14. JOINTS AND BEARINGS

Expansion joints and bearings provide mechanisms to accommodate movements of bridges without generating excessive internal forces. This section provides guidance on joint and bearing selection and the movement and loads that must be used in their designs.

14.1 Bridge Movements and Fixity

To determine movements for bearings and joints, the point of fixity must be established for the bridge or bridge segment. The point of fixity is the neutral point on the bridge that does not move horizontally as the bridge experiences temperature changes. Use the following guidance concerning bridge fixity:

1) For single span structures, fix the bearings at the low end of the bridge.
2) For two-span structures, fix the bearings at the pier.
3) For structures with three or more spans, investigate the longitudinal stiffness of the bridge. The longitudinal stiffness is a function of the interaction between pier stiffnesses, bearing types and joint locations. Consider the following:
    a) The number and location of expansion joints is determined based on a maximum joint opening of 4 inches at the ends of the bridge. When joint openings exceed 4 inches, two options are available:
        i) The preferred option is to provide additional joints at the piers to split the superstructure into segments.
        ii) On rare occasions, provide modular expansion joints at bridge ends only.
    b) Each bridge or bridge segment shall have fixed bearings at a minimum of two piers to provide increased resistance to longitudinal movements.
    c) Provide fixed bearings at all tall pier locations. Tall or flexible piers deflect prior to mobilizing the translational capacity of the bearing.
    d) A combination of fixed, expansion and limited expansion bearings can be provided at the piers to accommodate the movements for the bridge or bridge segments.
    e) Based on the point of fixity of each segment, the maximum movements can be determined for the design of joints and bearings.

14.2 Expansion Joints [14.5.3.2]

Minnesota bridges with parapet type abutments typically have strip seal expansion joints at the abutments to isolate superstructure movements from the abutments. When the maximum joint openings at the abutments exceed 4 inches additional joints are needed at piers or modular joints are required at the abutments.

Do not use elastomeric compression seal expansion joints.

14.2.1 Thermal Movements [Table 3.4.1-1]

Design joint openings for movements associated with a temperature range of 150°F (-30°F to 120°F). Use a load factor for movement of 1.00. (Note that this value differs from the LRFD Specification based on past performance of joints in Minnesota.)

The coefficients of thermal expansion are:

- Concrete: 6.0×10^{-6} per °F
- Steel: 6.5×10^{-6} per °F

14.2.2 Strip Seal Expansion Joints

For movements of $^1/_4$ inch to 4 inches, use strip seal expansion devices. Design joints to have a minimum opening of $^1/_2$ inch between the steel elements (extrusions) of the joint.

To provide a reasonably smooth roadway surface the maximum width of expansion openings is limited to 4 inches (measured perpendicular to joint) on roadway bridges. The maximum width for pedestrian bridges is 5 inches. Detail cover plates on sidewalks, medians, and pedestrian bridges to cover the opening.

The standard strip seal device is a Type 4.0, which has a movement capacity of 4 inches. Bridges on a horizontal curve or with a skew over 30° must accommodate "racking" or transverse movements as well. For these situations use a Type 5.0 strip seal (5 inch capacity). Type 5.0 strip seals can also be used on pedestrian bridges.

For skews less than 30°:

- For expansion distance less than 150'-0", dimension opening at 2 inches at all temperatures.
- For expansion distance greater than or equal to 150'-0", dimension opening at $1^1/_2$ inches at 90°F. Also determine and show dimension at 45°F, checking that the opening at -30°F does not exceed 4 inches. If so, reduce accordingly at 45°F and 90°F.

For skews greater than or equal to 30°:

- Dimension opening at $1^1/_2$ inches at 90°F. Also determine and show dimension at 45°F, checking that the opening at -30°F does not exceed $3^1/_2$ inches. If so reduce accordingly at 45°F and 90°F.

14.2.3 Modular Expansion Joints

Modular expansion joints shall be used when dividing the bridge into segments will not reduce the joint expansion to less than 4 inches. Provide a joint setting schedule with modular joints that lists the opening the joint should have at different construction temperatures. Show joint openings for a temperature range from 45°F to 90°F in 15°F increments.

Note that conventional modular joints are one-directional units. Bridges with skews or horizontal curvature may require the use of “swivel” modular joints. These accommodate lateral movement as well as longitudinal movements.

14.2.4 Expansion Joint Detailing

Show the elevation at the top of the extrusion at crown break points, gutter lines, and the start and end of curved sections. Dimension the lengths for straight and curved portions of the expansion joint.

For skews up to 20°, detail expansion joint as straight from edge of deck to edge of deck. See Figure 14.2.4.1.

For skews greater than 20° and up to 50°, detail expansion joint opening as straight between the top inside edge of barriers. Kink the joint opening at top inside edge of barriers so it is normal with outside edge of deck. See Figure 14.2.4.1.

For skews greater than 50°, curve the expansion joint ends. Use a 2'-0" radius for new bridges. A minimum radius of 1'-6" is allowed on bridge rehabilitation/reconstruction projects. Terminate the curved section 6 inches from gutter line. See Figure 14.2.4.1.

Use bend-up details for all bridges with curbs or barriers. For bridges with skewed joints, verify that the bend-up details in the barrier do not project out of the front face of the rail.

Use snowplow protection for expansion joint devices (Bridge Details Part II Fig. 5-397.628) when joints are skewed greater than 15° and less than 50°.

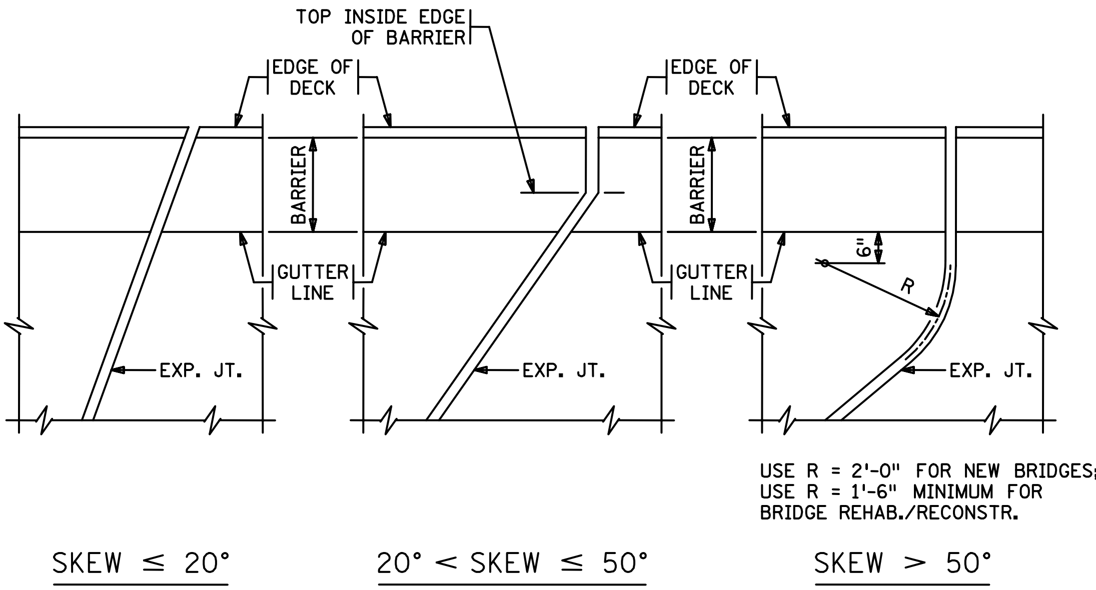


Figure 14.2.4.1
Expansion Joint Details

14.3 Bearings

The purpose of a bridge bearing is to transmit loads from the superstructure to the substructure while facilitating translation and rotation. Four types of bearings are typically used:

1) Expansion Bearing:
   - Transfers vertical load
   - Allows lateral movement in two directions
   - Allows longitudinal rotation
2) Guided Expansion Bearing:
   - Transfers vertical load and lateral load in one direction
   - Allows lateral movement in one direction
   - Allows longitudinal rotation
3) Limited Expansion Bearing:
   - Transfers vertical load and lateral load
   - Allows limited lateral movement in one direction
   - Allows longitudinal rotation
4) Fixed Bearing:
   - Transfers vertical load and lateral load
   - Resists lateral movement
   - Allows longitudinal rotation

[4.7.4.4]
[3.10.9]

In order to meet seismic requirements, bridges that are greater than 600'-0" in length and are placed on poor soils shall have the piers tied to the superstructure with fixed bearings or with limited displacement expansion bearings. Check the width of pier caps and abutment seat lengths to ensure the minimum support length requirements for Seismic Performance Category 1 are satisfied.

14.3.1 Loads and Movements

Design bearings for movements associated with a temperature range of 150°F (-30°F to 120°F) and a base construction temperature of 45°F.

Design elastomeric bearings for service loads and without Dynamic Load Allowance (IM).

[14.6.1]

Uplift at bearings is not permitted. Bearings shall be checked for uplift using the Strength I load combination with the minimum load factor for dead load.

14.3.2 Bearing Details

Identify the type of bearing used at each support location on the superstructure framing plan.

For bearing components, the length is measured parallel to the centerline of the beam and the width is measured perpendicular to the centerline of the beam.

Check the dimensions of the bearing. The bearing shall have adequate clearance to other bearings (pier locations), be consistent with the beam end details (pier and abutment locations), and have adequate clearance to vertical faces of supporting elements. For fixed bearings, provide a minimum of 1 inch clear from the face of the bearing seat to the bearing pad or masonry plate. For expansion bearings, increase this minimum dimension to 3 inches.

Locate bearing anchor rods to permit field drilling of holes and provide 2 inch minimum clearance to reinforcement in bridge seat.

Bearings typically provide a modest amount of lateral restraint. However, designers must consider whether or not additional restraint needs to be provided. Typically, this additional restraint is provided by reinforced concrete guide lugs in the substructure or slotted hole fixed bearing assemblies adjacent to the center beam at expansion piers and abutments for bridges on large skews or curves. A 1 inch clear dimension must be provided between elements for either of these restraint methods. Provide additional restraint for pedestrian bridges.

The service life of bearings is less than the anticipated service life of a bridge. To simplify future maintenance operations and potential replacement, provide adequate clearance for the installation of jacks (at least 6 inches) and also provide a jacking load path. The load path may involve properly designed and detailed diaphragms or a suitable superstructure element.

[14.8.2]

When the slope of steel beam or plate girder superstructures exceeds 3%, incorporate tapered sole plates into the bearings. Exceptions to this include bearings at integral abutments.

For proper load distribution, set masonry plates on a plain elastomeric pad, a grout bed, sheet lead or a seat that has been ground flat.

14.3.3 Elastomeric Bearings

Use of elastomeric bearings is preferred over other types of bearings. Fixed and expansion elastomeric bearing types are used most frequently. Mn/DOT's fixed elastomeric bearing consists of a plain elastomeric pad with a curved plate to allow rotation, and anchor rods for fixity. The expansion elastomeric bearing consists of a steel reinforced elastomeric pad with a curved plate to allow rotation. See Details B310, B311, B354, and B355.

14.3.3.1 Design

Use the tables found in Article 14.7 of this manual whenever possible for consistency and economy among bearing designs.

Elastomeric bearings are to be designed using Method A of the AASHTO LRFD Specifications.

Designs shall be based on an elastomer with a durometer hardness of 55. The minimum shear modulus (G) for this material is 115 psi. The maximum shear modulus is 165 psi.

The minimum size bearing pad for prestressed concrete beams is a 12" by 24" pad.

Except for special designs, use steel with a yield strength F_y equal to 36 ksi for all bearing assembly plates.

For Mn/DOT bridges with curved plate bearings, rotations need not be considered in the design.

For maximum compressive stress checks, use the minimum shear modulus value.

Holes are not permitted in elastomeric bearings.

14.3.3.1.1 Size and Stability

The shape factor, S, is limited to the following for plain pads and internal elastomeric laminates:

$$5.0 \leq S \leq 10.0$$

For fixed bearings use $^1/_2$ inch or $^3/_4$ inch thickness plain pads. For expansion bearings, use $^3/_8$ inch, $^1/_2$ inch, or $^3/_4$ inch thickness internal laminates with $^1/_8$ inch thick steel reinforcing plates and $^1/_4$ thick cover layers.

Minimum dimensions for elastomeric bearings shall be rounded to the nearest 2 inch increment. For prestressed beams the minimum length (A) is 12 inches and the minimum width (B) is 24 inches. For steel beams, the minimum length (A) is 8 inches. The width (B) shall not be less than the bottom flange width and not more than 2 inches greater than the bottom flange width for steel beams.

Based on the past performance of elastomeric bearings, Mn/DOT places a limit on the plan aspect ratio of a bearing. The length (A) is limited by the following equation:

$$B \leq 2.5 \cdot A$$

[14.7.6.3.6]

Additionally, the total elastomer thickness for the bearing (h_{rt}) must be no more than $^1/_3$ of the bearing pad length and width:

$$h_{rt} \leq \frac{A}{3} \text{ and } \frac{B}{3}$$

14.3.3.2 Fixed Bearings

Design fixed elastomeric bearings for a maximum compressive stress of 0.880 ksi. This includes a 10% increase for fixity.

Provide transverse fixity for $^2/_3$ of beams at fixed piers or fixed abutments for widths along skew greater than 70'-0".

14.3.3.3 Expansion Bearings

Expansion elastomeric bearings are reinforced and shall be designed for a maximum compressive stress of 1.00 ksi or less.

[14.7.6.3.4]
[Table 3.4.1-1]

The total height or thickness of elastomer (h_{rt}) must be greater than twice the maximum design movement. The LRFD Specification lists a load factor of 1.2 to be used for thermal movement calculations. However, based on past performance of bearings, use a load factor of 1.3 with half the design temperature range (75°F) when computing movement Δ_s for the height check.

14.3.3.3.1 Minimum Compressive Load
[14.7.6.4]

LRFD 14.7.6.4 requires that elastomeric bearings be secured against horizontal movement when $^1/_5$ of the minimum vertical load is less than the factored horizontal shear force H_u generated in the bearing due to temperature movement.

[14.6.3.1]

$$H_u = G \cdot A_{pad} \cdot \frac{\Delta_u}{h_{rt}}$$

Therefore, $\frac{P_{min}}{5} \geq G \cdot A_{pad} \cdot \frac{\Delta_u}{h_{rt}}$

For the minimum compressive load check, use the maximum shear modulus value and a load factor of 1.0 with half the design temperature range (75°F) to calculate the horizontal force at the bearing. The LRFD Specification lists a load factor of 1.2 for this calculation. However, based on past performance of bearings, use a load factor of 1.0. Also, we know that $A_{pad} = A \cdot B$.

Then the minimum required compressive load is:

$$\text{Req'd. } P_{min} \geq 5 \cdot 0.165 \cdot A \cdot B \cdot \frac{1.0 \cdot \Delta_u}{h_{rt}}$$

which, becomes Req'd. $P_{min} \geq \frac{0.825 \cdot A \cdot B \cdot \Delta_u}{h_{rt}}$

If the check is not satisfied, revise the number and/or thickness of the laminates as needed. If the requirement still cannot be met, the standard curved plate expansion bearing assemblies (B318 and B355) contain knock-off weld studs welded to the bearing plate. The studs can be considered as a mechanism that secures the pads.

14.3.4 Pot Bearings

Use pot or disk bearings where the loads are too high or the movements and rotations are too large to be readily accommodated with elastomeric bearings. See Details B312, B313, B314, B315, and B316.

To reduce the possibility of generating large lateral forces in wide bridges supported on pot bearings, do not use guided or fixed bearings for beam lines outside of the center 45 feet of the bridge (distance measured along the substructure).

All applicable design loads and movements for pot bearings must be provided in the contract documents. Due to a variety of preferences among pot bearing fabricators, explicit details are not provided in the plans. Instead, the fabricator determines the sizes of all of the bearing components, from the masonry plate to the sole plate. As a guide, the following equation may be used to estimate the height (rounded to the nearest $^1/_4$ inch) of the assembly for design:

$$\text{Height}\,(\text{inches}) = 6.5 + \text{Load}\,(\text{kips})\,/\,400$$

Include the following note on the appropriate substructure sheets when pot bearings are used:

Final construction elevations for bridge seats shall be determined based on the actual height of pot bearing assemblies furnished by the Contractor. Any required adjustment of seat elevations shall be made by the Contractor at no cost to Mn/DOT.

Fixed pot bearings provide rotation, but no movement.

Guided expansion pot bearings allow for free movement in one direction and provide rotational capacity. However, movement perpendicular to the free movement direction is restrained. For curved bridges, assume the free movement direction to be along a chord connecting the ends of the beam. Guide bars must resist a minimum of 10% of the vertical load applied to the bearing.

Expansion pot bearings provide for rotation and unguided movement in all horizontal directions.

For computation of movement for design of pot bearings, use a load factor of 1.2.

14.3.5 Other Types of Bearings

Steel Bearings

This type of bearing does not contain elastomeric components to accommodate horizontal movement. Rather, horizontal movement takes place at the interface of a machined masonry plate and a lubricated bronze plate. Bridge Details Part I B351, B352, and B353 detail fixed, expansion, and guided expansion steel bearings respectively. They have all been archived, but can be retrieved if necessary for a repair plan. Note that these bearings are for repair and replacement only and are not for new construction.

Modify the standard bearings as necessary to accommodate unusually wide flanges or to provide movement capacities greater than those permitted with the standard details.

Check the clearances on the guide bars for curved bridges.

To reduce the possibility of generating large lateral forces in wide bridges supported on steel bearings, do not use guided or fixed bearings for beam lines outside of the center 45'-0" of the bridge (distance measured along the substructure).

Bearings for Railroad Bridges

Due to the extremely large loads associated with railroad bridges, spherical bearings, rocker bearings or pot bearings are normally required. Rocker bearings may be considered for other applications where there is a combination of large load and large movement.

14.4 Curved Plate Design

Width

For prestressed concrete beams, set the width (H) equal to the bearing pad width (B) plus 2 inches. The width may change slightly (2 inches to 4 inches) for special designs. For steel beams, set the width equal to the bearing pad width (B).

Thickness

Use allowable stress design for curved plate thickness determination. Design for maximum allowable bending stress given in Standard Specifications Table 10.32.1A:

$$\text{Allowable } f_s = 0.55 \cdot F_y$$

The all around weld, together with the friction between plates, causes the curved plate and bearing plate to act compositely. Therefore, the thickness for design can be considered to include the curved plate thickness plus the bearing plate thickness. The minimum thickness for curved plates is $1^1/_4$ inches. When greater thickness is required, increase plate thickness in $^1/_4$ inch increments.

Length

The minimum length (G) for the curved plate is $4^1/_2$ inches. The next permitted length is 6 inches, after which the length may be increased by increments of 2 inches up to a maximum of 12 inches. If the bearing plate thickness exceeds 2 inches, increase the length of the curved plate to reduce the length of the cantilever for the bearing plate design. Increase the curved plate length until the bearing plate thickness alone and the composite plate thickness are approximately equal.

Radius

The radius of curved plates is to be no less than 16 inches. Check contact stresses to make sure that an adequate radius is provided. Based on past satisfactory performance of curved plate bearing assemblies, use LRFD Equations C14.7.1.4-1 and C14.7.1.4-2 for determination of curved plate radius. If the resulting radius exceeds 24 inches, a special design must be completed using LRFD Equation 14.7.1.4-1 and steel with a yield strength F_y equal to 50 ksi.

14.5 Bearing Plate Design

Width

For prestressed concrete beams, set the width (E) equal to the curved plate width (H) plus 1 inch for expansion bearings. For fixed bearings, set the width (E) equal to the beam bottom flange width plus 8 inches. For steel beams, set the width (E) equal to the curved plate width (B) plus 2 inches for expansion bearings and plus 10 inches for fixed bearings.

Length

Set the length of the bearing plate (C) 2 inches larger than the bearing pad length (A).

Thickness

Use allowable stress design for bearing plate thickness determination. Design for maximum allowable bending stress given in Standard Specifications Table 10.32.1A:

$$\text{Allowable } f_s = 0.55 \cdot F_y$$

The minimum thickness for bearing plates is $1^1/_2$ inches. When greater thickness is required, increase plate thickness in $^1/_4$ inch increments.

14.6 Sole Plate Design (Steel Beams)

Width

Set the width of the sole plate 2 inches larger than the curved plate width (B). The width cannot be equal to the beam flange width because of the fillet weld used to attach the sole plate to the flange. Increase the sole plate width by 1 inch if this occurs.

Length

The minimum length is 6 inches. Also, the length shall not be less than the curved plate length (G).

Thickness

Use allowable stress design for sole plate thickness determination. Design for maximum allowable bending stress given in Standard Specifications Table 10.32.1A:

$$\text{Allowable } f_s = 0.55 \cdot F_y$$

The minimum sole plate thickness is $1^1/_4$ inches. When greater thickness is required, increase plate thickness in $^1/_8$ inch increments.

14.7 Tables

The following tables contain standard curved plate bearing designs for prestressed concrete and steel beam superstructures based on the guidance given in this manual.

Table 14.7.1	Fixed Curved Plate Bearing Assembly for Prestressed Concrete I-Beams (B310)
Table 14.7.2	Expansion Curved Plate Bearing Assembly for Prestressed Concrete I-Beams (B311)
Table 14.7.3	Fixed Curved Plate Bearing Assembly for Steel Beams (B354)
Table 14.7.4	Expansion Curved Plate Bearing Assembly for Steel Beams (B355)
Table 14.7.5	Elastomeric Bearing Pad thickness for Expansion Bearings

The tables should be used whenever possible to increase consistency and economy among bearing designs. When actual calculated loads are greater than the maximum loads given in the table, two options are available to designers:

1) Complete a special elastomeric bearing design. Use LRFD Equation 14.7.1.4-1 for determination of curved plate radius. Also, use steel with a yield strength equal to 50 ksi for the curved plate. Modify the B-Detail by specifying that the curved plate shall comply with Mn/DOT Spec. 3310.
2) Use a pot bearing.

Table 14.7.1
Fixed Curved Plate Bearing Assembly for Prestressed Concrete I-Beams (B310)

Maximum DL + LL (kips)	Bearing Pad Size (in)		Plain Pad Thickness (in)	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Minimum Radius (in)
	A	B			C	E	F	G	H	J	
253	12	24	1/2	8.0	14	①	1 1/2	4 1/2	26	1 1/4	16
295	14	↓	↓	8.8	16	↓	1 3/4	↓	↓	↓	↓
337	16	↓	↓	9.6	18	↓	2	6	↓	↓	↓
380	18	↓	3/4	6.9	20	↓	2 1/4	↓	↓	↓	↓
422	20	↓	↓	7.3	22	↓	↓	8	↓	↓	20

① 34" for all "M" series I-beams
38" for all "MN" series I-beams.

Table 14.7.2
Expansion Curved Plate Bearing Assembly for Prestressed Concrete I-Beams (B311)

Maximum DL + LL (kips)	Bearing Pad Size (in)		Laminate Thickness (in)	Max. Number of Laminates ①	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Minimum Radius (in)
	A	B				C	E	F	G	H	J	
264	12	24	1/2	7	8.0	14	27	1 1/2	4 1/2	26	1 1/4	16
336	14	↓	↓	8	8.8	16	↓	2	↓	↓	↓	↓
384	16	↓	↓	9	9.6	18	↓	↓	6	↓	↓	↓
401	20	↓	3/4	8	7.3	22	↓	2 1/4	8	↓	↓	18

① See Table 14.7.5 for determination of required number of laminates.

Table 14.7.3 – Fixed Curved Plate Bearing Assembly for Steel Beams (B354)

Beam Flange Min. Width (in)	Beam Flange Max. Width (in)	Max. DL + LL (kips)	Bearing Pad Size (in)		Plain Pad Thick. (in)	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Min. Radius (in)	Sole Plate Size (in)		
			A	B			C	E	F	G	B	H		Length	Width	Thick.
12	14	98	8	14	$^1/_2$	5.1	10	24	$1^1/_2$	$4^1/_2$	14	$1^1/_4$	16	6	16	$1^1/_4$
↓	↓	123	10	↓	↓	5.8	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	147	12	↓	↓	6.5	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	172	14	↓	↓	7.0	16	↓	$1^3/_4$	↓	↓	↓	↓	↓	↓	↓
14	16	112	8	16	$^1/_2$	5.3	10	26	$1^1/_2$	$4^1/_2$	16	$1^1/_4$	16	6	18	$1^1/_4$
↓	↓	140	10	↓	↓	6.2	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	168	12	↓	↓	6.9	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	197	14	↓	↓	7.5	16	↓	$1^3/_4$	↓	↓	↓	↓	↓	↓	↓
↓	↓	225	16	↓	↓	8.0	18	↓	2	6	↓	↓	17	↓	↓	↓
16	18	126	8	18	$^1/_2$	5.5	10	28	$1^1/_2$	$4^1/_2$	18	$1^1/_4$	16	6	20	$1^1/_4$
↓	↓	158	10	↓	↓	6.4	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	190	12	↓	↓	7.2	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	221	14	↓	↓	7.9	16	↓	$1^3/_4$	↓	↓	↓	↓	↓	↓	↓
↓	↓	253	16	↓	↓	8.5	18	↓	2	6	↓	↓	↓	↓	↓	↓
↓	↓	285	18	↓	↓	9.0	20	↓	$2^1/_4$	↓	↓	↓	19	↓	↓	↓
18	20	140	8	20	$^1/_2$	5.7	10	30	$1^1/_2$	$4^1/_2$	20	$1^1/_4$	16	6	22	$1^1/_4$
↓	↓	176	10	↓	↓	6.7	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	211	12	↓	↓	7.5	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	246	14	↓	↓	8.2	16	↓	$1^3/_4$	↓	↓	↓	↓	↓	↓	↓
↓	↓	281	16	↓	↓	8.9	18	↓	2	6	↓	↓	↓	↓	↓	↓
↓	↓	316	18	↓	↓	9.5	20	↓	$2^1/_4$	↓	↓	↓	18	↓	↓	↓
↓	↓	352	20	↓	↓	10.0	22	↓	↓	8	↓	↓	22	8	↓	↓

Table 14.7.3 *(Cont.)* **– Fixed Curved Plate Bearing Assembly for Steel Beams (B354)**

Beam Flange Min. Width (in)	Beam Flange Max. Width (in)	Max. DL + LL (kips)	Bearing Pad Size (in)		Plain Pad Thick. (in)	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Min. Radius (in)	Sole Plate Size (in)		
			A	B			C	E	F	G	B	H		Length	Width	Thick.
20	22	193	10	22	$\frac{1}{2}$	6.9	12	32	$1\frac{1}{2}$	$4\frac{1}{2}$	22	$1\frac{1}{4}$	16	6	24	$1\frac{1}{4}$
↓	↓	232	12	↓	↓	7.8	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	271	14	↓	↓	8.6	16	↓	$1\frac{3}{4}$	↓	↓	↓	↓	↓	↓	↓
↓	↓	309	16	↓	↓	9.3	18	↓	2	6	↓	↓	↓	↓	↓	↓
↓	↓	348	18	↓	↓	9.9	20	↓	$2\frac{1}{4}$	↓	↓	↓	17	↓	↓	↓
↓	↓	387	20	↓	$\frac{3}{4}$	7.0	22	↓	↓	8	↓	↓	21	8	↓	↓
↓	↓	418	22	↓	↓	7.3	24	↓	$2\frac{3}{4}$	↓	↓	↓	24	↓	↓	↓
22	24	211	10	24	$\frac{1}{2}$	7.1	12	34	$1\frac{1}{2}$	$4\frac{1}{2}$	24	$1\frac{1}{4}$	16	6	26	$1\frac{1}{4}$
↓	↓	253	12	↓	↓	8.0	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	295	14	↓	↓	8.8	16	↓	$1\frac{3}{4}$	↓	↓	↓	↓	↓	↓	↓
↓	↓	337	16	↓	↓	9.6	18	↓	2	6	↓	↓	↓	↓	↓	↓
↓	↓	380	18	↓	$\frac{3}{4}$	6.9	20	↓	$2\frac{1}{4}$	↓	↓	↓	↓	↓	↓	↓
↓	↓	422	20	↓	↓	7.3	22	↓	$2\frac{3}{4}$	↓	↓	↓	20	↓	↓	↓
↓	↓	464	22	↓	↓	7.7	24	↓	↓	8	↓	↓	24	8	↓	↓
24	26	228	10	26	$\frac{3}{8}$	9.6	12	36	$1\frac{1}{2}$	$4\frac{1}{2}$	26	$1\frac{1}{4}$	16	6	28	$1\frac{1}{4}$
↓	↓	274	12	↓	$\frac{1}{2}$	8.2	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	320	14	↓	↓	9.1	16	↓	$1\frac{3}{4}$	↓	↓	↓	↓	↓	↓	↓
↓	↓	366	16	↓	↓	9.9	18	↓	2	6	↓	↓	↓	↓	↓	↓
↓	↓	411	18	↓	$\frac{3}{4}$	7.1	20	↓	$2\frac{1}{4}$	↓	↓	↓	↓	↓	↓	↓
↓	↓	457	20	↓	↓	7.5	22	↓	↓	8	↓	↓	19	8	↓	↓
↓	↓	503	22	↓	↓	7.9	24	↓	$2\frac{3}{4}$	↓	↓	↓	23	↓	↓	↓

Table 14.7.4 – Expansion Curved Plate Bearing Assembly for Steel Beams (B355)

Beam Flange Min. Width (in)	Beam Flange Max. Width (in)	Max. DL + LL (kips)	Bearing Pad Size (in)		Laminate Thick. (in)	Max. Number of Lamin-ates ①	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Min. Radius (in)	Sole Plate Size (in)		
			A	B				C	E	F	G	B	H		Length	Length	Thick.
12	14	87	8	14	$^3/_8$	5	6.8	10	16	$1^1/_2$	$4^1/_2$	14	$1^1/_4$	16	6	16	$1^1/_4$
↓	↓	125	10	↓	↓	7	7.8	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	166	12	↓	↓	9	8.6	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	196	14	↓	↓	11	9.3	16	↓	2	↓	↓	↓	18	↓	↓	↓
14	16	104	8	16	$^3/_8$	5	7.1	10	18	$1^1/_2$	$4^1/_2$	16	$1^1/_4$	16	6	18	$1^1/_4$
↓	↓	150	10	↓	↓	7	8.2	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	192	12	↓	↓	9	9.1	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	224	14	↓	↓	11	10.0	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	235	16	↓	$^1/_2$	9	8.0	18	↓	↓	6	↓	↓	18	↓	↓	↓
16	18	122	8	18	$^3/_8$	5	7.4	10	20	$1^1/_2$	$4^1/_2$	18	$1^1/_4$	16	6	20	$1^1/_4$
↓	↓	177	10	↓	↓	7	8.6	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	216	12	↓	↓	9	9.6	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	228	14	↓	$^1/_2$	8	7.9	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	280	16	↓	↓	9	8.5	18	↓	↓	6	↓	↓	19	↓	↓	↓
↓	↓	322	18	↓	↓	11	9.0	20	↓	$2^1/_2$	↓	↓	↓	24	↓	↓	↓
18	20	140	8	20	$^3/_8$	5	7.6	10	22	$1^1/_2$	$4^1/_2$	20	$1^1/_4$	16	6	22	$1^1/_4$
↓	↓	200	10	↓	↓	7	8.9	12	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	240	12	↓	↓	9	10.0	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	265	14	↓	$^1/_2$	8	8.2	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	320	16	↓	↓	9	8.9	18	↓	↓	6	↓	↓	18	↓	↓	↓
↓	↓	360	18	↓	↓	11	9.5	20	↓	$2^1/_2$	↓	↓	↓	23	↓	↓	↓

① See Table 14.7.5 for determination of required number of laminates.

Table 14.7.4 *(Cont.)* **– Expansion Curved Plate Bearing Assembly for Steel Beams (B355)**

Beam Flange Min. Width (in)	Beam Flange Max. Width (in)	Max. DL + LL (kips)	Bearing Pad Size (in)		Laminate Thick. (in)	Max. Number of Laminates ①	Shape Factor	Bearing Plate Size (in)			Curved Plate Size (in)			Min. Radius (in)	Sole Plate Size (in)		
			A	B				C	E	F	G	B	H		Length	Width	Thick.
20	22	220	10	22	$^3/_8$	7	9.2	12	24	$1^1/_2$	$4^1/_2$	22	$1^1/_4$	16	6	24	$1^1/_4$
↓	↓	235	12	↓	$^1/_2$	↓	7.8	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	303	14	↓	↓	8	8.6	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	352	16	↓	↓	9	9.3	18	↓	↓	6	↓	↓	17	↓	↓	↓
↓	↓	396	18	↓	↓	11	9.9	20	↓	$2^1/_2$	↓	↓	↓	22	↓	↓	↓
↓	↓	408	22	↓	↓	9	7.3	24	↓	$2^3/_4$	↓	↓	↓	23	↓	↓	↓
22	24	240	10	24	$^3/_8$	7	9.4	12	26	$1^1/_2$	$4^1/_2$	24	$1^1/_4$	16	6	26	$1^1/_4$
↓	↓	264	12	↓	$^1/_2$	↓	8.0	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	336	14	↓	↓	8	8.8	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	384	16	↓	↓	9	9.6	18	↓	↓	6	↓	↓	17	↓	↓	↓
↓	↓	401	20	↓	↓	8	7.3	22	↓	$2^1/_4$	8	↓	↓	18	8	↓	↓
↓	↓	464	22	↓	↓	9	7.7	24	↓	$2^3/_4$	↓	↓	↓	24	↓	↓	↓
24	26	260	10	26	$^3/_8$	7	9.6	12	28	$1^1/_2$	$4^1/_2$	26	$1^1/_4$	16	6	28	$1^1/_4$
↓	↓	294	12	↓	$^1/_2$	↓	8.2	14	↓	↓	↓	↓	↓	↓	↓	↓	↓
↓	↓	364	14	↓	↓	8	9.1	16	↓	2	↓	↓	↓	↓	↓	↓	↓
↓	↓	416	16	↓	↓	9	9.9	18	↓	↓	6	↓	↓	↓	↓	↓	↓
↓	↓	450	20	↓	↓	8	7.5	22	↓	$2^1/_4$	8	↓	↓	19	8	↓	↓
↓	↓	513	22	↓	↓	9	7.9	24	↓	$2^3/_4$	↓	↓	↓	24	↓	↓	↓

① See Table 14.7.5 for determination of required number of laminates.

Table 14.7.5
Elastomeric Bearing Pad Thickness for Expansion Bearings ①

	D (in) ②	Number of Laminates	Total Elastomer Thickness, h_{rt} (in) ②	Maximum Movement (in) ③
$^3/_8$" Interior Laminates	$1^1/_8$	1	$^7/_8$	$^7/_{16}$
	$1^5/_8$	2	$1^1/_4$	$^5/_8$
	$2^1/_8$	3	$1^5/_8$	$^{13}/_{16}$
	$2^5/_8$	4	2	1
	$3^1/_8$	5	$2^3/_8$	$1^3/_{16}$
	$3^5/_8$	6	$2^3/_4$	$1^3/_8$
	$4^1/_8$	7	$3^1/_8$	$1^9/_{16}$
	$4^5/_8$	8	$3^1/_2$	$1^3/_4$
	$5^1/_8$	9	$3^7/_8$	$1^{15}/_{16}$
	$5^5/_8$	10	$4^1/_4$	$2^1/_8$
	$6^1/_8$	11	$4^5/_8$	$2^5/_{16}$
$^1/_2$" Interior Laminates	$1^1/_4$	1	1	$^1/_2$
	$1^7/_8$	2	$1^1/_2$	$^3/_4$
	$2^1/_2$	3	2	1
	$3^1/_8$	4	$2^1/_2$	$1^1/_4$
	$3^3/_4$	5	3	$1^1/_2$
	$4^3/_8$	6	$3^1/_2$	$1^3/_4$
	5	7	4	2
	$5^5/_8$	8	$4^1/_2$	$2^1/_4$
	$6^1/_4$	9	5	$2^1/_2$
	$6^7/_8$	10	$5^1/_2$	$2^3/_4$
	$7^1/_2$	11	6	3
$^3/_4$" Interior Laminates	$1^1/_2$	1	$1^1/_4$	$^5/_8$
	$2^3/_8$	2	2	1
	$3^1/_4$	3	$2^3/_4$	$1^3/_8$
	$4^1/_8$	4	$3^1/_2$	$1^3/_4$
	5	5	$4^1/_4$	$2^1/_8$
	$5^7/_8$	6	5	$2^1/_2$
	$6^3/_4$	7	$5^3/_4$	$2^7/_8$
	$7^5/_8$	8	$6^1/_2$	$3^1/_4$
	$8^1/_2$	9	$7^1/_4$	$3^5/_8$

① Table is based on requirements of AASHTO LRFD Bridge Design Specifications Section 14.7.6.3.4: $h_{rt} \geq 2\Delta_s$. Engineer must also check that the minimum compressive load requirement (discussed in Article 14.3.3.1.2) is satisfied. Specifically:

$$P_{min} \geq 0.825 \cdot \left(\frac{\Delta_u}{h_{rt}}\right) \cdot A \cdot B$$

where P_{min} is the minimum factored load $(0.9 \cdot DC + 1.75 \cdot LL_{min})$ and Δ_u is the movement of the bearing pad from the undeformed state using a 75°F temperature change with a 1.0 load factor.

② h_{rt} includes interior laminates plus $^1/_4$" cover layers. Pad thickness "D" includes h_{rt} and $^1/_8$" steel reinforcement plates.

③ Maximum movement is the movement of the bearing pad from the undeformed state to the point of maximum deformation. Use a 75°F temperature change with a 1.3 load factor for calculation of maximum movement.

14.8 Design Examples

Two design examples follow. The first is a fixed elastomeric bearing. The second is an expansion elastomeric bearing.

14.8.1 Fixed Elastomeric Bearing Design Example

This example is a continuation of the prestressed girder design example found in Section 5.7.2. The bearing used in this example is based on Bridge Details Part I B310. The elastomeric bearing pad is designed using Method A (LRFD 14.7.6). Figure 14.8.1.1 shows the bearing components. The length, width, and thickness labels used for the different elements of the bearing are consistent with Detail B310. See Figure 14.8.1.4.

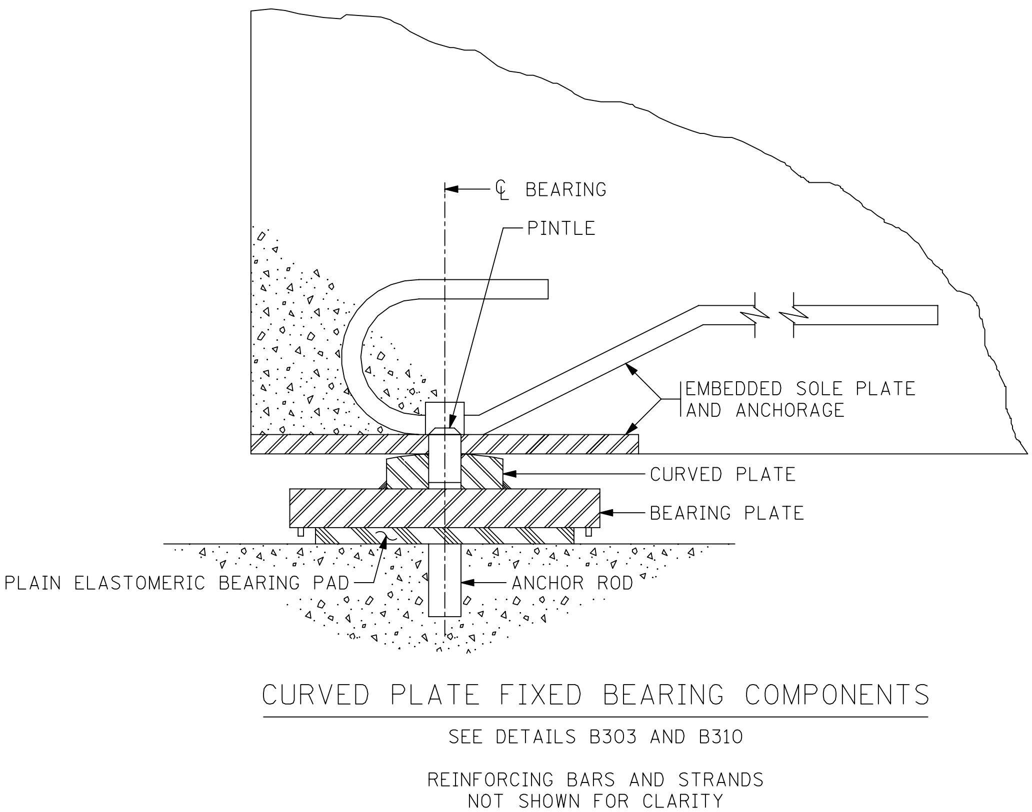


Figure 14.8.1.1

With the maximum reaction calculated, the bearing design should be selected from the standard tables found in Section 14.7. If a standard design will not work due to unusual loads or geometric constraints, a custom design will be required.

This example will outline the procedure to custom design a fixed elastomeric bearing. First, design the elastomeric pad. Next determine the steel plate requirements for the rest of the bearing assembly.

A. Design Elastomeric Bearing Pad [14.7.6]

Unfactored reactions from Table 5.7.2.4 of the prestressed beam design example are used as the design loads for this example. They are:

Dead Load $= P_{dl} = 146$ kips

Maximum Live Load $= P_{llmax} = 37 + \dfrac{79}{1.33}$

$= 96.4$ kips (Does not include dynamic load allowance; IM)

Minimum Live Load $= P_{llmin} = 0$ kips

Maximum $P_s = P_{dl} + P_{llmax} = 242.4$ kips at the service limit state

Minimum $P_u = 0.9 \cdot P_{dl} + 1.75 \cdot P_{llmin} = 0.9 \cdot 146 + 1.75 \cdot 0 = 131.4$ kips at the strength limit state. Therefore, there is no uplift.

For prestressed beams, the minimum bearing pad width (B) is 24 inches.

[14.7.6.3.2]

The allowable compressive stress for plain pads is 0.80 ksi. The allowable is increased by 10% for a fixed bearing because shear deformation is prevented.

Allowable $\sigma_s = 1.10 \cdot 0.80 = 0.88$ ksi

Using the vertical load, the allowable compressive stress, and width (B) of the bearing pad, a trial length (A) can be found.

$$A = \frac{P_s}{0.88 \cdot B} = \frac{242.4}{0.88 \cdot 24} = 11.48 \text{ in}$$

Try a bearing pad with the following dimensions:

$A = 12$ in, $B = 24$ in, and thickness $h_{rt} = 0.50$ in

Then the maximum service load stress under total load is:

Actual $\sigma_s = \dfrac{P_s}{A \cdot B} = \dfrac{242.4}{12 \cdot 24} = 0.842 \text{ ksi} < 0.880 \text{ ksi}$ <u>OK</u>

There are two geometric checks on the bearing pad to ensure that it has good proportions. First, in plan, the length of the long side can be no more the 2.5 times the length of the short side. Second, the height of the elastomeric portion can be no more than $^{1}/_{3}$ the length of the short side of the pad.

$$2.5 \cdot A = 2.5 \cdot 12 = 30 \text{ in} \geq 24 \text{ in} \qquad \underline{OK}$$

[14.7.6.3.6]

$$\frac{A}{3} = \frac{12}{3} = 4 \text{ in} > 0.50 \text{ in} = h_{rt} \qquad \underline{OK}$$

Mn/DOT specifies a range of permissible values for the shape factor (S).

$$5.0 \leq S \leq 10.0$$

[14.7.5.1]

$$\text{Actual } S = \frac{A \cdot B}{2 \cdot (A + B) \cdot h_{rt}} = \frac{12 \cdot 24}{2 \cdot (12 + 24) \cdot 0.50} = 8.0$$

$$5.0 \leq S = 8.0 \leq 10.0 \qquad \underline{OK}$$

B. Curved Plate Design

Set the curved plate width 2 inches wider than the bearing pad.

$$H = B + 2 = 24 + 2 = 26 \text{ in}$$

The all around weld, together with the friction between plates, causes the curved plate and bearing plate to act compositely. Therefore, the thickness for design can be considered to include the curved plate thickness plus the bearing plate thickness.

Begin by checking the thickness for a curved composite plate with a length of 4.5 inches. If the thickness of the bearing plate is more than 2 inches, increase the length of the curved plate until the bearing plate thickness and composite plate thickness are approximately equal. After 4.5 inches, try 6 inches. If 6 inches does not work, increase length by increments of 2 inches thereafter.

$$\text{Curved Plate length} = G = 4.5 \text{ in}$$

The radius of the contact surface is the first parameter to determine for the curved plate. The radius of the curved plate is a function of the yield strength of the steel and the load intensity.

The contact length of the sole plate with the curved plate is equal to the sole plate width minus the chamfers at each side, the pintles, and the associated bevels around each of the pintles. See Figure 14.8.1.2.

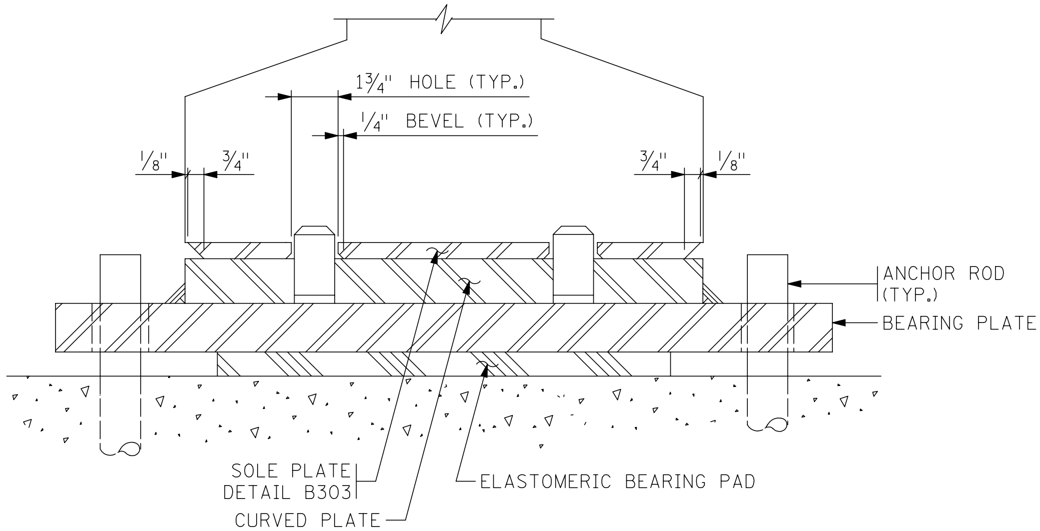


Figure 14.8.1.2

Contact length L_{sp} is equal to

$$L_{sp} = 26 - 2 \cdot (0.125) - 2 \cdot (0.75) - 2 \cdot (2.25) = 19.75 \text{ in}$$

[14.7.1.4]

Based on past satisfactory performance of curved plate bearing assemblies, the minimum radius permitted is determined with LRFD Equation C14.7.1.4-1 and C14.7.1.4-2. Start by assuming radius is 12.5 inches or less, so use the first equation. Rearranging the equation to solve for d, and dividing by 2 (to compute a radius) results in the following:

$$R_{min} = \frac{10 \cdot p}{0.6 \cdot (F_y - 13)} = \frac{10 \cdot \left(\frac{P_s}{L_{sp}}\right)}{0.6 \cdot (F_y - 13)} = \frac{10 \cdot \left(\frac{242.4}{19.75}\right)}{0.6 \cdot (36 - 13)} = 8.9 \text{ in} < 12.5 \text{ in}$$

Assumption was correct.

The radius of curved plates is to be no less than 16 inches. Therefore, specify the minimum radius for the curved plate to be 16 inches.

The required thickness of the curved composite plate is based on a simple model in which a uniform pressure is applied to the bottom of the plate and the reaction is a line load. See Figure 14.8.1.3.

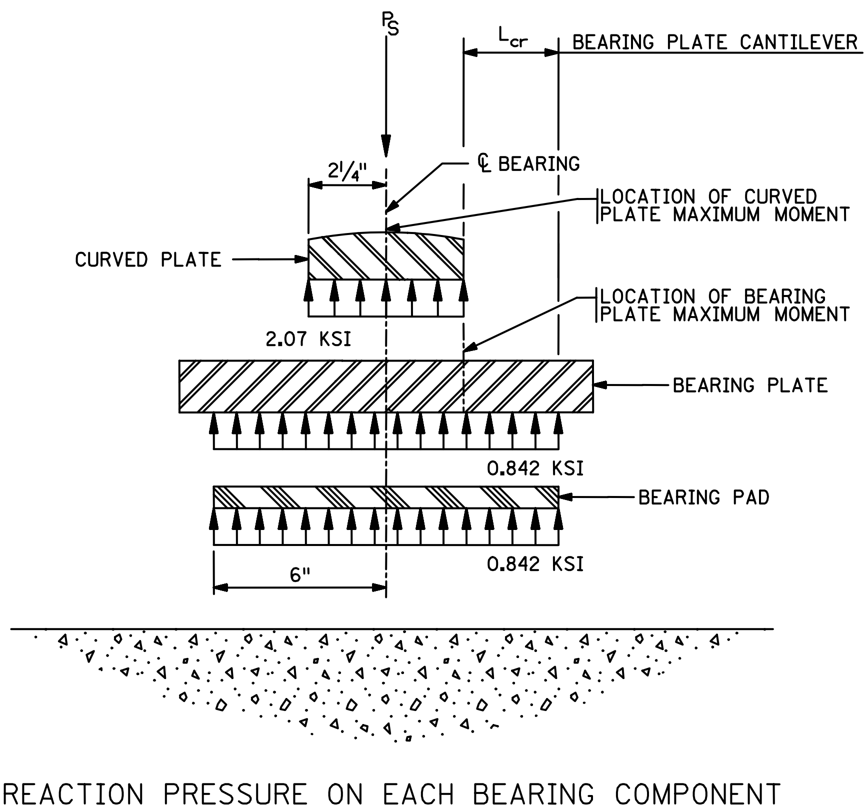


Figure 14.8.1.3

Pressure on the composite plate is:

$$\sigma_{cp} = \frac{P_s}{G \cdot H} = \frac{242.4}{4.5 \cdot 26} = 2.07 \text{ ksi}$$

Maximum moment on the composite plate on a 1 inch wide strip is:

$$M_{cp} = \sigma_{cp} \cdot \frac{G}{2} \cdot \frac{G}{4} = 2.07 \cdot \frac{4.5}{2} \cdot \frac{4.5}{4} = 5.24 \text{ kip-in/in width}$$

The required curved composite plate thickness is determined by finding the thickness of plate that has sufficient section modulus to carry the moment. (i.e., $\sigma = M / S$, rearranged to $S = M / \sigma$). Past designs based on allowable stress have performed well. Size the plate with the maximum allowable bending stress permitted in the Standard Specifications [Table 10.32.1A].

$$f_s = 0.55 \cdot F_y = 0.55 \cdot 36 = 19.8 \text{ ksi}$$

The required section modulus is:

$$S_{req} = \frac{M_{cp}}{f_s} = \frac{5.24}{19.8} = 0.265 \text{ in}^3$$

Solving for thickness, J

$$\text{Minimum } J = \sqrt{6 \cdot S_{req}} = 1.26 \text{ in} \approx 1^1/_4 \text{ in}$$

This is the same as the standard curved plate thickness of $1^1/_4$ inches, so in this case composite action is not needed.

Use curved plate with thickness $J = 1^1/_4$ inches.

C. Bearing Plate Design

Per Detail B310, the length (C) is set at 2 inches longer than the pad length. This provides room for the keeper studs to be attached to the bottom of the bearing plate. The width (E) is set 8 inches greater than the beam bottom flange width. This provides room on each side for the anchor rods.

$$E = b_f + 8 = 26 + 8 = 34 \text{ in}$$

$$C = A + 2 = 12 + 2 = 14 \text{ in}$$

The bearing plate is assumed to act as a cantilever (See Figure 14.8.1.3) that carries the bearing pad pressure back to the curved plate. The cantilever length is half the difference in length between the bearing pad and the curved plate.

$$L_{cr} = \frac{A}{2} - \frac{G}{2} = \frac{12}{2} - \frac{4.5}{2} = 3.75 \text{ in}$$

$$M_{bp} = \sigma_s \cdot \frac{{L_{cr}}^2}{2} = 0.842 \cdot \frac{3.75^2}{2} = 5.92 \text{ kip-in/in width}$$

Use the same procedure that was used to arrive at a curved plate thickness. Note that the minimum thickness for bearing plates is $1^1/_2$ inches.

$$S_{req} = \frac{M_{bp}}{f_s} = \frac{5.92}{19.8} = 0.299 \ \text{in}^3$$

$$F_{req} = \sqrt{6 \cdot S_{req}} = \sqrt{6 \cdot 0.299} = 1.34 \ \text{in}$$

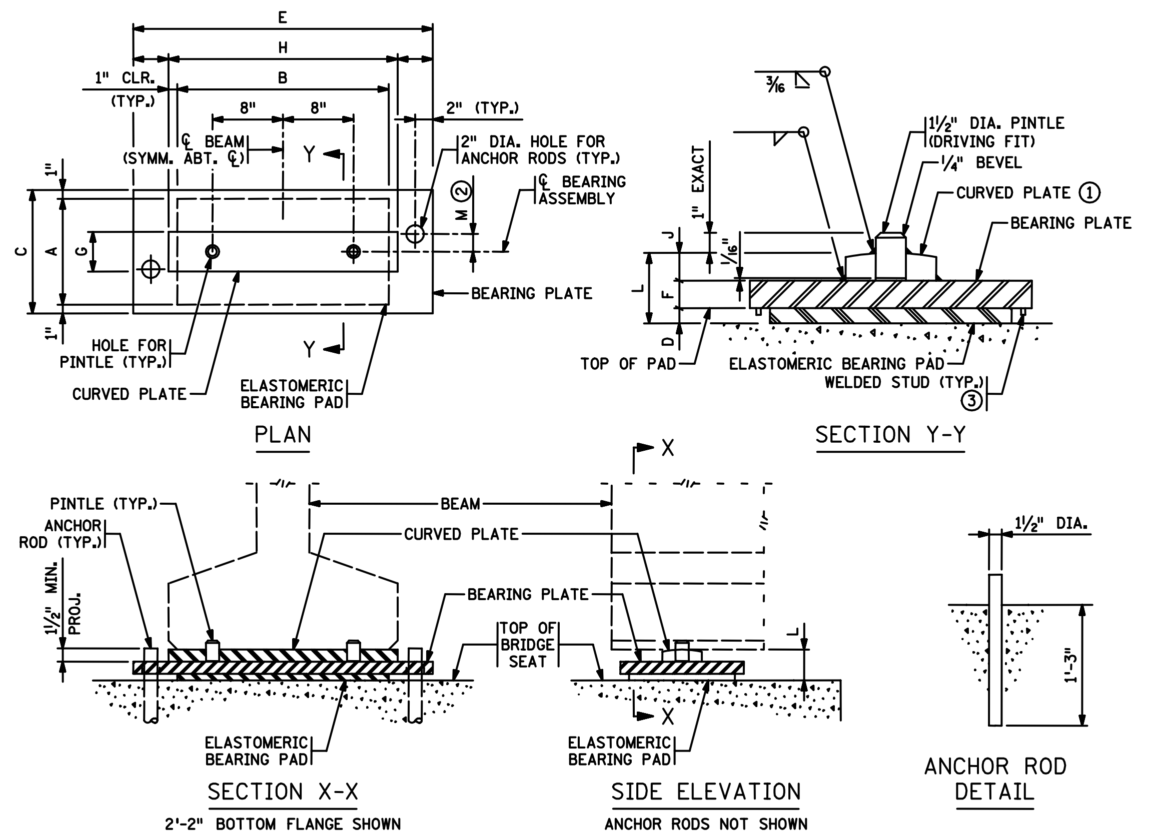
Use bearing plate with thickness $F = 1^1/_2$ inches.

D. Anchor Rods/Pintles

The standard $1^1/_2$ inch anchor rods and pintles with Detail B310 have a service load capacity of 70 kips. For many projects, such as the superstructure assumed for this design example, the capacity of the anchor rods and pintles will be adequate by inspection. For projects where two or more piers are fixed or where significant longitudinal forces are anticipated, evaluate the capacity of the anchor rods and pintles.

The anchor rod offset dimension (M) is to be calculated such that the anchor rods are located along the beam centerline of bearing. In this case, the skew is zero, so $M = 0$ inches.

The bearing design is summarized in Figure 14.8.1.4.



ASSEMBLY TYPE	LOCATION	BEAM SIZE	BEARING PAD SIZE			SHAPE FACTOR	BEARING PLATE SIZE			CURVED PLATE SIZE			ANCHOR ROD OFFSET		ASSY. HEIGHT	CURVED PLATE
			A	B	D		C	E	F	G	H	J	+/- ②	M	L	R ①
F1	PIER	72M	12"	24"	½"	8.0	14"	34"	1½"	4½"	26"	1¼"		0"	3¼"	16"

NOTES:

ELASTOMERIC MATERIALS AND PAD CONSTRUCTION SHALL COMPLY WITH Mn/DOT SPEC. 3741.

ALL STEEL PLATES SHALL COMPLY WITH Mn/DOT SPEC. 3306.

ANCHOR RODS SHALL COMPLY WITH Mn/DOT SPEC. 3306. GALVANIZE PER Mn/DOT SPEC. 3394.

PINTLES SHALL COMPLY WITH Mn/DOT SPEC. 3309.

GALVANIZE STRUCTURAL STEEL BEARING ASSEMBLY AFTER FABRICATION PER Mn/DOT SPEC. 3394, EXCEPT AS NOTED.

PAYMENT FOR BEARING ASSEMBLY SHALL INCLUDE ALL MATERIAL ON THIS DETAIL.

① THE MIN. RADIUS SHALL BE 16" UNLESS OTHERWISE SPECIFIED IN THE TABLE. THE MAX. RADIUS SHALL BE 24". FINISH TO 250 MICRO. THE FINISHED THICKNESS OF THE PLATE MAY BE 1/16" LESS THAN SHOWN.

② "+" DENOTES OFFSET AS SHOWN. "-" DENOTES OFFSET OPPOSITE OF SHOWN.

③ 5/16" DIA. × 3/8" KNOCK-OFF WELD STUDS INSTALLED ON BEARING PLATE AROUND PERIMETER OF BEARING PAD. CENTERLINE STUD TO EDGE OF PAD DIMENSION = ½", MAX. STUD SPACING = 4", AND MAX. SPACING TO PAD CORNER = 2".

DESIGN DATA:

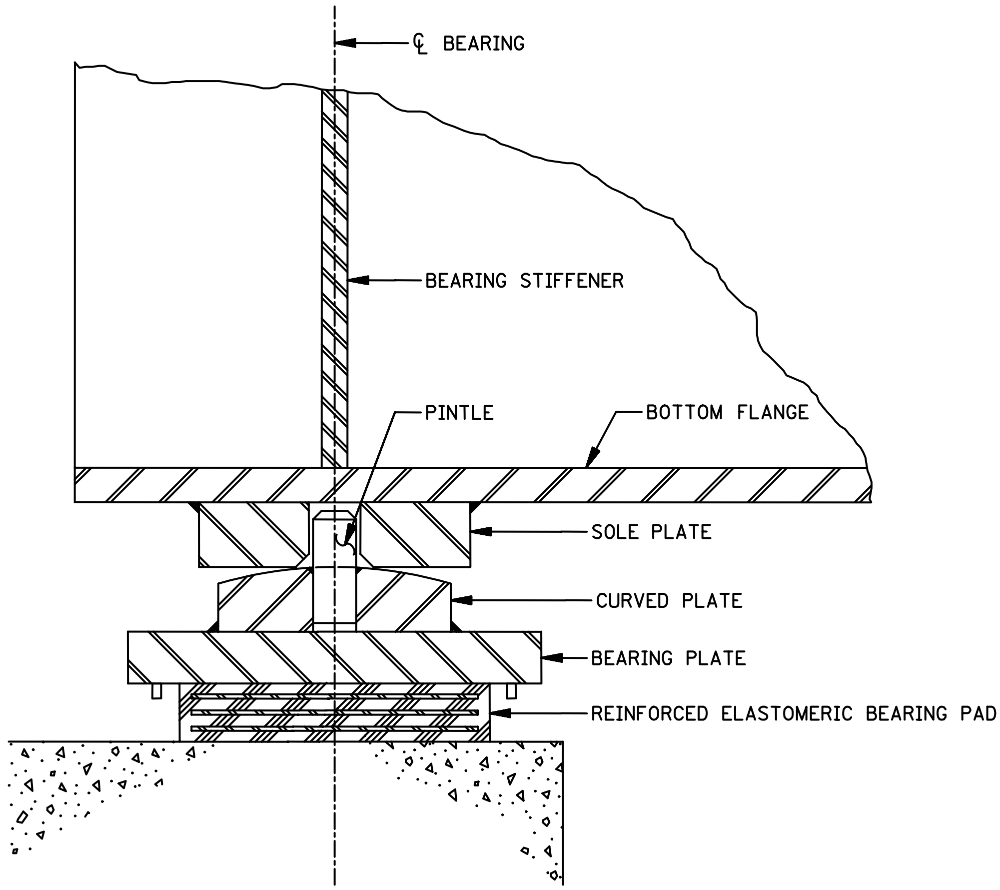
MAXIMUM HORIZONTAL LOAD IS 70 KIPS FOR 1½" PINTLES.

APPROVED: OCTOBER 26, 2005 STATE BRIDGE ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION CURVED PLATE BEARING ASSEMBLY (PRESTRESSED CONCRETE BEAMS) (FIXED)	REVISED 08-10-2006	DETAIL NO. B310

Figure 14.8.1.4

14.8.2 Expansion Elastomeric Bearing Design Example

This example illustrates the design of an expansion curved plate elastomeric bearing. It is a continuation of the steel plate girder design example found in Section 6.9. The example is based on Bridge Details Part I, B355. The elastomeric bearing pad is designed using Method A [LRFD 14.7.6]. Figure 14.8.2.1 labels the primary components for this type of bearing. The length, width, and thickness variables for the different components are consistent with Detail B355. See Figure 14.8.2.4.



CURVED PLATE EXPANSION BEARING COMPONENTS

SEE DETAIL B355

Figure 14.8.2.1

With the maximum reaction calculated, the bearing design should be selected from standard bearing tables in Section 14.7. If a standard design will not work due to unusual loads or geometric constraints, a custom design will be required.

This example will outline the procedure to custom design an expansion elastomeric bearing. First determine the size of the pad required. Next determine the steel plate requirements for the rest of the assembly.

Two movements are accommodated with this type of bearing, rotation and horizontal translation. The rotation takes place at the interface between the sole plate and the curved plate. The horizontal translation takes place in the reinforced elastomeric bearing pad.

A. Design Reinforced Elastomeric Bearing Pad

The bearing pad needs sufficient plan area to ensure that compression stresses are below the limit. It also needs sufficient thickness to accommodate the horizontal translation. Begin by determining the design movements and loads for the bearing.

Design Movements

The plate girder design example is for a two-span bridge with equal spans of 152'-0".

Fixity is assumed at the middle of the bridge. The bearing for this design example is assumed to be located at one of the abutments.

Expansion length $= L_{exp} = 152$ ft

[6.4.1] Coefficient of thermal expansion for steel $= \alpha_{steel} = 0.0000065$

Design temperatures:

Base Construction Temperature: $T_{constr} = 45\ °F$

Low: $T_{low} = -30\ °F$ High: $T_{high} = 120\ °F$

Fall: $T_{fall} = T_{constr} - T_{low} = 75\ °F$

Rise: $T_{rise} = T_{high} - T_{constr} = 75\ °F$

Movement for minimum compressive stress (Load Factor $= 1.0$)

$$\Delta_u = 1.0 \cdot T_{fall} \cdot \alpha_{steel} \cdot L_{exp} = 1.0 \cdot 75 \cdot 0.0000065 \cdot 152 \cdot 12 = 0.89 \text{ in}$$

Movement for shear deflection (Load Factor $= 1.3$)

$$\Delta_s = 1.3 \cdot T_{fall} \cdot \alpha_{steel} \cdot L_{exp} = 1.3 \cdot \Delta_u = 1.3 \cdot 0.89 = 1.16 \text{ in}$$

The material properties for 55 durometer elastomer can be found by interpolating between the values for 50 and 60 durometer materials. The minimum shear modulus is found to be 0.115 ksi and the maximum is 0.165 ksi.

Design Loads

The design loads for the bearing are obtained from the steel plate girder design example. They are as follows:

$$\text{Dead load} = P_{dl} = 117 \text{ kips}$$

$$\text{Maximum live load} = P_{ll_{max}} = 108 \text{ kips}$$

$$\text{Minimum live load} = P_{ll_{min}} = -15 \text{ kips}$$

The bearing is sized with service limit state loads

$$\text{Maximum } P_s = P_{dl} + P_{ll} = 117 + 108 = 225 \text{ kips}$$

The minimum compressive load check is made with Strength I limit state loads

$$\text{Minimum } P_u = 0.9 \cdot P_{dl} + 1.75 \cdot P_{llmin} = 0.9 \cdot 117 + 1.75 \cdot (-15) = 79.1 \text{ kips}$$

Size Elastomeric Bearing Pad

Begin by sizing the elastomeric pad. The total thickness of elastomer must be at least twice the design movement. The movement with the 1.3 multiplier is used for this check.

[Eq. 14.7.6.3.4-1]

$$\text{Minimum } h_{rt} = 2 \cdot \Delta_s = 2 \cdot 1.16 = 2.32 \text{ in}$$

Thickness of cover elastomer laminate, $h_{cover} = 0.25$ in

Try an internal elastomer laminate thickness, $h_{ri} = 0.375$ in

Thickness of steel plates, $h_s = 0.125$ in

Determine the number of internal laminates, n, required:

$$n = \frac{\text{Min. } h_{rt} - 2 \cdot h_{cover}}{h_{ri}} = \frac{2.32 - 2 \cdot 0.25}{0.375} = 4.85 \qquad \text{Use } n = 5$$

Number of steel plates, $n_s = n + 1 = 6$

Total elastomer thickness:

$$h_{rt} = 2 \cdot (h_{cover}) + n \cdot (h_{ri}) = 2 \cdot (0.25) + 5 \cdot (0.375) = 2.375 \text{ in}$$

Height of reinforced elastomeric pad, $D = h_{rt} + n_s \cdot h_s = 3.125$ in

For preliminary pad sizing, assume the pad allowable compression is 1.0 ksi. Round the pad width and length dimensions to even inch dimensions.

Try a pad width, $B = 20$ in

Solve for the minimum pad length (A):

$$A_{min} = \frac{Max.P_s}{1.0 \cdot B} = \frac{225}{1.0 \cdot 20} = 11.25 \text{ in}$$

Try a pad length, $A = 12$ in

Shape Factor Check

Check the shape factor of the internal laminate:

$$S = \frac{A \cdot B}{2 \cdot (A + B) \cdot h_{ri}} = \frac{12 \cdot 20}{2 \cdot (12 + 20) \cdot 0.375} = 10.0$$

$5.0 \le S = 10.0 \le 10.0$ OK

Compute the shape for the cover layers for later use in the deflection computations.

$$S = \frac{A \cdot B}{2 \cdot (A + B) \cdot h_{ri}} = \frac{12 \cdot 20}{2 \cdot (12 + 20) \cdot 0.25} = 15.0$$

Pad Dimensional Checks

Check that the bearing satisfies aspect ratio checks. The total elastomeric thickness must be less than $^1/_3$ the length of the pad's shortest side.

[14.7.6.3.6] $\frac{A}{3} = \frac{12}{3} = 4 \text{ in} > 2.375 \text{ in}$ OK

Also check that maximum pad dimension (B) is no greater than 2.5 times the smallest pad dimension (A):

$$2.5 \cdot A = 2.5 \cdot 12 = 30 \text{ in} > 20 \text{ in} \quad \underline{\text{OK}}$$

[14.7.6.3.2]

Maximum Compressive Stress Check

Now check the maximum compressive stress in the pad. Use the minimum shear modulus for this computation ($G_{min} = 0.115 \text{ ksi}$).

$$\text{Maximum } \sigma_s = 1.0 \cdot G_{min} \cdot S = 1.15 \text{ ksi} > 1.0 \text{ ksi} \quad \text{Use 1.0 ksi}$$

Using $\sigma_s = 1.0 \text{ ksi}$ results in a maximum load for the bearing of:

$$\text{Maximum } P_s = \sigma_s \cdot A \cdot B = 1.0 \cdot 12 \cdot 20 = 240 \text{ kips} > 225 \text{ kips} \quad \underline{\text{OK}}$$

[14.7.6.3.3]
[14.7.5.3.3]

Compressive Deflection

To ensure that joints and appurtenances perform properly, the vertical deflection in elastomeric bearings is checked. Due to the nonlinear behavior of the elastomer, the movement associated with live load is computed by subtracting the dead load deflection from the total load deflection.

Begin by determining the average vertical compressive stress in the bearings under dead load alone and under total load.

$$\sigma_{dl} = \frac{P_{dl}}{A \cdot B} = \frac{117}{12 \cdot 20} = 0.488 \text{ ksi}$$

$$\sigma_{tl} = \frac{P_{tl}}{A \cdot B} = \frac{225}{12 \cdot 20} = 0.938 \text{ ksi}$$

Using the stress strain figures in the commentary to Article 14.7.5.3.3, one can estimate the strain in the interior laminates and the cover layers. To arrive at strain values for 55 durometer bearings, the strains from the 50 durometer figure and the 60 durometer figure are averaged.

Laminate	Load	S	Stress (ksi)	50 durometer Strain	60 durometer Strain	Average Strain (ε)
Interior	Dead Load	10	0.488	2.4%	2.1%	2.3%
	Total Load	10	0.938	4.1%	3.6%	3.9%
Cover	Dead Load	15	0.488	2.1%	1.9%	2.0%
	Total Load	15	0.938	3.4%	3.1%	3.3%

The initial compressive deflection of a single interior laminate under total load is:

[14.7.6.3.3]

$$\Delta_{tlhri} = h_{ri} \cdot \varepsilon_{ri} = h_{ri} \cdot 0.039 < h_{ri} \cdot 0.07 \qquad \underline{\text{OK}}$$

With five interior laminates and two cover layers the deflection under total load is:

$$\Delta_{tl} = 5 \cdot h_{ri} \cdot \varepsilon_{ri} + 2 \cdot h_{cover} \cdot \varepsilon_{cover}$$

$$= 5 \cdot 0.375 \cdot 0.039 + 2 \cdot 0.25 \cdot 0.033 = 0.090 \text{ in}$$

The deflection under dead load is:

$$\Delta_{dl} = 5 \cdot h_{ri} \cdot \varepsilon_{ri} + 2 \cdot h_{cover} \cdot \varepsilon_{cover}$$

$$= 5 \cdot 0.375 \cdot 0.023 + 2 \cdot 0.25 \cdot 0.020 = 0.053 \text{ in}$$

[Table 14.7.5.2-1]

The deflection due to creep is:

$$\Delta_{cr} = 0.30 \cdot \Delta_{dl} = 0.30 \cdot 0.053 = 0.016 \text{ in}$$

[C14.7.5.3.3]

The difference between the two deflections is the estimated live load deflection. The total deflection due to live load plus creep should be no greater than $^1/_8$ inch.

$$\Delta_{ll} = \Delta_{tl} - \Delta_{dl} = 0.090 - 0.053 = 0.037 \text{ in}$$

$$\Delta_{ll} + \Delta_{cr} = 0.037 + 0.016 = 0.053 \text{ in} < 0.125 \text{ in} \qquad \underline{\text{OK}}$$

[14.7.6.4]

Minimum Compressive Load Check

[14.6.3.1]

Using the equation derived in Article 14.3.3.1.2 of this manual:

$$\text{Req'd. } P_{min} = \frac{0.825 \cdot A \cdot B \cdot \Delta_u}{h_{rt}}$$

$$= \frac{0.825 \cdot 12 \cdot 20 \cdot 0.89}{2.375} = 74.2 \text{ kips}$$

$$\text{Actual Min. } P_u = 79.1 \text{ kips} > 74.2 \text{ kips} \quad \underline{\text{OK}}$$

[14.7.5.3.7]

Check Service and Fatigue of Steel Plates

Check the service and fatigue limit states for the steel plates. At the service limit state the following equation must be satisfied:

$$h_s \geq \frac{3 \cdot h_{max} \cdot \sigma_s}{F_y}$$

The yield strength of the steel plates (F_y) is 36 ksi.

$$h_{max} = h_{ri} = 0.375 \text{ in}$$

$$\sigma_s = \frac{P_s}{A \cdot B} = \frac{225}{12 \cdot 20} = 0.938 \text{ ksi}$$

$$\text{Min. } h_s = \frac{3 \cdot h_{max} \cdot \sigma_s}{F_y} = \frac{3 \cdot 0.375 \cdot 0.938}{36} = 0.029 \text{ in} < 0.125 \text{ in} \quad \underline{\text{OK}}$$

When considering the fatigue limit state, the following equation must be satisfied:

$$h_s \geq \frac{2 \cdot h_{max} \cdot \sigma_L}{\Delta_{FTH}}$$

[Table 6.6.1.2.5-3]

where, $\Delta_{FTH} = 24$ ksi (Category A steel detail).

Note that the live load used for this check is not based on reactions from the fatigue truck. Rather, it is the total live load for the service limit state.

$$\sigma_L = \frac{P_{ll}}{A \cdot B} = \frac{108}{12 \cdot 20} = 0.450 \text{ ksi}$$

Minimum steel plate thickness for this check is

$$\text{Min. } h_s = \frac{2 \cdot h_{max} \cdot \sigma_L}{\Delta_{FTH}} = \frac{2 \cdot 0.375 \cdot 0.450}{24} = 0.014 < 0.125 \text{ in} \quad \underline{\text{OK}}$$

Use a 12" x 20" x 3 1/8" bearing pad, composed of two 1/4 inch cover laminates, five 3/8 inch interior laminates, and six 1/8 inch steel plates.

B. Curved Plate Design

The thickness of the plate is H. The curved plate has a width (B), which is equal to the width of the bearing pad. The length (G) is determined in an iterative process with the thickness. Begin by checking the thickness for a curved composite plate with a length of 4.5 inches. If thickness of the bearing plate is more than 2 inches, increase the length of the curved plate until the bearing plate thickness and composite plate thickness are approximately equal. After 4.5 inches, try 6 inches. If 6 inches does not work, increase length by increments of 2 inches thereafter.

Try a 20" x 4.5" curved plate ($B = 20 \text{ in}$, $G = 4.5 \text{ in}$).

First, determine the radius of the contact surface. The radius of the curved plate is a function of the yield strength of the steel and the load intensity.

The contact length of the sole plate with the curved plate is equal to the curved plate width minus the pintles and bevels. Refer to Figure 14.8.2.2.

Contact length L_{sp} is equal to

$$L_{SP} = 20 - 2 \cdot (1.75) - 2 \cdot (0.25) - 2 \cdot (0.25) = 15.50 \text{ in}$$

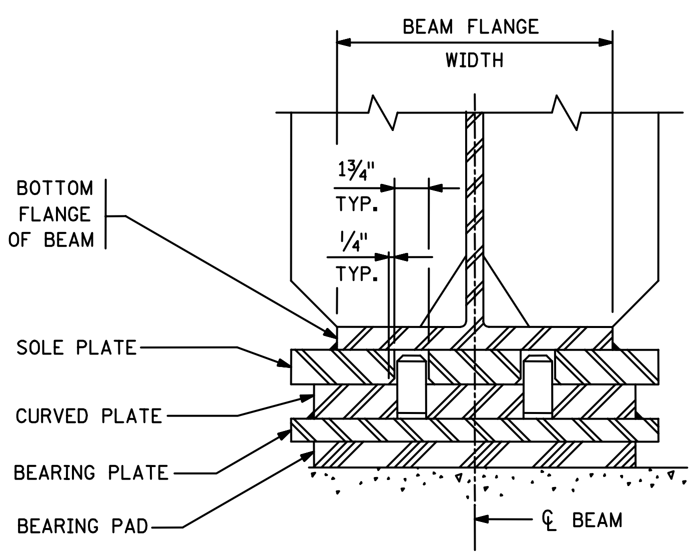


Figure 14.8.2.2

[14.7.1.4]

Based on past satisfactory performance of curved plate bearing assemblies, the minimum radius permitted is determined with LRFD Equation C14.7.1.4-1 and C14.7.1.4-2. Start by assuming radius is 12.5 inches ore less, so use the first equation. Rearranging the equation to solve for d, and dividing by 2 (to compute a radius) results in the following:

$$R_{min} = \frac{10 \cdot p}{0.6 \cdot (F_y - 13)} = \frac{10 \cdot \left(\frac{P_s}{L_{sp}}\right)}{0.6 \cdot (F_y - 13)} = \frac{10 \cdot \left(\frac{225}{15.50}\right)}{0.6 \cdot (36 - 13)} = 10.5 \text{ in} < 12.5 \text{ in}$$

Assumption was correct.

The radius of curved plates is to be no less than 16 inches. Therefore, specify the minimum radius for the curved plate to be 16 inches.

The required thickness of the curved composite plate is found using a simple model where a uniform load is applied to the bottom of the plate and the reaction is a line load. See Figure 14.8.2.3. Pressure on the composite plate is:

$$\sigma_{cp} = \frac{P_s}{B \cdot G} = \frac{225}{20 \cdot 4.5} = 2.50 \text{ ksi}$$

The maximum moment on a 1 inch strip of the composite plate is:

$$M_{cp} = \sigma_{cp} \cdot \frac{G}{2} \cdot \frac{G}{4} = 2.50 \cdot \frac{4.5}{2} \cdot \frac{4.5}{4} = 6.33 \text{ kip-in/in width}$$

The maximum allowable bending stress from Table 10.32.1A of the Standard Specifications is used to size the plate:

$$f_s = 0.55 \cdot F_y = 0.55 \cdot 36 = 19.8 \text{ ksi}$$

The required composite plate thickness is found by finding the thickness of plate that has sufficient section modulus to carry the moment.

$$S_{req} = \frac{M_{cp}}{f_s} = \frac{6.33}{19.8} = 0.32 \text{ in}^3$$

$$\text{Minimum } H = \sqrt{6 \cdot S_{req}} = \sqrt{6 \cdot 0.32} = 1.39 \text{ in}$$

The standard curved plate thickness is $1^1/_4$ inches. Since composite action is assumed and the bearing plate thickness will be more than $^1/_8$ inch, use a $1^1/_4$ inch thick curved plate.

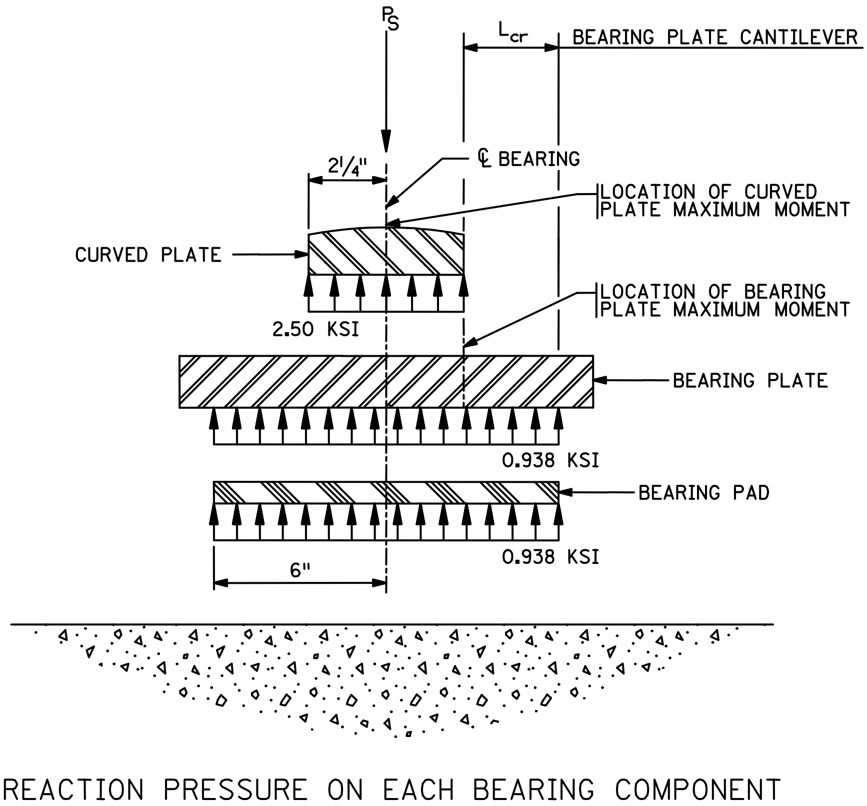


Figure 14.8.2.3

C. Bearing Plate Design

Now determine the thickness of the bearing plate. The bearing plate has plan dimensions that are slightly larger than the bearing pad to provide adequate space for the attachment of knock-off weld studs. One inch is provided on all sides for this purpose.

Bearing Plate width, $E = 22$ in

Bearing Plate length, $C = 14$ in

The bearing plate is assumed to act as a cantilever that carries the bearing pad pressure back to the curved plate. See Figure 14.8.2.3.

The cantilever length is half the difference in length between the bearing pad and the curved plate.

$$L_{cr} = \frac{A}{2} - \frac{G}{2} = \frac{12}{2} - \frac{4.5}{2} = 3.75 \text{ in}$$

$$M_{bp} = \sigma_s \cdot \frac{L_{cr}^{\ 2}}{2} = 0.938 \cdot \frac{3.75^2}{2} = 6.60 \text{ kip-in/in width}$$

Use the same procedure that was used to arrive at a curved plate thickness. Note that the minimum thickness for bearing plates is $1^1/_2$ inches.

$$S_{req} = \frac{M_{bp}}{f_s} = \frac{6.60}{19.8} = 0.333 \text{ in}^3$$

$$F_{req} = \sqrt{6 \cdot S_{req}} = \sqrt{6 \cdot 0.333} = 1.41 \text{ in}$$

Use a $1^1/_2$ inch thick bearing plate.

D. Sole Plate Constraints

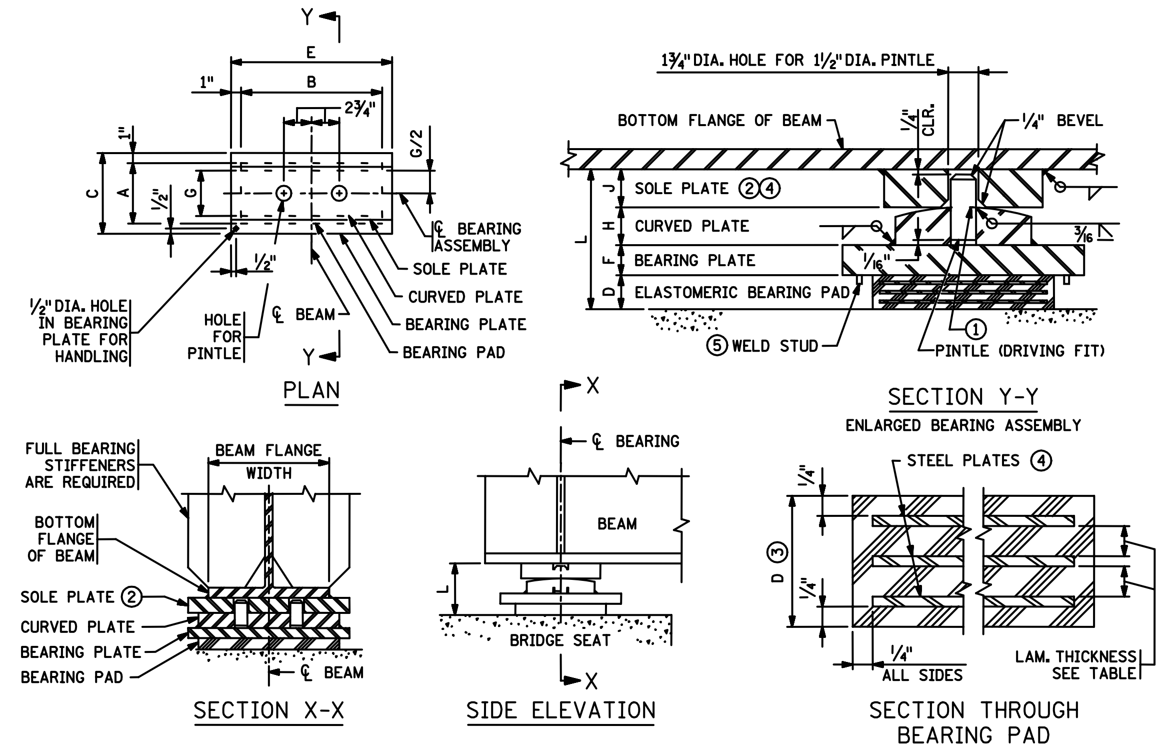
Set the sole plate width 2 inches greater than the curved plate width and check that it is sufficiently wider than the beam bottom flange to allow welding.

Sole plate width $= 20 + 2 = 22$ in > 20 in flange   OK

The sole plate length must be 6 inches minimum, but not less than the curved plate length. Therefore, set sole plate length equal to 6 inches.

The minimum sole plate thickness is $1^1/_4$ inches. When the bearing pad width exceeds the bottom flange width, the sole plate must be designed as a cantilever to resist the load from the pad that extends outside the flange. In this case, the bottom flange width equals the pad width, so set sole plate thickness equal to $1^1/_4$ inches.

The bearing design is summarized in Figure 14.8.2.4.



TABLE

ASSEMBLY TYPE	LOCATION	BEAM FLANGE WIDTH	BEARING PAD SIZE			STEEL PLATES		LAMINATES		SHAPE FACTOR	BEARING PLATE SIZE			CURVED PLATE SIZE				SOLE PLATE SIZE			PINTLE DIA.	ASSY. HEIGHT
			A	B	D	NO.	THICK.	NO.	THICK.		C	E	F	G	B	H	R ①	WID.	LEN.	J ②		L
E	ABUT.	20"	12"	20"	3⅛"	6	⅛"	5	⅜"	10.0	14"	22"	1½"	4½"	20"	1¼"	16"	22"	6"	1¼"	1½"	7⅛"

NOTES:

ELASTOMERIC MATERIALS AND PAD CONSTRUCTION SHALL COMPLY WITH Mn/DOT SPEC. 3741.

ALL STEEL PLATES SHALL COMPLY WITH Mn/DOT SPEC. 3306 EXCEPT THE SOLE PLATE. THE SOLE PLATE SHALL BE THE SAME MATERIAL SPECIFICATION AS THE STEEL BEAMS.

PINTLES SHALL COMPLY WITH Mn/DOT SPEC. 3309.

GALVANIZE STRUCTURAL STEEL BEARING ASSEMBLY AFTER FABRICATION PER Mn/DOT SPEC. 3394, EXCEPT AS NOTED.

PAYMENT FOR BEARING ASSEMBLY SHALL INCLUDE ALL MATERIAL ON THIS DETAIL EXCEPT THE SOLE PLATE. THE SOLE PLATE IS INCLUDED IN THE WEIGHT OF STRUCTURAL STEEL.

① THE MIN. RADIUS SHALL BE 16" UNLESS OTHERWISE SPECIFIED IN THE TABLE. THE MAX. RADIUS SHALL BE 24". FINISH TO 250 MICRO. THE FINISHED THICKNESS OF THE PLATE MAY BE 1/16" LESS THAN SHOWN.

② WHEN THE SOLE PLATE IS TAPERED, DIMENSIONS "J" AND "L" ARE THICKNESS OF SOLE PLATE AND BEARING ASSEMBLY AT CENTERLINE OF BEARING.

③ THE TOTAL THICKNESS SHOWN INCLUDES THE STEEL PLATES.

④ DO NOT GALVANIZE THIS PLATE.

⑤ 5/16" DIA. x ⅜" KNOCK-OFF WELD STUDS INSTALLED ON BEARING PLATE AROUND PERIMETER OF BEARING PAD. CENTERLINE STUD TO EDGE OF PAD DIMENSION = ½", MAX. STUD SPACING = 4" AND THE MAX. SPACING TO THE PAD CORNTER = 2".

DESIGN DATA:

MAXIMUM HORIZONTAL LOAD IS 70 KIPS. MINIMUM SOLE PLATE THICKNESS IS 1¼".

APPROVED: NOVEMBER 22, 2002	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION	REVISED 08-10-2006	DETAIL NO.
Daniel L. Dorgan STATE BRIDGE ENGINEER	CURVED PLATE BEARING ASSEMBLY (STEEL BEAMS) (EXPANSION)		B355

Figure 14.8.2.4