonded on each face. Exterior layers are defined as those layers which are bonded only on one face. When the thickness of the exterior layer of elastomer is more than one-half the thickness of an interior layer, the parameter, n, may be increased by one-half for each such exterior layer.

WisDOT exception to AASHTO:

Lateral rotation about the longitudinal axis of the bearing shall not be considered for straight girders.

WisDOT policy item:

Per **LRFD [14.8.2]**, a tapered plate shall be used if the inclination of the underside of the girder to the horizontal exceeds 0.01 radians. Additionally, if the rotation multiplied by the plate length is 1/8 inch or more, taper the plate.

WisDOT policy item:

For service rotation due to total load about the transverse axis, the effect from grade line and residual camber inclination can be eliminated with the use of a tapered plate. Per **LRFD [14.4.2.1]**, a rotation of 0.005 radians shall be included to allow for construction tolerances. Live load rotation is the other effect that needs consideration.

For several years, plain elastomeric bearing pads have performed well on prestressed concrete girder structures. Refer to the Standard for Bearing Pad Details for Prestressed Concrete Girders for details. Prestressed concrete girders using this detail are fixed into the concrete diaphragms at the supports, and the girders are set on 1/2" thick plain elastomeric bearing pads. Laminated (steel reinforced) bearing details and steel plate and elastomer thicknesses are given on the Standard for Elastomeric Bearings for Prestressed Concrete Girders.

27.2.2 Steel Bearings

For fixed bearings, a rocker plate attached to the girder is set on a masonry plate which transfers the girder reaction to the substructure unit. The masonry plate is attached to the substructure unit with anchor bolts. Pintles set into the masonry plate prevent the rocker from sliding off the masonry plate while allowing rotation to occur. This bearing is represented on the Standard for Fixed Bearing Details Type "A" - Steel Girders.

For expansion bearings, two additional plates are utilized, a stainless steel top plate and a Teflon plate allowing expansion and contraction to occur, but not in the transverse direction. This bearing is shown on the Standard for Stainless Steel - TFE Expansion Bearing Details Type "A-T".

Type "B" rocker bearings have been used for reactions greater than 400 kips and having a requirement for smaller longitudinal forces on the substructure unit. However, in the future, WisDOT plans to eliminate rocker bearings for new bridges and utilize pot bearings.

Pot bearings are commonly used for moderate to large bridges. They are generally used for applications requiring a multi-directional rotational capacity and a medium to large range of load.

Hold down devices are additional details added to the Type "A-T" bearings for situations where live load can cause uplift at the abutment end of a girder. Ideally, proper span configurations would eliminate the need for hold down devices as they have proven to be a maintenance problem.

Since strength is not the governing criteria, anchor bolts are designed with Grade 36 steel for all steel bearings.

27.2.2.1 Type "A" Fixed Bearings

Type "A" Fixed Bearings prevent translation both transversely and longitudinally while allowing rotation in the longitudinal direction. This bearing is represented on the Standard for Fixed Bearing Details Type "A" - Steel Girders. An advantage of this bearing type is that it is very low maintenance. See 27.2.2.2 Type "A-T" Expansion Bearings for design information.

27.2.2.2 Type "A-T" Expansion Bearings

Type "A-T" Expansion bearings are designed to translate by sliding an unfilled polytetrafluoroethylene (PTFE or TFE) surface across a smooth, hard mating surface of stainless steel. Expansion bearings of Teflon are not used without provision for rotation. A rocker plate is provided to facilitate rotation due to live load deflection or change of camber. The Teflon sliding surface is bonded to a rigid back-up material capable of resisting horizontal shear and bending stresses to which the sliding surfaces may be subjected.

Design requirements for TFE bearing surfaces are given in **LRFD [14.7.2]**. Stainless steel-TFE expansion bearing details are given on the Standard for Stainless Steel – TFE Expansion Bearing Details Type "A-T."

Friction values are given in the **LRFD [14.7.2.5]**; they vary with loading and temperature. It is permissible to use 0.10 for a maximum friction value and 0.06 for a minimum value when determining unbalanced friction forces.

The design of type "A-T" bearings is relatively simple. The first consideration is the rocker plate length which is proportional to the contact stress based on a radius of 24" using Grade 50W steel. The rocker plate thickness is determined from a minimum of 1 1/2" to a maximum computed from the moment by assuming one-half the bearing reaction value (N/2) acting at a lever arm of one-fourth the width of the Teflon coated plate (W/4) over the length of the rocker plate. The Teflon coated plate is designed with a minimum width of 7" and the allowable stress as specified in **LRFD [14.7.2.4]** on the gross area; in many cases this controls the capacity of the expansion bearings as given in the Standard for Stainless Steel – TFE Expansion Bearing Details Type "A-T."

The design of the masonry plate is based on a maximum allowable bearing stress as specified in **LRFD [14.8.1]**. The masonry plate thickness is determined from the maximum bending moments about the x-or y-axis using a uniform pressure distribution.

In lieu of designing specific bearings, the designer may use Service I limit state loading, including dynamic load allowance, and Standards for Fixed Bearing Details Type “A” – Steel Girders, Stainless Steel – TFE Expansion Bearing Details Type “A-T” and Steel Bearings for Prestressed Concrete Girders to select the appropriate bearing.

27.2.2.3 Pot Bearings

Pot bearings are commonly used for moderate to large bridges. They are generally used for applications requiring a multi-directional rotational capacity (curved and/or highly skewed bridges) and a medium to large range of load. The bearing consists of a circular non-reinforced neoprene or rubber pad, of relatively thin section, which is totally enclosed by a steel pot. The rubber is prevented from bulging by the pot containing it and acts similar to a fluid under high pressure. The result is a bearing providing suitable rotation and at the same time giving the effect of a point-contact rocker bearing since the center of pressure does not vary more than 4 percent. As specified in **LRFD [14.7.4.1]**, the minimum vertical load on a pot bearing should not be less than 20 percent of the vertical design load.

Pot bearings resist vertical load primarily through compressive stress in the elastomeric pad. The pad can deform and it has some shear stiffness, but it has very limited compressibility. Pot bearings generally have a large reserve of strength against vertical load. Pot bearings facilitate rotation through deformation of the elastomeric pad. During rotation, one side of the pad compresses and the other side expands. Pot bearings can sustain many cycles of small rotations with little or no damage. However, they can experience significant damage when subjected to relatively few cycles of large rotations.

Pot bearings can also resist horizontal loads. They can either be fixed, guided or non-guided. Fixed pot bearings (see Figure 27.2-3) can not translate in any direction, and they resist horizontal load primarily through contact between the rim of the piston and the wall of the pot. Guided pot bearings (see Figure 27.2-4) can translate in only one direction, and they resist horizontal load in the other direction through the use of guide bars. Non-guided pot bearings (see Figure 27.2-5) can translate in any direction, and they do not resist horizontal loads in any direction.

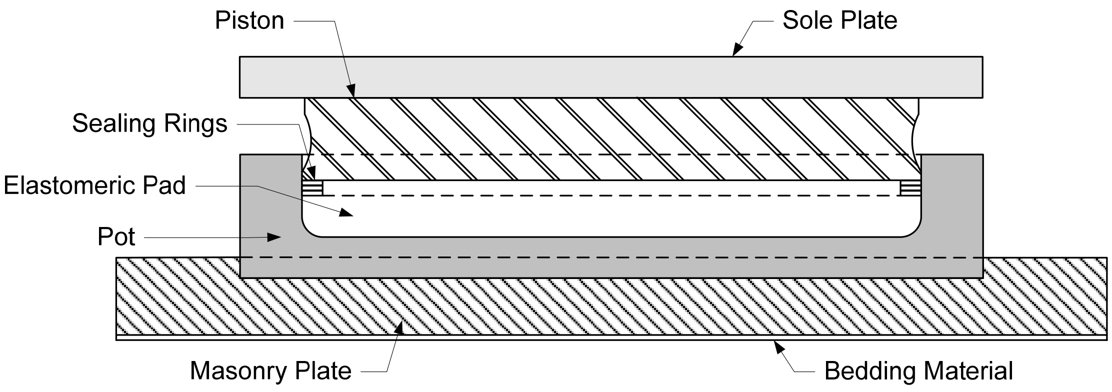

Figure 27.2-3
Fixed Pot Bearing

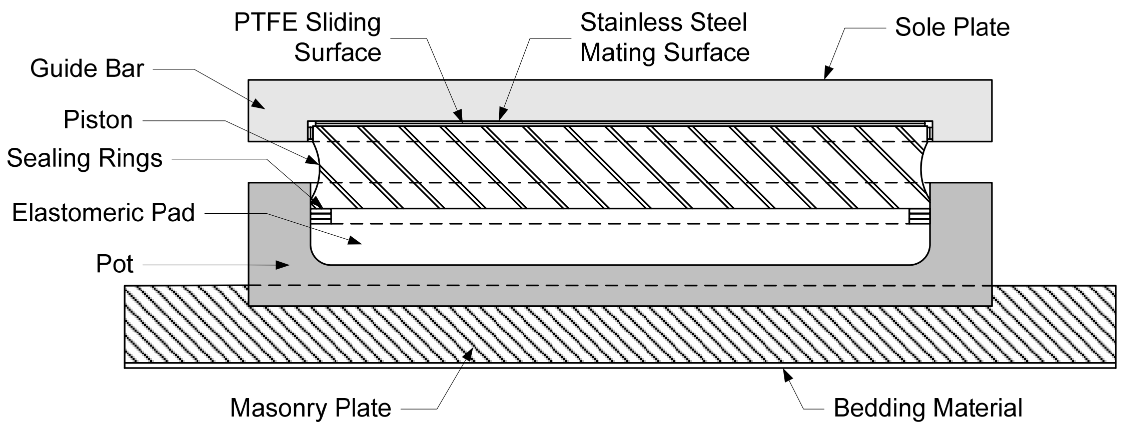

Figure 27.2-4
Guided Pot Bearing

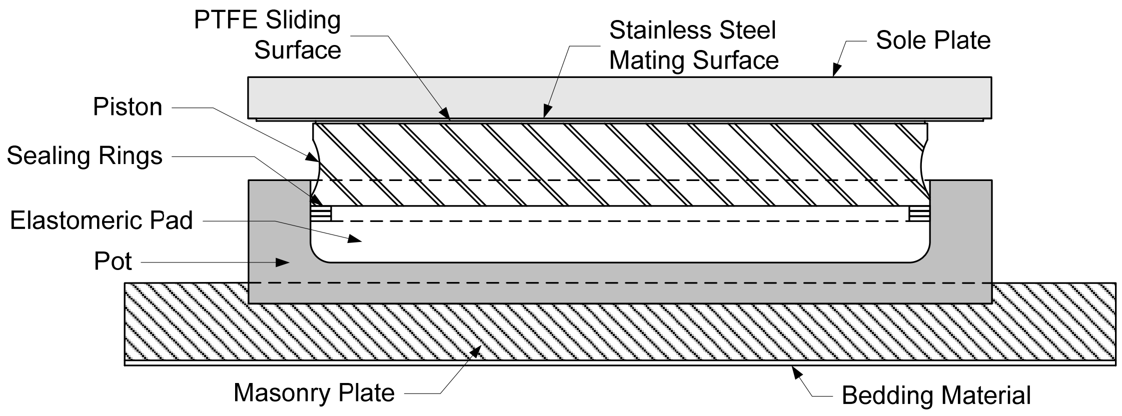

Figure 27.2-5
Non-Guided Pot Bearing

The design of a pot bearing generally involves the following steps:

1. Obtain required design input **LRFD [14.4 & 14.6]**
2. Select a feasible bearing type: fixed, guided or non-guided
3. Select preliminary bearing properties **LRFD [14.7.4.2]**
4. Design the elastomeric disc **LRFD [14.7.4.3 and 14.7.4.4]**
5. Design the sealing rings **LRFD [14.7.4.5]**

6. Design the pot **LRFD [C14.7.4.3, 14.7.4.6 and 14.7.4.7]**
7. Design the piston **LRFD [14.7.4.7]**
8. Design the guides and restraints, if applicable **LRFD [14.7.9]**
9. Design the PTFE sliding surface, if applicable **LRFD [14.7.2]**
10. Design the sole plate, masonry plate (or bearing plate), anchorage and connections **LRFD [6 and 14.8]**
11. Check the concrete or steel support **LRFD [5.7.5 and 6]**

Although the steps for pot bearing design are given above, typically the actual bearing design is done by the manufacturer. The design of the masonry plate is done either by the design engineer or by the bearing manufacturer.

When using pot bearings, the design plans need to specify the following: degree of fixity (fixed, guided in one direction or non-guided), maximum vertical load, minimum vertical load, maximum horizontal load (fixed and guided, only) and an assumed height. The loads specified are Service I limit state loads, including dynamic load allowance.

Field adjustments to the given beam seat elevations will be required if the actual bearing height differs from the assumed bearing height stated on the plan. To facilitate such an adjustment without affecting the structural integrity of the substructure unit, a concrete pedestal (plinth) is detailed at each bearing location. Detailing a pedestal height of 10” based on the assumed bearing height will give sufficient room for adjustment should the actual bearing height differ from the assumed bearing height.

27.3 Hold Down Devices

Hold down devices are additional elements added to the Type "A-T" bearings for situations where live load can cause uplift at the abutment end of a girder. Ideally, proper span configurations would eliminate the need for hold down devices as they have proven to be a maintenance problem. Details for hold down devices are given in the Standard for Hold Down Devices.

27.4 Design Examples

E27-1	Steel Reinforced Elastomeric Bearing

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E27-1 DESIGN EXAMPLE - STEEL REINFORCED ELASTOMERIC BEARING

ThIs design example is for a 3-span prestressed girder structure. The piers are fixed supports and the abutments accommodate expansion.
(Example is current through LRFD Fourth Edition - 2009 Interims)

E27-1.1 Design Data

Bearing location: Abutment (Type A3)

Girder type: 72W

$L_{exp} := 220$	Expansion length, ft
$b_f := 2.5$	Bottom flange width, ft
$DL_{serv} := 167$	Service I limit state dead load, kips
$DL_{ws} := 23$	Service I limit state future wearing surface dead load, kips
$LL_{serv} := 62$	Service I limit state live load, kips
$h_{rcover} := 0.25$	Elastomer cover thickness, in
$h_s := 0.125$	Steel reinforcement thickness, in
$F_y := 36$	Minimum yield strength of the steel reinforcement, ksi

Temperature Zone:	C (Southern Wisconsin)	**LRFD [Fig. 14.7.5.2-1]**
Minimum Grade of Elastomer:	3	**LRFD [Table 14.7.5.2-1]**
Elastic Hardness:	Durometer 60 +/- 5	(used 55 for design)
Shear Modulus (G):	0.1125 ksi < G <0.165 ksi	**LRFD [Table 14.7.6.2-1]**
Creep Deflection @ 25 Years		
divided by instantaneous deflection:	0.3	**LRFD [Table 14.7.6.2-1]**

E27-1.2 Design Method

Use Design Method A **LRFD [14.7.6]**
Method A results in a bearing with a lower capacity than a bearing designed using Method B. However the increased capacity resulting from the use of Method B requires additional testing and quality control.

E27-1.3 Dynamic Load Allowance

The influence of impact need not be included for bearings **LRFD [14.4.1]**; however, dynamic load allowance will be included to follow a **<u>WisDOT policy item</u>**.

E27-1.4 Shear **LRFD [14.7.6.3.4]**

The maximum shear deformation of the pad shall be taken as the maximum horizontal superstructure displacement, reduced to account for the pier flexibility.

$h_{rt} \geq 2\Delta_S$ **LRFD [Equation 14.7.6.3.4-1]**

Temperature range: T_{low} and T_{high} values below are from WisDOT policy item in 27.1

$T_{low} := 5$ Minimum temperature, °F

$T_{high} := 85$ Maximum temperature, °F

$\gamma_{TU} := 1.2$ Service I Load factor for deformation **LRFD [Table 3.4.1-1]**

$T_{install} := 60$ Installation temperature, °F

$\alpha_c := 0.000006$ Coefficient of thermal expansion of concrete, ft/ft/°F

$S_{crsh} := 0.0003$ Coefficient of creep and shrinkage of concrete, ft/ft

$\Delta_T := T_{install} - T_{low}$ $\boxed{\Delta_T = 55}$ °F

Maximum total shear deformation of the elastomer

$\Delta_S := L_{exp} \cdot \alpha_c \cdot \Delta_T \cdot 12 + L_{exp} \cdot S_{crsh} \cdot 12$ $\boxed{\Delta_S = 1.663}$ in

Required total elastomer thickness

$H_{rt} \geq 2 \cdot \gamma_{TU} \cdot \Delta_S$ $\boxed{H_{rt} = 3.992}$ in

Elastomer internal layer thickness

$h_{ri} := 0.5$ in

Required elastomer thickness **LRFD [14.7.6.1)**

$$\frac{h_{rcover}}{h_{ri}} \leq 0.7 \qquad \boxed{\frac{h_{rcover}}{h_{ri}} = 0.5}$$

$\boxed{\text{check} = \text{"< 0.7, OK"}}$

Determine the number of internal elastomer layers:

$$n := \frac{H_{rt} - 2 \cdot h_{rcover}}{h_{ri}}$$

Note:

$\boxed{h_{rcover} = 0.25}$ in

$\boxed{n = 6.983}$ layers

Use: $\boxed{n = 7}$ layers

Total elastomer thickness:

$h_{rt} := 2 \cdot h_{rcover} + n \cdot h_{ri}$ $\boxed{h_{rt} = 4.0}$ in

Total height of reinforced elastomeric pad:

$H := h_{rt} + (n+1) \cdot h_s$ $\boxed{H = 5.000}$ in

E27-1.5 Compressive Stress **LRFD [14.7.6.3.2]**

$\sigma_{s\_all} \le 1.25$ and $\sigma_{s\_all} \le 1.25 \cdot G \cdot S$

$edge := 3$ in Transverse distance from the edge of the flange to edge of bearing

$W := 12 \cdot b_f - 2 \cdot edge$ Transverse dimension $\boxed{W = 24}$ in

$L \ge \dfrac{DL_{serv} + LL_{serv}}{W \cdot \sigma_{s\_all}}$ Since $\sigma_{s\_all} \le \dfrac{DL_{serv} + LL_{serv}}{L \cdot W}$

$\sigma_{s\_all} := 1.25$ ksi

$L := \dfrac{DL_{serv} + LL_{serv}}{W \cdot \sigma_{s\_all}}$ Longitudinal dimension $\boxed{L = 7.633}$ in

$increment := 5$ in <== Rounding increment

$\boxed{L = 10}$ in

(can be used to increase L dimension to satisfy subsequent stress checks, etc.)

Determine shape factor for internal layer **LRFD [Equation 14.7.5.1-1]**

$S_i := \dfrac{L \cdot W}{2 \cdot h_{ri} \cdot (L + W)}$ $\boxed{S_i = 7.059}$

$G := 0.1125$ ksi $0.1125\text{ksi} < G < 0.165\text{ksi}$

$\boxed{1.25 \cdot G \cdot S_i = 0.993}$ ksi (Verify that **LRFD** is satisfied for a full range of G values. The minimum G values is used here. See also E27-1.8)

$\sigma_s := \dfrac{DL_{serv} + LL_{serv}}{L \cdot W}$ $\boxed{\sigma_s = 0.954}$ ksi

$\boxed{\sigma_s = \text{"< 1.25GS, OK"}}$

E27-1.6 Stability **LRFD [14.7.6.3.6]**

$H \le \frac{L}{3}$ and $H \le \frac{W}{3}$

$\boxed{H = 5.000}$ in

Bearing length check:

$L_{min} := 3 \cdot H$ $\boxed{L_{min} = 15}$ in

$\boxed{L = 10}$ in

Use the larger value: $\boxed{L = 15}$ in

Bearing width check:

$W_{min} := 3 \cdot H$ $\boxed{W_{min} = 15}$ in

$\boxed{W = 24}$ in

Use the larger value: $\boxed{W = 24}$ in

Revised shape factor and compressive stress for internal layer:

$\boxed{h_{ri} = 0.5}$ in

$\boxed{G = 0.1125}$ ksi

$S_i := \frac{L \cdot W}{2 \cdot h_{ri} \cdot (L + W)}$ $\boxed{S_i = 9.231}$

$\boxed{1.25 \cdot G \cdot S_i = 1.298}$ ksi

$\sigma_s := \frac{DL_{serv} + LL_{serv}}{L \cdot W}$ $\boxed{\sigma_s = 0.636}$ ksi

$\boxed{\sigma_s = \text{"< 1.25GSi, OK"}}$

Revised shape factor and compressive stress for the cover layer:

$\boxed{h_{rcover} = 0.25}$ in

$$S_{cover} := \frac{L \cdot W}{2 \cdot h_{rcover} \cdot (L + W)}$$

$$\boxed{S_{cover} = 18.462} \quad \text{ksi}$$

$$\boxed{1.25 \cdot G \cdot S_{cover} = 2.596} \quad \text{ksi}$$

$$\sigma_s := \frac{DL_{serv} + LL_{serv}}{L \cdot W}$$

$$\boxed{\sigma_s = 0.636} \quad \text{ksi}$$

$$\boxed{\sigma_s = \text{"< 1.25GS, OK"}}$$

E27-1.7 Compressive Deflection **LRFD [14.7.6.3.3, 14.7.5.3.6]**

Average vertical compressive stress:

Average compressive stress due to total load

$$\boxed{\sigma_s = 0.636} \quad \text{ksi}$$

Average compressive stress due to live load

$$\sigma_L := \frac{LL_{serv}}{L \cdot W}$$

$$\boxed{\sigma_L = 0.172} \quad \text{ksi}$$

Average compressive stress due to dead load

$$\sigma_D := \frac{DL_{serv}}{L \cdot W}$$

$$\boxed{\sigma_D = 0.464} \quad \text{ksi}$$

Use **LRFD [Figure C14.7.6.3.3-1]** to estimate the compressive strain in the interior and cover layers. Average the values from the 50 Durometer and 60 Durometer curves to obtain values for 55 Durometer bearings.

LAYER	LOAD	S	STRESS	50 DUROMETER STRAIN	60 DUROMETER STRAIN	AVERAGE STRAIN
INTERNAL	DEAD LOAD	9.231	0.636	**2.3%**	**2.1%**	2.2%
	TOTAL LOAD	9.231	0.636	**3.1%**	**2.7%**	2.9%
COVER	DEAD LOAD	18.462	0.464	**1.8%**	**1.5%**	1.7%
	TOTAL LOAD	18.462	0.464	**2.2%**	**1.9%**	2.1%

Initial compressive deflection of n-internal layers and 2 cover layers under total load:

$\boxed{\varepsilon_{int} = 0.029}$ Compressive strain in the interior layer

$\boxed{\varepsilon_{cover} = 0.021}$ Compressive strain in the cover layer

$\boxed{n = 7}$ layers

$\boxed{h_{ri} = 0.5}$ in

$\boxed{h_{rcover} = 0.25}$ in

$\delta := n \cdot h_{ri} \cdot \varepsilon_{int} + 2 \cdot h_{rcover} \cdot \varepsilon_{cover}$ Modification of **LRFD [Equation 14.7.5.3.6-1]**

$\boxed{\delta = 0.112}$ in

Initial compressive deflection under dead load:

$\boxed{\varepsilon_{intDL} = 0.022}$

$\boxed{\varepsilon_{coverDL} = 0.017}$

$\delta_{DL} := n \cdot h_{ri} \cdot \varepsilon_{intDL} + 2 \cdot h_{rcover} \cdot \varepsilon_{coverDL}$ $\boxed{\delta_{DL} = 0.086}$ in

Deflection due to creep:

$C_d := 0.30$ Average value between 50 and 60 Durometer
LRFD [Table 14.7.6.2-1]

$\delta_{CR} := C_d \cdot \delta_{DL}$ $\boxed{\delta_{CR} = 0.026}$ in

Compressive deflection due to live load:

$\delta_{LL} := \delta - \delta_{DL}$ $\boxed{\delta_{LL} = 0.027}$ in

Deflection due to creep and live load: **LRFD [C14.7.5.3.6]**

$\delta_{CRLL} := \delta_{CR} + \delta_{LL}$ $\boxed{\delta_{CRLL} = 0.052}$ in

$\boxed{\delta_{CRLL} = \text{"< 0.125 in., OK"}}$

Initial compressive deflection of a single internal layer:

$\varepsilon_{int} \cdot h_{ri} < 0.07 \cdot h_{ri}$ **LRFD [14.7.6.3.3]** $\boxed{\varepsilon_{int} = 0.029}$

$\boxed{\varepsilon_{int} = \text{"< 0.07, OK"}}$

E27-1.8 Anchorage **LRFD [14.8.3]**

Shear force generated in the bearing due to temperature movement:

$H_u := G \cdot A \cdot \frac{\Delta_u}{h_{rt}}$ **LRFD [Equation 14.6.3.1-2]**

$G := 0.165$ conservative assumption, maximum value of G, ksi

Factored shear deformation of the elastomer

$\Delta_u := \gamma_{TU} \cdot \Delta_s$ $\boxed{\Delta_u = 1.996}$ in

Plan area of elastomeric element

$\boxed{L = 15}$ in $\boxed{W = 24}$ in

$A := L \cdot W$ $\boxed{A = 360}$ in^2

$H_u := G \cdot A \cdot \frac{\Delta_u}{h_{rt}}$ $\boxed{H_u = 29.638}$ kips

(This value of H_u can be used for substructure design)

Minimum vertical force due to permanent loads:

$\gamma_{DLserv} := 1.0$

$P_{sd} := \gamma_{DLserv} \cdot (DL_{serv} - DL_{ws})$ $\boxed{P_{sd} = 144}$ kips

$\sigma := \frac{P_{sd}}{A}$ $\boxed{\sigma = 0.400}$ ksi

$\boxed{\sigma = \text{"> 0.200 ksi, OK, anchorage is not required per WisDOT exception to AASHTO"}}$

E27-1.9 Reinforcement: **LRFD [14.7.6.3.7, 14.7.5.3.5]**

Service limit state:

$h_{max} := h_{ri}$ $\boxed{h_{max} = 0.5}$ in

$\boxed{\sigma_s = 0.636}$ ksi

$\boxed{F_y = 36}$ ksi

| $h_s \ge \frac{3 \cdot h_{max} \cdot \sigma_s}{F_y}$ **LRFD [Eq 14.7.5.3.5-1]** $\boxed{h_s = 0.125}$ in

$\boxed{\frac{3 \cdot h_{max} \cdot \sigma_s}{F_y} = 0.027}$ in

$\boxed{\text{check = "< hs, OK"}}$

Fatigue limit state:

| $h_s \ge \frac{2 \cdot h_{max} \cdot \sigma_L}{\Delta F_{TH}}$ **LRFD [Eq 14.7.5.3.5-2]** $\boxed{\sigma_L = 0.172}$ ksi

$\boxed{h_s = 0.125}$ in

$\Delta F_{TH} := 24.0$ ksi Constant amplitude fatigue threshold for Category A **LRFD [Table 6.6.1.2.5-3]**

$\boxed{\frac{2 \cdot h_{max} \cdot \sigma_L}{\Delta F_{TH}} = 0.007}$ in

$\boxed{check = \text{"< hs,   OK"}}$

E27-1.10 Rotation: **LRFD [14.7.6.3.5]**

Check requirement for tapered plate: **LRFD [14.8.2]**

Find the angle between the alignment of the underside of the girder and a horizontal line. Consider the slope of the girder, camber of the girder, and rotation due to unfactored dead load deflection.

Inclination due to grade line:

$L_{span} := 150$ Span length, ft

@ pier:

$EL_{Pseat} := 856.63$ Beam seat elevation at the pier, in feet

$h_{Pbrg} := 0.5$ Bearing height at the pier, in

Bottom of girder elevation at the pier, in feet

$EL_1 := EL_{Pseat} + \frac{h_{Pbrg}}{12}$ $\boxed{EL_1 = 856.672}$

@ abutment:

$EL_{Aseat} := 853.63$ Beam seat elevation at the abutment, in feet

$t_{plate} := 1.5$ Steel top plate thickness, in

$\boxed{H = 5}$ Total elastomeric bearing height, in

Total bearing height, at the abutment, in

$h_{Abrg} := H + t_{plate}$ $\boxed{h_{Abrg} = 6.5}$ in

Bottom of girder elevation in feet

$EL_2 := EL_{Aseat} + \frac{h_{Abrg}}{12}$ $\boxed{EL_2 = 854.172}$

Slope of girder

$S_{GL} := \frac{|EL_1 - EL_2|}{L_{span}}$ $\boxed{S_{GL} = 0.017}$

Inclination due to grade line in radians

$\theta_{GL} := \operatorname{atan}(S_{GL})$ $\boxed{\theta_{GL} = 0.017}$ radians

Inclination due to residual camber:

$\Delta_{camber} := 3.83$ Maximum camber of girder, in

$\Delta_{DL} := 2.54$ Maximum dead load deflection, in

$\Delta_{LL} := 0.663$ Maximum live load deflection, in

Residual camber, in

$\Delta_{RC} := \Delta_{camber} - \Delta_{DL}$ $\boxed{\Delta_{RC} = 1.290}$ in

To determine the slope due to residual camber, use a straight line from C/L Bearing to the 1/10 point. Assume that camber at 1/10 point is 40% of maximum camber (at midspan).

$S_{RC} := \frac{0.4 \cdot \Delta_{RC}}{0.1 \cdot L_{span} \cdot 12}$ Slope due to residual camber $\boxed{S_{RC} = 0.003}$

Inclination due to residual camber in radians

$\theta_{RC} := \operatorname{atan}(S_{RC})$ $\boxed{\theta_{RC} = 0.003}$ radians

Total inclination due to grade line and residual camber in radians

$\theta_{SX} := \theta_{GL} + \theta_{RC}$ $\boxed{\theta_{SX} = 0.020}$ radians

$\boxed{\theta_{SX} = \text{"> 0.01 rad, NG, top plate must be tapered"}}$

(The plate should also be tapered if θ_{SX} x L_P >= 1/8")

Top plate dimensions:

$\boxed{t_{plate} = 1.5}$ Minimum thickness of top plate, in

$L_p := L + 2$ Length of top plate

$\boxed{L_p = 17}$ in

$\boxed{L_p \cdot \theta_{SX} = 0.332}$ in

Thickness of top plate on thicker edge

$t_{pmax} := t_{plate} + L_p \cdot \tan(\theta_{SX})$ $\boxed{t_{pmax} = 1.832}$ in

Check rotation at service limit state:

$$\sigma_{sx} \geq 0.5 \cdot G \cdot S \cdot \left(\frac{L}{h_{ri}}\right)^2 \cdot \frac{\theta_{sx\_tot}}{n}$$

Rotation about transverse axis
LRFD [Equation 14.7.6.3.5d-1]

$$\sigma_{sz} \geq 0.5 \cdot G \cdot S \cdot \left(\frac{W}{h_{ri}}\right)^2 \cdot \frac{\theta_{sz\_tot}}{n}$$

Rotation about longitudinal axis
LRFD [Equation 14.7.6.3.5d-2]

$\boxed{G = 0.165}$ ksi $\boxed{L = 15}$ in

$\boxed{S = 9.231}$ in Consider shape factor for interior layer only

$\boxed{n = 7}$ number of internal layers

$\boxed{h_{rcover} = 0.25}$ Thickness of external elastomeric layer, in

$\boxed{h_{ri} = 0.5}$ Thickness of internal elastomeric layer, in

Adjusted "n" since the top elastomer cover is bonded to the reinforcing steel plate as well as the top plate.

$n' := n + \dfrac{h_{rcover}}{h_{ri}}$ $\boxed{n' = 7.5}$

$\theta_U := 0.005$ Allowance for uncertainties **LRFD [14.4.2.1]**, radians

Service rotation due to total load about the transverse axis:

$\theta_{LL} := \theta_{RC} \cdot \left(\dfrac{\Delta_{LL}}{\Delta_{RC}}\right)$ Inclination due to live load deflection in radians

$\boxed{\theta_{LL} = 0.0015}$ radians

Total inclination due to grade line and residual camber is "0" when top plate is tapered.

$\boxed{\theta_{SX} = 0}$ radians

Rotation about transverse axis

$\theta_{sx\_tot} := \theta_U + \theta_{LL} + \theta_{SX}$ $\boxed{\theta_{sx\_tot} = 0.0065}$ radians

Let:

$\sigma_{sx} := 0.5 \cdot G \cdot S \cdot \left(\frac{L}{h_{ri}}\right)^2 \cdot \frac{\theta_{sx\_tot}}{n'}$ $\boxed{\sigma_{sx} = 0.592}$ ksi

$\boxed{\sigma_s = 0.636}$ ksi, (from E27-1.5)

$\sigma_s =$ "> σ_{sx} OK"

Service rotation due to total load about the longitudinal axis:

This check is not required in accordance with WisDOT design policy.

E27-1.11 Bearing summary:

Laminated Elastomeric Bearing Pad:

Length = 15 inches

Width = 24 inches

Steel reinforcing plates: 8 @ 1/8"

Internal elastomer layers: 7 @ 1/2"

Cover elastomer layers: 2 @ 1/4"

Total pad height: 5"

Steel Top Plate (See standard detail):

Length = 17 inches

Width = 30 inches